EUROfusion

EU-DEMO Operation and Maintenance Issues and NPP Experience

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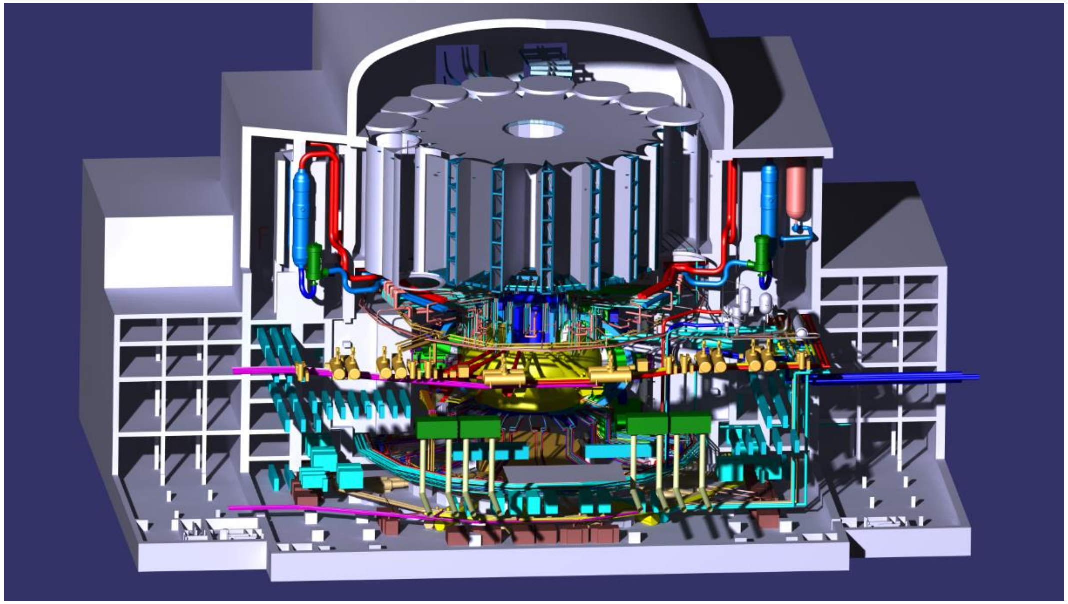
Outlines

- Introduction
- DEMO System Complexity
- Operation Challenges
- Maintenance Challenges
- Availability target Challenges
- Synopsis and Outlook

Introduction

DEMO must demonstrate the viability of Nuclear Fusion as an energy source:

1. Reliable plasma operation
2. Tritium-self sufficiency
3. Several full power years
4. Fusion power plant relevance: allow extrapolation of DEMO solutions to a fusion power plant
5. Conversion of fusion power into electricity to the Grid (2.000 MWth into 300-500 MWe)
6. Availability ~30%
7. Minimize radioactive wastes



