WPPMI-CPR(17) 17253

CG Gliss et al.

Initial layout of DEMO buildings and configuration of the main plant systems

Preprint of Paper to be submitted for publication in Proceeding of
13th International Symposium on Fusion Nuclear Technology
(ISFNT)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Initial Layout of DEMO Buildings and Configuration of the Main Plant Systems

Curt Gliss[a,*], Sergio Ciattaglia[a], Walter Korn[b], Ivo Moscato[c]

[a]Eurofusion, PMU ,Garching, Germany
[b]AREVA , Erlangen, Germany
[c]University of Palermo, Palermo, Italy

The realization of a Demonstration Fusion Power Reactor (DEMO) to follow ITER, with the capability of generating several hundred MW of net electricity and operating with a closed fuel-cycle is viewed by Europe and many of the nations engaged in the construction of ITER as the remaining crucial step towards the exploitation of fusion power. The development of suitable configurations of plant systems inside the tokamak building to allow for the various maintenance operations and to meet the numerous system operating functions and safety requirements is one of the initial priorities. A task to establish an initial layout of the DEMO buildings and the integration of the main plant systems was launched by EUROfusion with an industrial partner with experience in the construction of nuclear power plants.

This paper provides an overview of the main plant systems to be integrated in the tokamak building including requirements due to their prescribed functions as well as from the overall safety and maintenance approach. These are transferred into layout requirements such as the need for separation of certain components, fire zones, access zoning, etc. In addition, the design requirements for the building itself are summarized. Some considerations of the lesson being learnt from ITER design and construction experience are provided too.

Keywords: Integration, Plant systems, Tokamak Building, Layout, DEMO.

Corresponding author: Curt.Gliss@euro-fusion.org

1. Introduction

DEMO has a clear objective, which is to demonstrate electricity production from fusion power, with a certain efficiency and plant availability [1]. This goal depends not only upon successful plasma physics but also the reliable operation of the numerous systems necessary for the DEMO operation. In this respect DEMO represents an important but ambitious technological step between ITER and the fusion power plant. Being a prototype, DEMO could not rely fully on detailed design and technological knowledge which is available for commercial fission Power Plants (NPP). Typically, designing the layout of the fusion plant it is a process of trial and change and proceeds in parallel with the analysis of its performance of the various systems. Very little analysis of this process has been published, though the work is a substantial part of the engineering development of a project.

Considering the complexity of a fusion plant, the layout development has to follow the design progress of the different DEMO design options since the early phase in order to provide the necessary design basis to develop a technically feasible, operable and maintainable conceptual plant design and to identify areas in which there are significant technical or cost uncertainties. During the layout process of plant systems and site, optimization and possible simplification should be part of the task.

In the current pre-conceptual design phase, the design options for a number of important plant systems (i.e, the blanket Primary Heat Transfer System (PHTS) coolant and Tritium Extraction System) are still under development. Two combinations of these two systems are considered for the first definition of the plant layout inside the tokamak building:

1) Helium as blanket PHTS coolant together with Helium as purge gas for the tritium extraction.
2) Water as blanket PHTS coolant with lithium led for tritium extraction.

1.1 DEMO main differences from ITER

A number of plant systems of DEMO are expected to be similar to those of ITER.

However, DEMO has additional plant systems which do not exist in ITER. For example, the Power Conversion System which consists of an intermediate storage system and a steam turbine coupled with an electric generator to convert heat into electrical power. In the current layout phase, the intermediate storage system is included as the present steam turbines cannot cope with the pulsed plasma power of DEMO. This constraint is still a point for optimization and possible simplification. The second plant system is the Tritium Extraction System as DEMO is breeding its own tritium inside the blankets. Two options are under development, lithium led or helium purge gas to deliver the tritium to its extraction system. Figure 1 shows the main DEMO systems.

2. Plant site layout

The layout of the site has to follow several design criteria. The arrangement of the buildings must satisfy functional criteria determined by the machine as well as by auxiliary plant systems and safety requirements. As an example of functional requirement, the location of the Heating Neutral Beam (HNB) power supply building (number 37 in Figure 2), depends strongly on the position of the heating neutron beam system. Examples of system requirements are the length of the cooling pipes to energy storage building which needs to be minimized (e.g. secondary molten salt pipe, building 78 in Figure 2) or the need to provide sufficient distance from the tokamak to reach an acceptable magnetic field as required by Electron Cyclotron RF heating system, see [2] Figure 3. Safety requirements [3] might require redundant systems located in separate buildings on opposite sides, compared to the tokamak building, in order to avoid possible Common Mode Failures (CMF), as well as non Safety Important Classified (SIC) building should be far away from SIC building in order not to challenge safety function following their collapse. As an example, the emergency diesel generators are each located on the opposite side of the tokamak building 44 and 45).