Complexity: DEMO and Fusion Plants need many Systems

Fusion Reaction

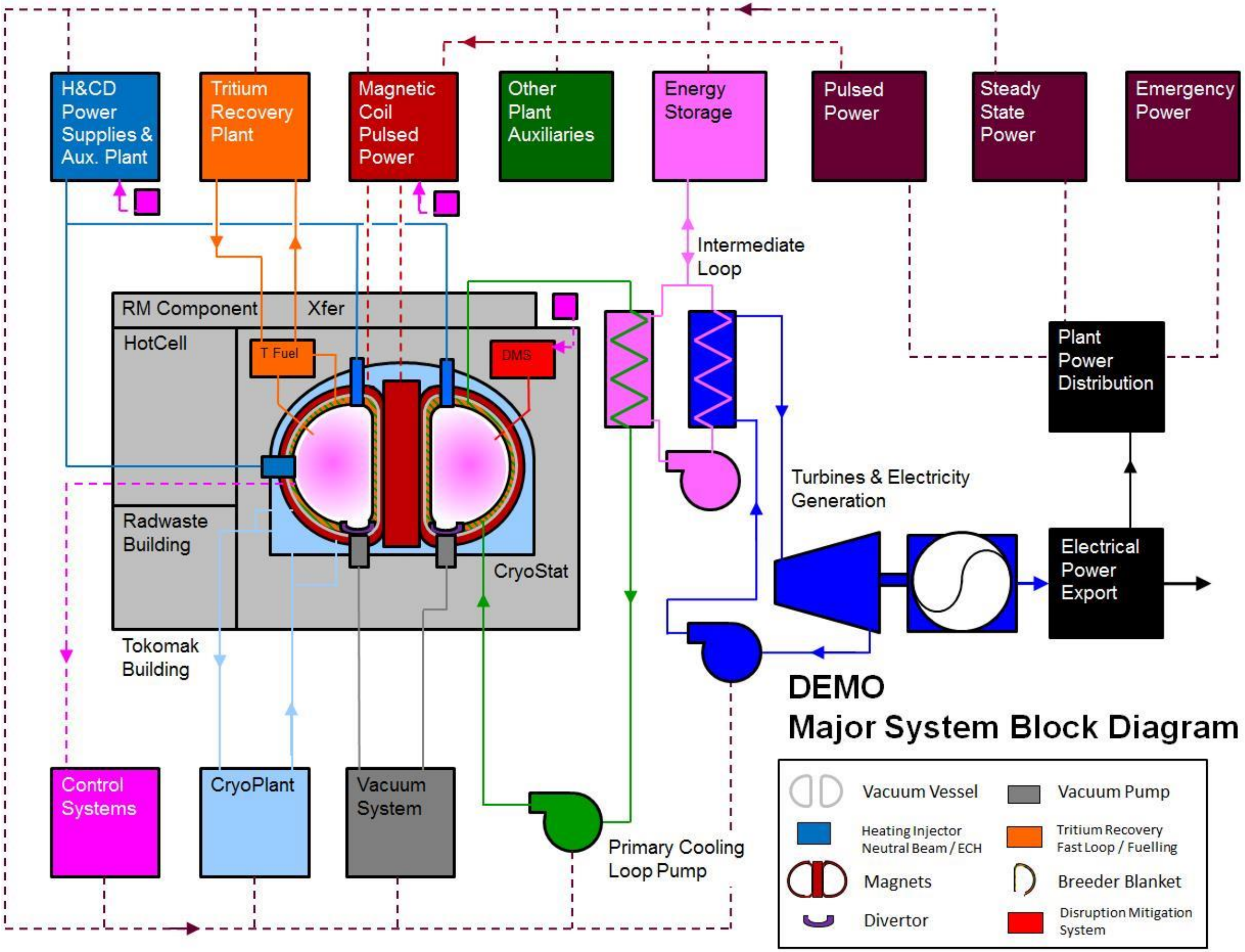
D + T → He4 + n + 17.6 MeV

Breeding Reactions

6Li + n ® 4He + T

7Li + n ® 4He + T + n

Simplified Block Scheme of the main DEMO Systems

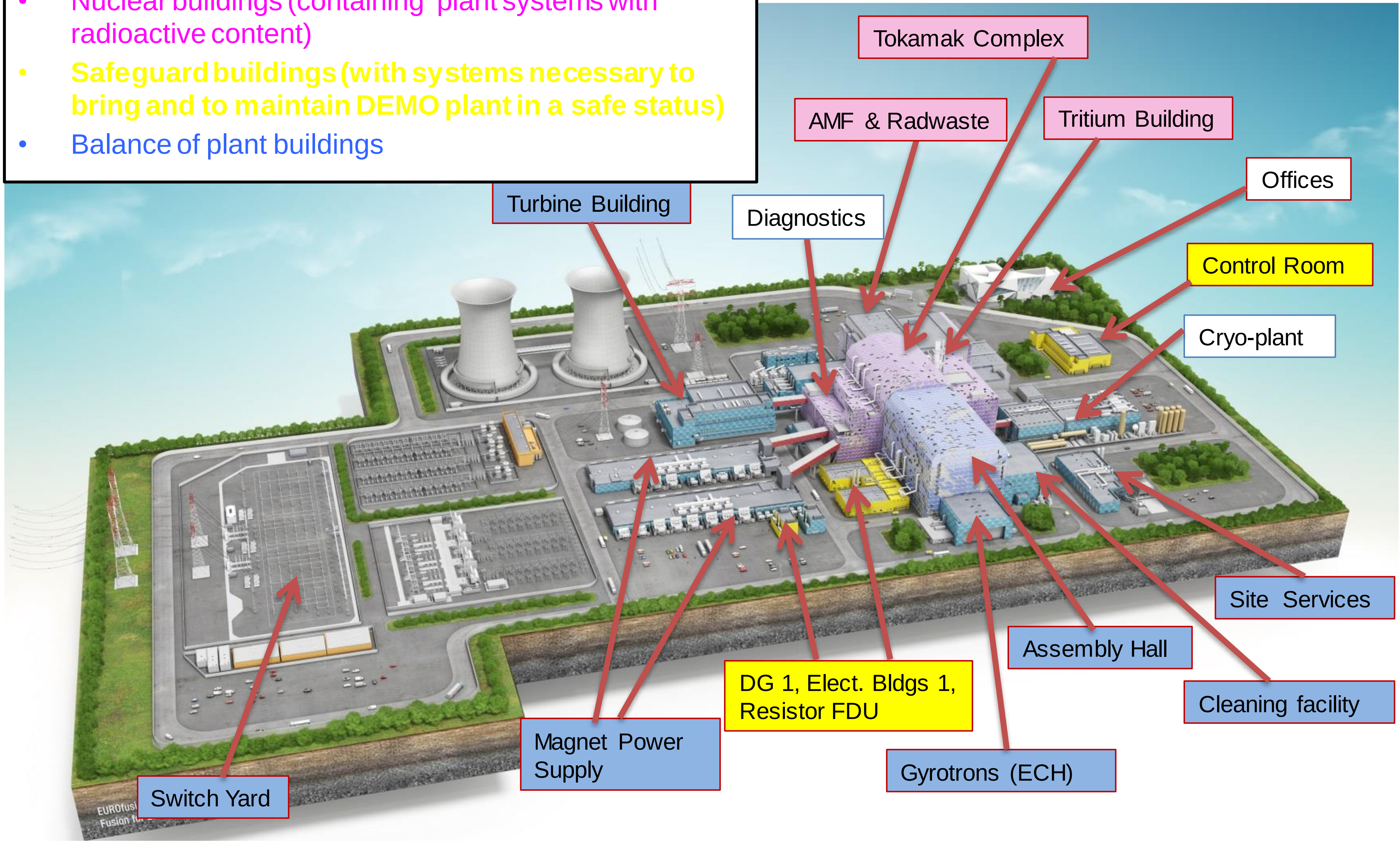


Many systems are necessary to produce, diagnose, control the plasma.
Differently from ITER, systems are also needed in DEMO to transform fusion power into electrical energy to be delivered to the grid.

Huge Dimensions: DEMO site preliminary layout

Buildings classification

- Nuclear buildings (containing plant systems with radioactive content)
- Safeguard buildings (with systems necessary to bring and to maintain DEMO plant in a safe status)
- Balance of plant buildings



Operation Challenges: Plasma Formation and Stability

<u>To obtain a significant amount of fusion power, one needs</u>:

- **High plasma current**

  but:

  - *If the current is too large wrt. the available toroidal field, magnetohydrodynamic instabilities can develop and compromise plasma stability (Fig.1)*

  $$q \approx \frac{r B_T}{R B_p} > 3$$

- **High plasma density**

  but:

  - *Too high plasma density and pressure can also trigger instabilities (Fig.2). The maximum plasma density is determined by the plasma current.*

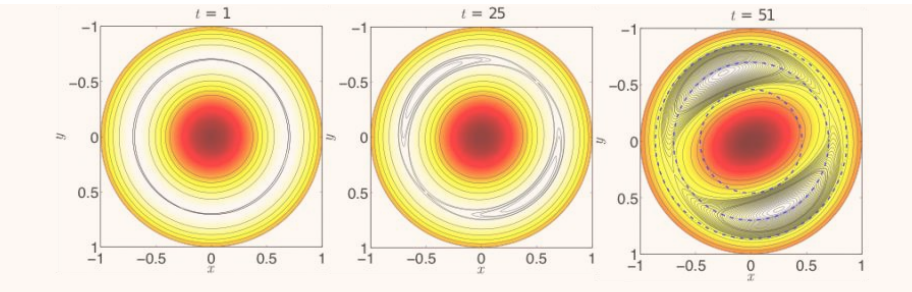
  $$n < n_{GW} = \frac{I_p}{\pi a^2}$$

- **High plasma volume**

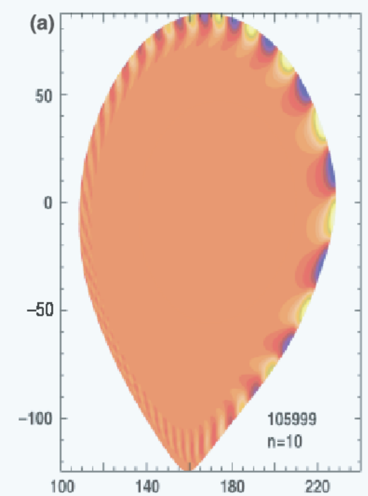
  but:

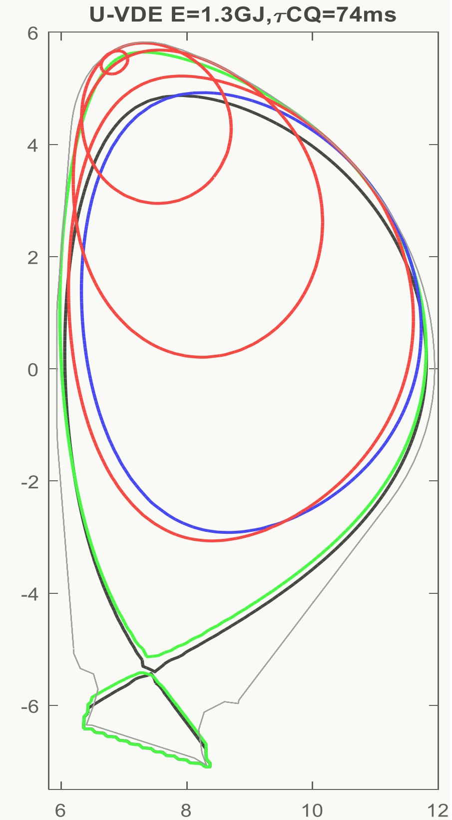
  - *High radius impacts strongly on the costs of the machine.*
  - *High elongation ("ellipticity") makes the vertical position control difficult (Fig.3)*