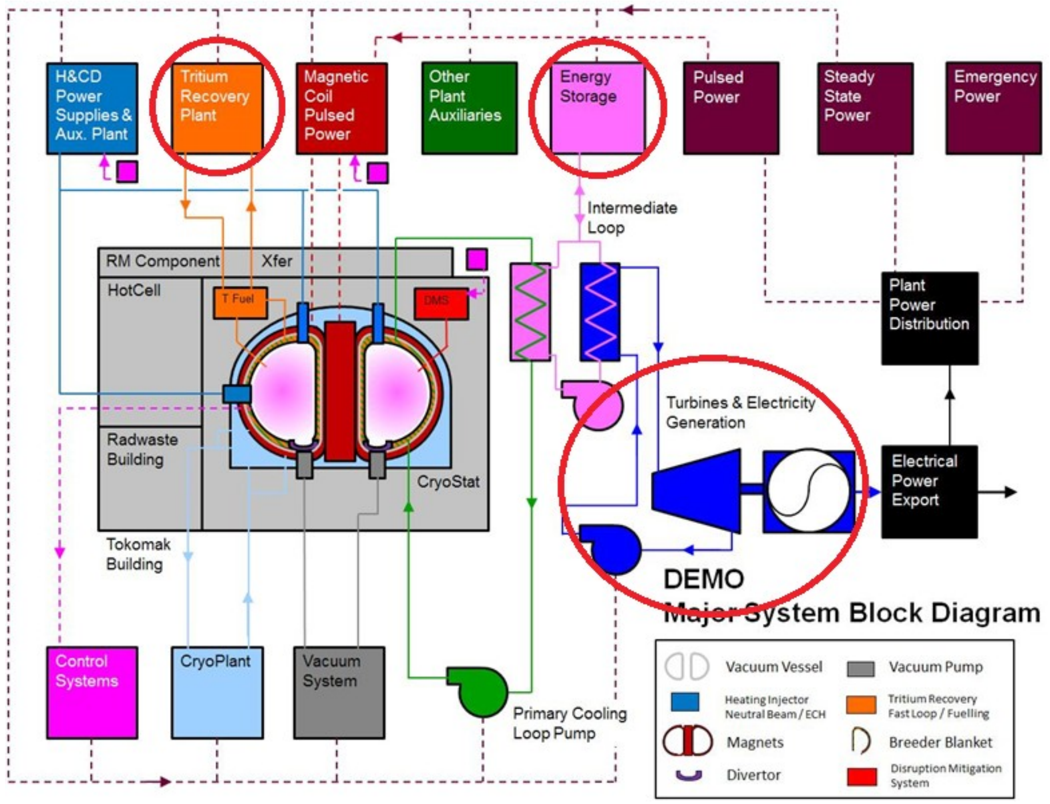
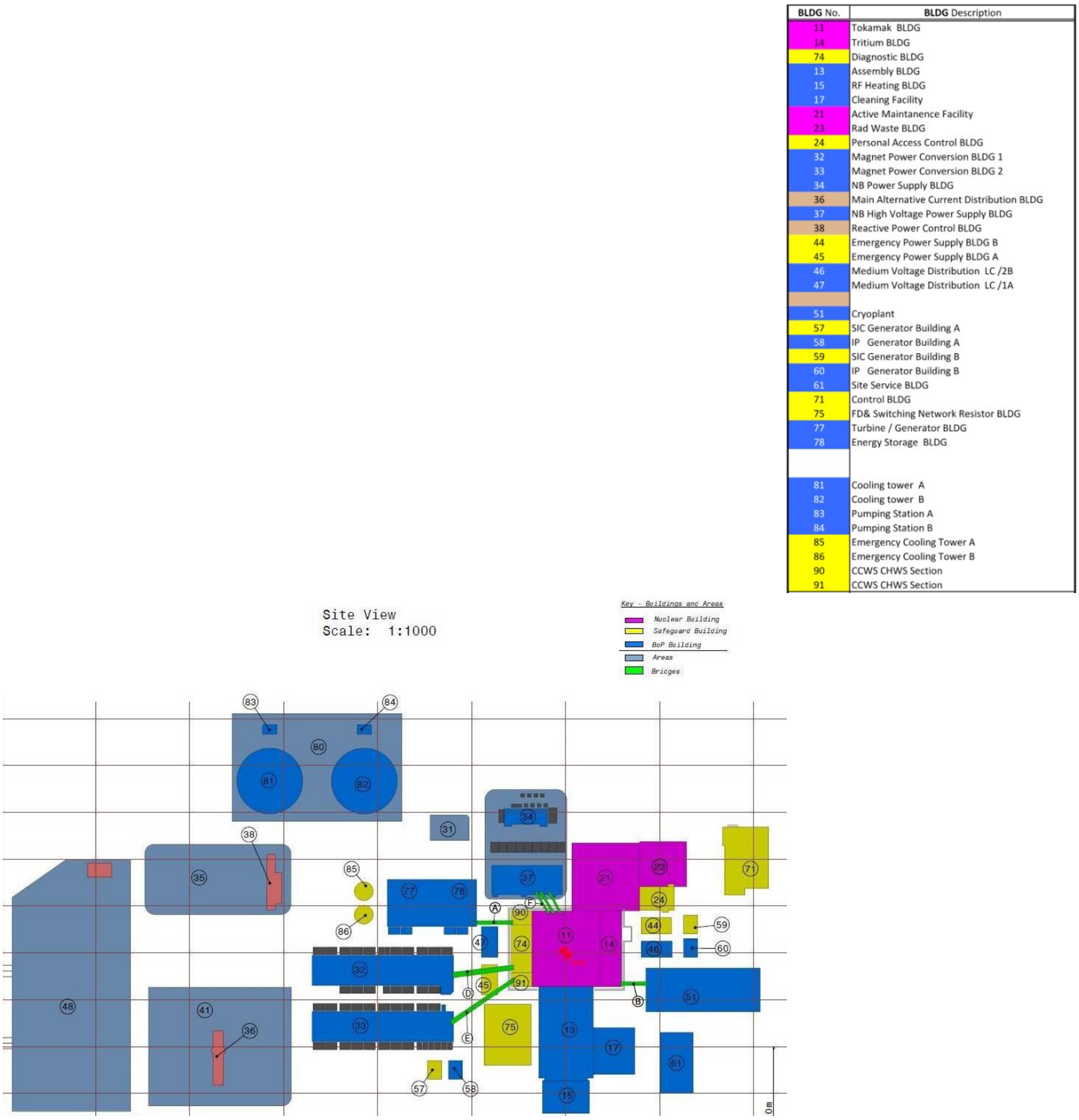