[Fig.1]



[Fig.2]



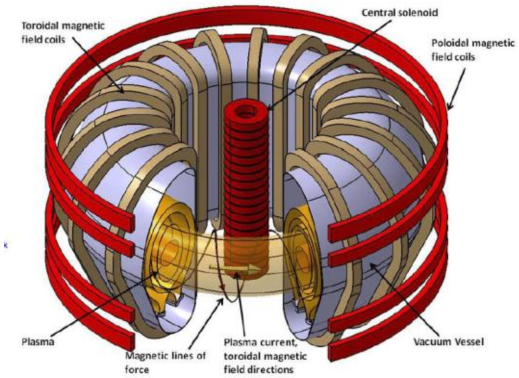


[Fig.3]

Operation Challenges: Machine parameters

DEMO must have a **validated plasma scenario** as stable as possible.

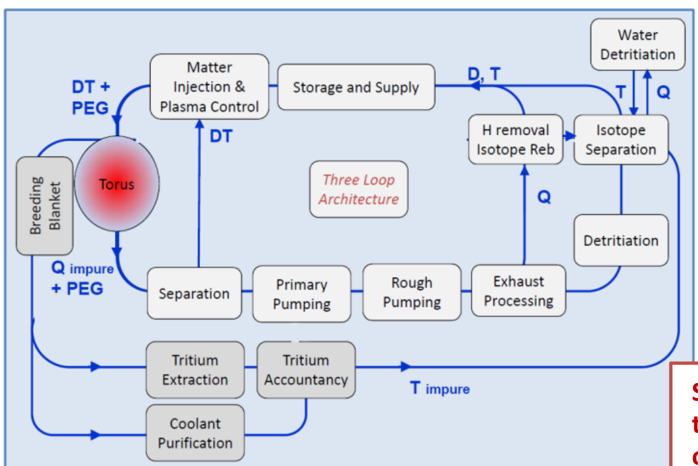
- H mode is the reference scenario. Others ELM free scenarios (QH-mode, I-mode) are being investigated.
- Field correction coils and ELMS and Vertical Stabilization Coils are under investigation.



Fuel Cycle

- Tritium production rate (= ~ burnt) ~320 g/day.
- As only few % is burnt, the throughput into the torus is very huge, most of which has to be recovered and re-injected asap.
- Contamination risk of areas (tokamak building in particular).

Tritium control will be one of the most difficult issues for DEMO, from technical and "public acceptance" points of view.



Systems operating in contniuous to replace technologies operating in batch mode

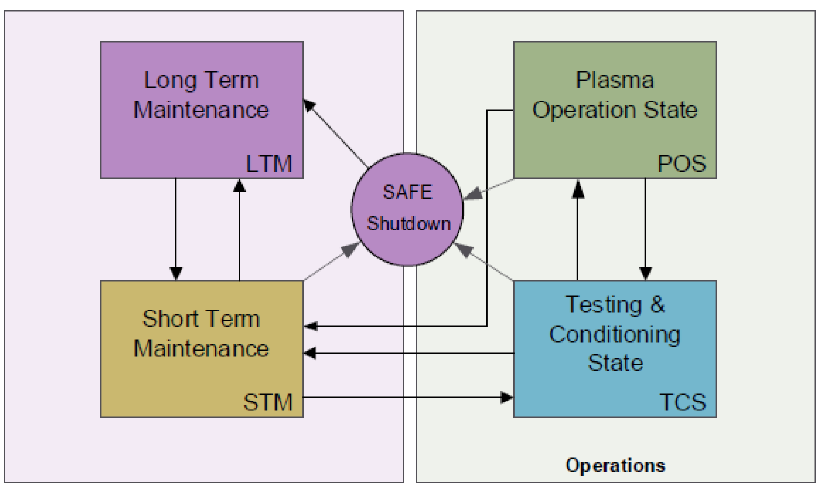
R_0, a (m, m)	9, 2.9
A	3.1
B_T(T)	5.9
Ip (MA), q	18, 3.9
k_{95} / δ_{95}	1.65, 0.33
$<T_e>$ (keV)	12.6
$<n_{e,vol}>$ ($10^{20}m^{-3}$)	0.73
Z_{eff}	2.12
H 98	~1
t_{burn} (hrs)	2
f_{bs}	0.39
fcd	<0.1
P_{div} (MW)	170
P_{LH} (MW)	**120**
P_{fus} (MW)	2012
$P_{e,net}$ (MW)	500
Av_{NWL}(MW/m^2)	1.0

DEMO few main parameters

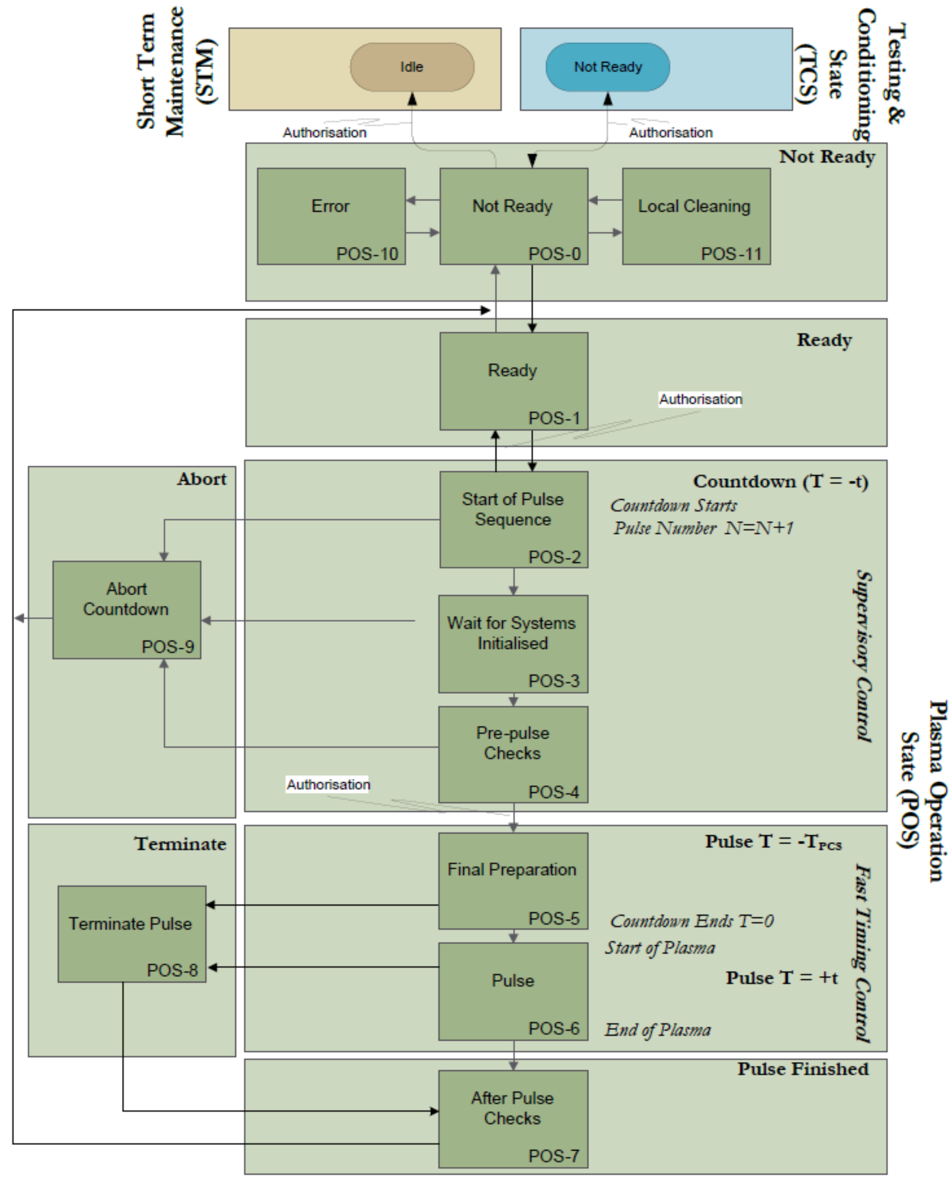
Operation Challenges: Pulsed operation – pulse sequence

- **EU-DEMO will have a pulsed operation**: 2h pulse, 10m (challenging) dwell time necessary to recharge the CS and to re-create a good vacuum in the Torus for the next plasma formation. *About 25.000 pulses are foreseen*.
- DEMO needs to be connected to a very stable-strong electrical node of the electrical grid also because it needs peaked power to create and control the plasma.

Those might be factors challenging the availability of DEMO.