Fig.1. DEMO Block Diagram (red circles indicate additional DEMO systems in comparison with ITER)



BLDG No.	BLDG Description
11	Tokamak BLDG
14	Tritium BLDG
74	Diagnostic BLDG
13	Assembly BLDG
15	RF Heating BLDG
17	Cleaning Facility
21	Active Maintanence Facility
23	Rad Waste BLDG
24	Personal Access Control BLDG
32	Magnet Power Conversion BLDG 1
33	Magnet Power Conversion BLDG 2
34	NB Power Supply BLDG
36	Main Alternative Current Distribution BLDG
37	NB High Voltage Power Supply BLDG
38	Reactive Power Control BLDG
44	Emergency Power Supply BLDG B
45	Emergency Power Supply BLDG A
46	Medium Voltage Distribution LC /2B
47	Medium Voltage Distribution LC /1A
51	Cryoplant
57	SIC Generator Building A
58	IP Generator Building A
59	SIC Generator Building B
60	IP Generator Building B
61	Site Service BLDG
71	Control BLDG
75	FD& Switching Network Resistor BLDG
77	Turbine / Generator BLDG
78	Energy Storage BLDG
81	Cooling tower A
82	Cooling tower B
83	Pumping Station A
84	Pumping Station B
85	Emergency Cooling Tower A
86	Emergency Cooling Tower B
90	CCWS CHWS Section
91	CCWS CHWS Section

Fig. 2. DEMO site layout.