Plasma Pulse Sequence: ITER Operation State Transitions

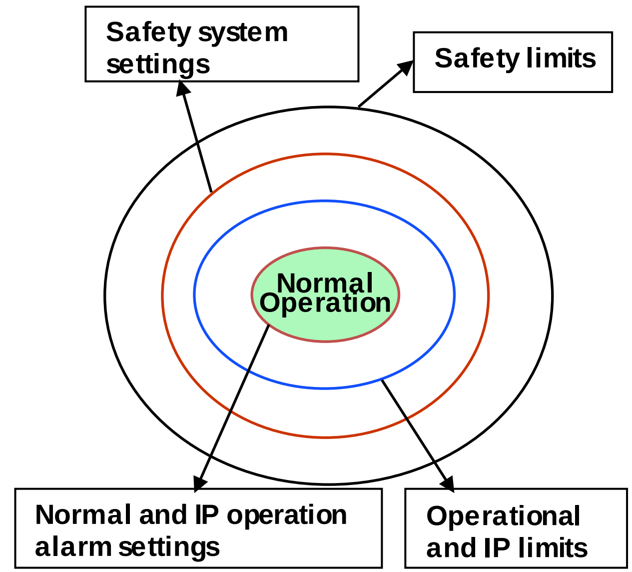


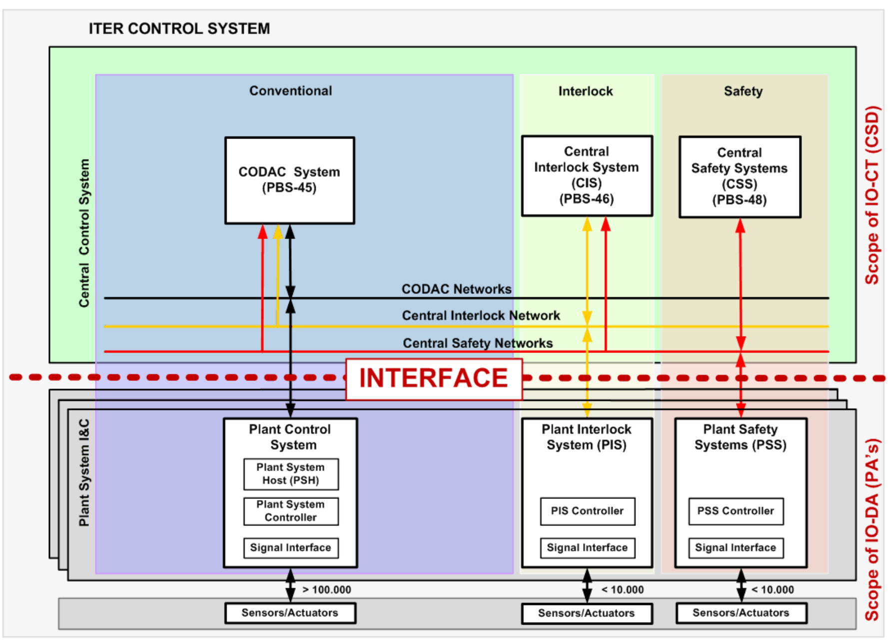
Operation Challenges: Operation Limits and Conditions

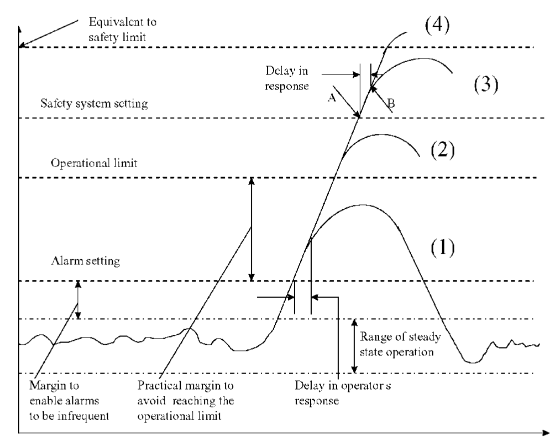
Few thousands parameters have to be verified at each sequence, relevant to conventional, investment protection and safety functions.

The safe operation domain (on which the operation license will be based on) is assured by

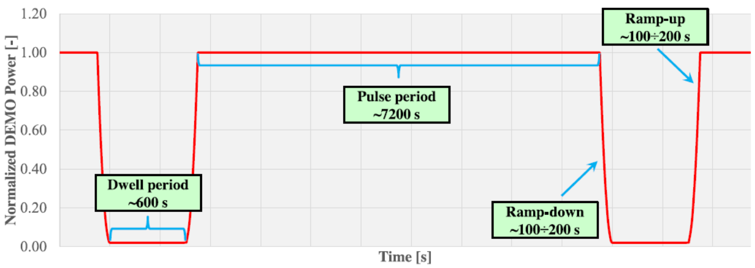
- <u>Safety Operational Limits and Conditions (few hundreds)</u> controlled by I&C safety signals e.g. plasma current ≤19 MA, radioactive material confinement process functions, safety and safeguard system parameters, radiological monitoring, radioactive mobilisable inventory limits, etc.

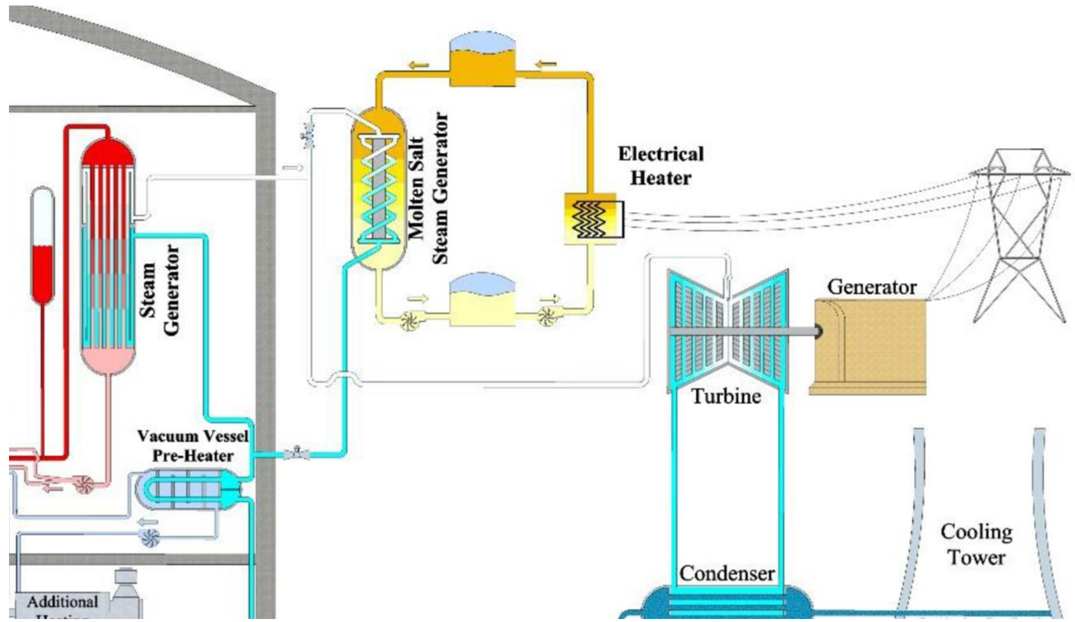






Operation Challenges: Pulsed Operation ➡ System Complexity

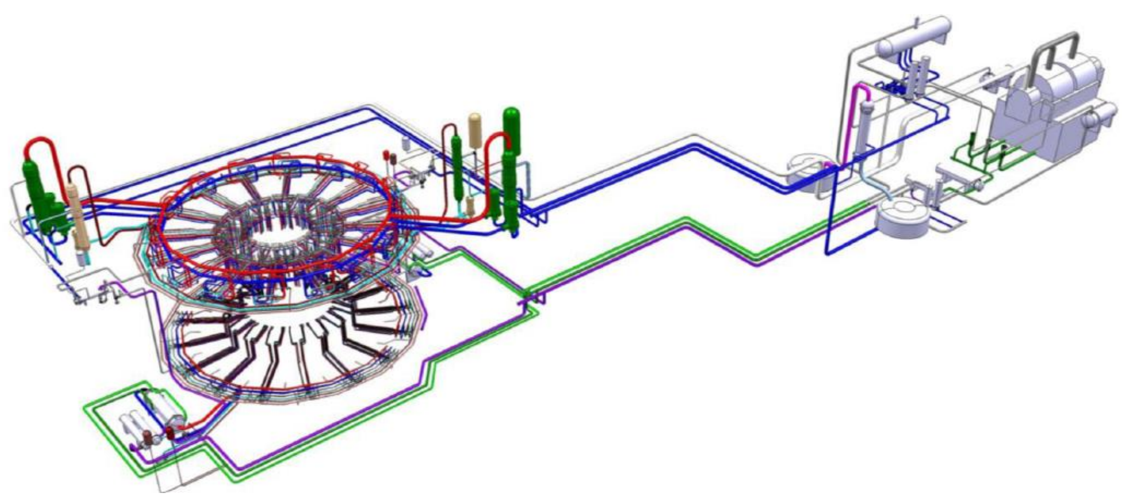




Several systems have to face and to be adapted to the pulsed plasma operation.

E.g. Fusion Power Heat Transfer and Power Conversion Systems (WCLL model)

- DEMO Electrical Generator has to be maintained synchronized with the Grid
- The power conversion system needs an accumulation of energy
  - huge accumulators to have a steady state Turbine –Generator operation
  - Smaller accumulator asks for a pulsed operation of power conversion components



Maintenance Challenges: In-VV Maintenance

In-VV Maintenance: qualified life of heavy and complex components shorter than the operation life of DEMO