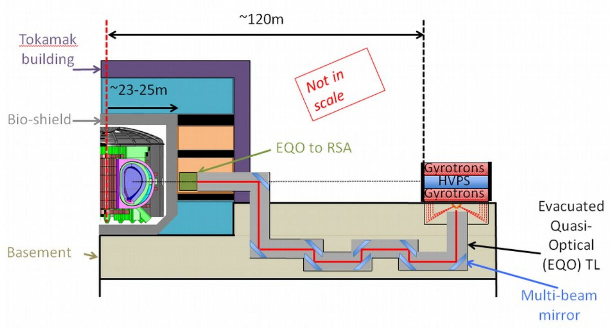


Fig. 3. RF building distance from the machine [4]

2.1 Building and area categories

Similar to a nuclear fission power plant, DEMO buildings and areas are grouped according to their function into three main categories: (see Figure 2 & below).

Nuclear Buildings (pink colour)

Buildings containing radioactive inventories and safety mitigation systems able to confine those radioactive inventories that might be mobilized in case of an accident. Also relevant monitoring and control system are located there.

Safeguards Buildings (yellow colour)

Buildings with systems and components necessary to bring and maintain the plant into a safe state, e.g. the SIC auxiliary systems (emergency electrical power supply and fluids, central control safety, etc.).

Balance of Plant (BoP) (blue colour)

All the other Buildings and Areas with systems and components necessary for the operation and maintenance of DEMO within the site area.

3. Plant systems and tokamak building layout preliminary definition

The tokamak building has a very complex layout as the operation of a fusion plants require several large systems for their operation and control.

In this DEMO pre-conceptual design phase, different options for the blanket PHTS coolant (He/H_2O) and tritium extraction (lithium-led/ He) with rather different space requirements shall be considered: Fig. 4 shows the preliminary breeding blanket PHTS layout: 6 plus 3 heat exchangers are being considered for breeding blankets cooled by He and 2 plus 2 heat exchangers for breeding blankets cooled by H_2O [5]. Therefore, two layouts of the tokamak buildings are being developed. Ongoing safety analyses could lead to modification of the design and plant layout (i.e. number of cooling loops, safety isolation valves, etc.).

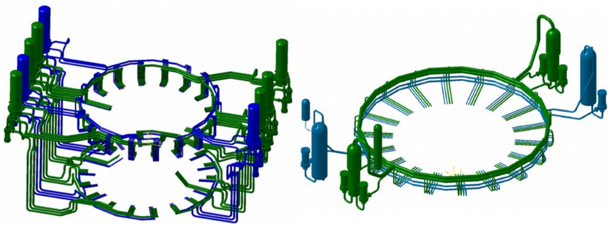


Fig. 4. Helium-cooled (left) and Water-cooled (right) Blanket PHTS

The design of the tokamak building and the plant system integration are driven by the requirements described below.

3.1 Building criteria

Many of the objectives in defining the layout of a reactor are common to other engineering projects. The cost of space has to be balanced against the value of good access to the plant. Construction methods, access to the plant in operation and for maintenance and safety aspects have to be considered. In DEMO as in other conventional fission plants it is the massive shielding and other provisions for radiation protection that mainly affect the layout.

In particular, there are two main sets of criteria which drive the tokamak building design: safety and functional criteria.

3.1.1 Safety criteria

The main function of the tokamak building is the secondary confinement of radioactive source terms, which is ensured against internal and external hazards that may damage the first confinement barrier [3]. Following any kind of hazards as earthquake, air plane crash or loss of fluids and radioactive materials, the radioactive releases from the tokamak building should be well below those requiring evacuation. Shielding from radiation and neutrons to meet the ALARA criterion (minimum achievable man dose rate [person-mSv/y]) is another safety function and also one major design driving requirement; this defines e.g. thickness of walls, design of penetration, etc. [6]. The huge tokamak building volume is divided in smaller areas, segregated from each other, in order to limit radioactive and fluid enthalpy inventories below the safety limits and to protect redundant systems from Common Mode Failures (CMF). This has implications on the systems crossing these volumes, e.g. isolation valves in the fluid pipes, fire barriers to avoid fire propagation. A function which is linked to this partition is segregation between redundant systems. E.g. the electrical divisions A&B for a SIC system should be separated in different areas to fulfil the redundancy in case of an initiating Design Base Event (DBE), like fire, flooding or explosion [7]. Thanks to this segregation, a DBE can cause a single failure but not a Common Mode Failures.

3.1.2 Functional criteria

One requirement which sounds not so obvious is providing sufficient space for plant system integration, including installation, commissioning, maintenance and replacement. Fig. 5 shows the preliminary layout of the tokamak building with some of the main plant systems. Adequate shielding for all components sensible to radiation is another essential criteria to make feasible the qualification of components particularly those classified SIC.

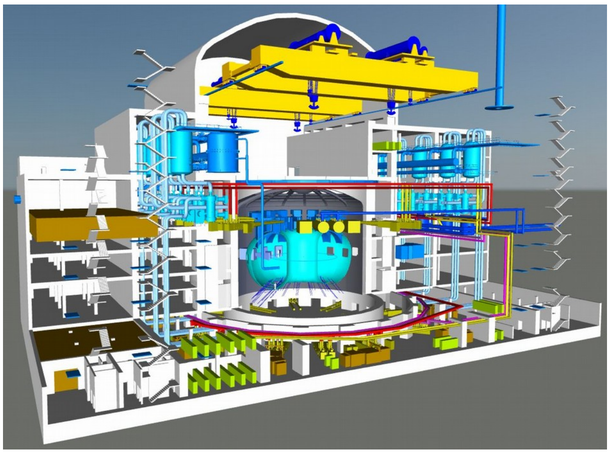


Fig. 5. Tokamak Complex building

A clear function of the tokamak building is to support the machine itself and of course the plant systems. This implies that the building has to withstand the forces coming from the machine (e.g. Plasma Vertical Displacement Event) or the forces coming from systems e.g. cryo-system. An example is the cryolines shrinking during operation that produces forces to be taken by the supports and as a result by the building structures.

3.2 Plant system & components integration requirements

The complexity of a fusion power plant like DEMO with regards to integration of plant systems is much higher than in a fission power plant. The larger number of different plant systems with their system specific requirements is responsible for this. Fig. 6 gives an overview of the systems which are already preliminarily integrated into the plant design with the He breeding blanket PHTS. One point making the integration task very challenging is the fact that most systems might have a different design maturity and technology readiness for example the vacuum system might have been already designed with supports and pipe diameters, while the cooling system is still in an earlier design stage. To prioritize the important systems is one way to avoid endless integration loops. Three main points drive the integration work of the plant systems inside the tokamak building:(i) safety requirements,(ii) functional requirements of the plant systems themselves and (iii) the maintenance approach. Cost considerations should also be taken into account in the future.

3.2.1 Safety requirements

The safety requirements of plant system layout are devoted to 1) avoid CMF of redundant safety functions; 2) limit the inventory of radioactive source terms and enthalpies that can be released by a single failure, 3) minimise the occupational radiation exposure for operation and maintenance, 4) avoid component challenging a safety function. Therefore, physical segregation between certain systems is applied at the maximum extent to avoid knock on effects. For example a guillotine break of a high energy pipe must not challenge a fuelling pipe containing deuterium or tritium.

Placing components and systems considering the relevant environmental qualification is an integration requirement too. As soon as the tokamak building layout will be more consolidated a room book for the DEMO Tokamak will be defined, like in ITER, in order to provide information about the environmental conditions of the place where the component will be installed as magnetic field, γ radiation, neutron flux, seismic floor response spectra, pressure, temperature and humidity in normal and accidental conditions.

3.2.2 Functional requirements

From the early design phase, the layout of the building must be preliminary fixed, so that the line and levels where to put the various system and the related interconnections are known.

For example, the neutral beam heating system should enter the plasma chamber at the equatorial plane. The torus vacuum pumping system is located at the divertor level, any drain tanks should be placed at the lowest level. The distance from the machine might be also a relevant requirement of the plant system. E.g. the pellet injection system and its losses of fuel gas inside the flight tube are dependent from the length of the flight tube. One complex integration task is the layout of the numerous auxiliary systems that have to follow their clients, like the service vacuum system, the electrical power supply and the control and data acquisition system that have to be routed nearly everywhere because the clients are spread around the whole machine.

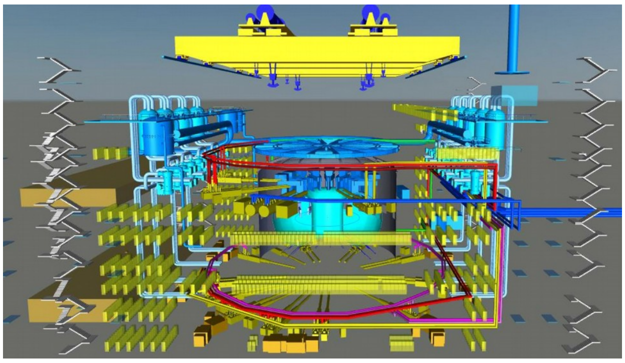


Fig. 6. Preliminary integration of main plant systems.

3.2.3 Maintenance approach

Maintenance of plant systems and machine components should be taken in account at an early design stage of the DEMO plant [6]. Maintenance requirements of course cannot overrule fundamental safety requirements like physical segregation and avoidance of radioactive contamination spread. The first assessment of maintenance operation, frequency, man power and time required, constitute the basic elements to assess the occupational radiation exposure figure and to decide eventually to improve the shielding design or for some remote maintenance needs [8].

Two principle methods of maintenance are foreseen, manually by workers or remote by dedicated tools. The choice depends on factors like environmental conditions (particularly radiation dose to the workers), complexity, capability, frequency and time requested which might affect the plant availability. Preliminary analyses are ongoing to assess from one side the identification of the maintenance needs for all systems in the tokamak building and on the other side the occupational radiation exposure. Possible improvement of shielding to meet the ALARA criterion is ongoing as well as the feasibility study of the remote maintenance considering the huge variety of systems and the need to meet the safety criteria particularly the partitioning of the tokamak building.

4. ITER Lessons learnt

As DEMO is the step between ITER and the future fusion power plant, the DEMO designers are implementing the recommendations from ITER as much as possible to avoid some problems which were and are being recognized during ITER design and construction. DEMO should from the start of the design put an important focus on shielding even if it can be only preliminary. It needs continuous reassessment as the design around the torus is progressing. A homogeneous development of main systems and relevant criteria will drastically simplify the integration task, beside the prioritization in the plant systems. A practical engineering advice is to have, as minimum, the process flow diagrams of main plant systems available before starting to model systems in 3D. Another ITER recommendation is to provide sufficient space and margin for integration, which means "to make the building bigger". It is also important that the safety culture is part of the entire DEMO team. For this reason DEMO has already defined the safety classification criteria, the reference accident sequences and just started the SIC system classification, a joint task between safety group and designers. This early definition is important considering the implications of safety classification on the design of the systems and on their layout.

Finally an early layout definition progressing with the design should reduce the design changes as well as should indicate the possible simplifications to be pursued in order to take under control the large dimension of the tokamak building.

5. Conclusion

An initial DEMO plant layout is being developed to identify the major buildings and structures needed to contain the plant equipment. Sufficient attention must be given to this problem in the early design phase: (i) to develop a technically feasible, operable, and maintainable plant design; (ii) to identify areas in which there are significant technical or cost uncertainties; (iii) to provide a clear basis for further improvements; and (iv) to identify the relative difficulties and act as a guide for further design work and R&D

In DEMO the plant and system integration is based on following basic principles: 1) define plant and tokamak building layout requirements; 2) define main systems and safety requirements before integration; 3) keep system design at the same maturity level particularly for the main plant systems and auxiliaries; 4) have a constant interaction among the designers defining the various systems, the safety and the layout integration. This may reduce the iteration loop for the integration and facilitate optimal integration solutions. The fact that currently some DEMO plant systems are largely undefined might be a significant risk for the identification of a suitable configuration of the tokamak complex. The experience gained in NPPs and in ITER and the extrapolation to DEMO of relevant solutions, considering the relevant lessons learnt, should reduce this risk. Further aspects, like cost saving and design simplification could be done once a mature state of the overall configuration is reached; otherwise too many uncertainties will jeopardize the goal to achieve a consolidated integrated design. This doesn't exclude standardization on common components like pipe supports or pipe sizes which should be derived from existing industrial applications where applicable. ITER has successfully managed large part of plant system integration. ITER has faced issues and established some recommendations for solutions. DEMO project should take benefit from it.

Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] G. Federici et al., DEMO Design Activity in Europe: Progress and Updates, this conference.

[2] Franke, T. et al., Innovative H&CD designs and the impact of their configurations on the performance of the EU DEMO fusion power plant reactor, submitted to IEEE TPS, special issue – selected papers from SOFE 2017

[3] N. Taylor, Safety and Licensing of Nuclear Facilities for Fusion, SOFE 2015.

[4] Garavaglia, S. et al., "EU DEMO EC System preliminary conceptual design", this conference

[5] L. Barucca et al., Status of EU DEMO Heat Transport and Power Conversion Systems, this conference.

[6] C. Bachmann et al., Overview over DEMO design integration challenges and their impact on component design concepts, this conference.

[7] T. Pinna et al., Identification of accident sequences for the DEMO plant, SOFT 2016.

O. Croft et al., integrated maintenance of a fusion power plant, this conference.