- The neutron flux will create displacement damage and transmutations in the structural material
  - by irradiation hardening and embrittlement at <350°C
  - include helium embrittlement and reduction in fatigue(-creep) life at >550°C
- The first set of BB can operate in DEMO up to 20 dpa.
- R&D is on going to qualify the Blanket lifetime up to 50 dpa.
- The replacement of In-VV components is complex and will require several months of shutdown
- The in-VV inspection is a difficult task because of
  - for the high radiation dose for the RH equipment
  - the difficult access to welding and other critical areas to be inspected
- Complexity and time consuming of some diagnosis, e.g. leak detection (large number of VV penetrations)

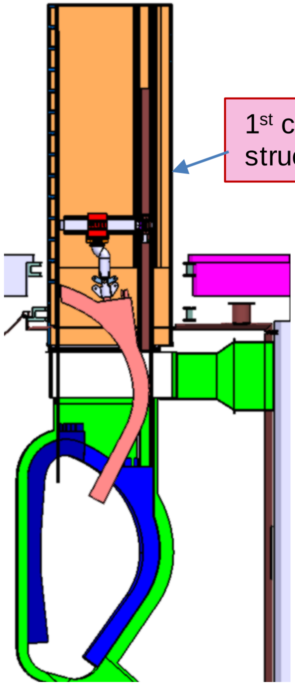
Presently all that affects the availability of the machine.

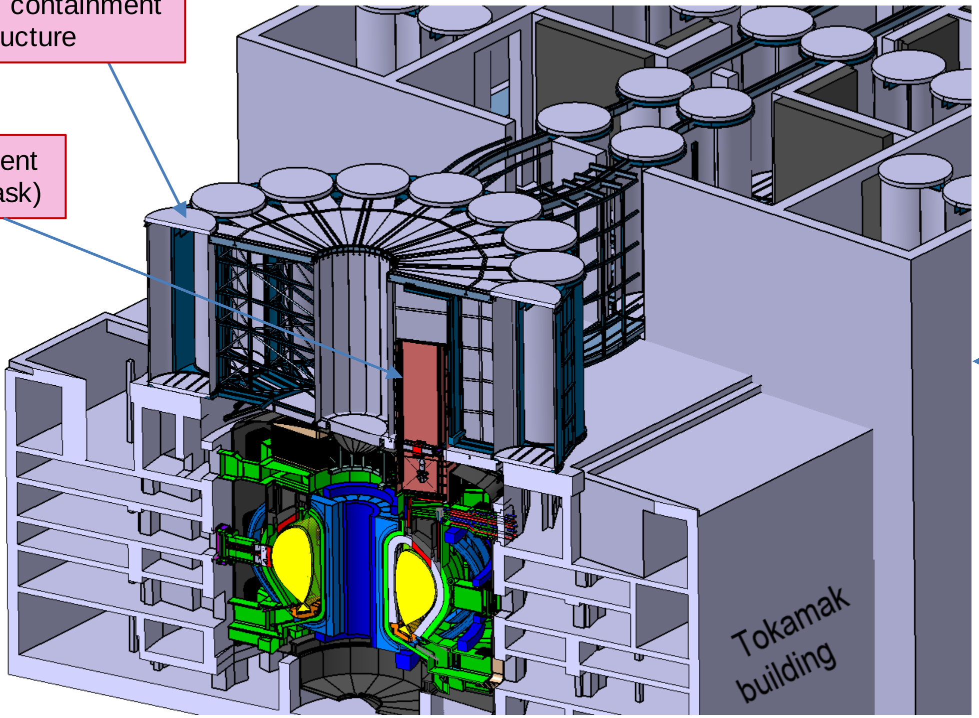
Experience of ITER will solve some of the issues, as well as the operating experience with RH in NPP (e.g. qualification of RH equipment versus radiation)

Maintenance Challenges: In-VV Maintenance

The maintenance and replacements of in-VV components include

- Breeding Blanket: the most demanding for dimensions and weight (>100 ton), radioactivity and contamination risk, location
- Divertor and Limiters from lower and equatorial ports
- Diagnostics, ECH launchers, vacuum pumps, etc.





Maintenance Challenges: Ex-VV Maintenance

The ex-VV maintenance take advantage of the huge experience of NPPs: several systems are very similar, e.g. primary heat transfer system, electrical and auxiliary systems, penetrations, radioactive monitoring systems, etc.

The ex-VV maintenance of specific fusion systems, e.g. RF, SC Magnet Systems, Cryo-plant and distribution system, Fuel Cycle and Fueling Systems, Vacuum Systems, Plasma Diagnostics will benefit strongly from ITER experience.

Main differences between DEMO and NPPs

- Environmental conditions
  - Presence of magnetic field
  - Radiation during operation due to ^{16}N and ^{17}N in the PFC cooling water system
  - Risk of low temperature (below 0°C) in case of release of cryogenic fluid (He at 4k/80k)
  - The radiation dose during severe accident doesn't increase(differently from NPP)
- Much larger number of components in nuclear buildings higher occupational radiation exposure for workers (DEMO target 700mSv*p/y):

Availability Challenges

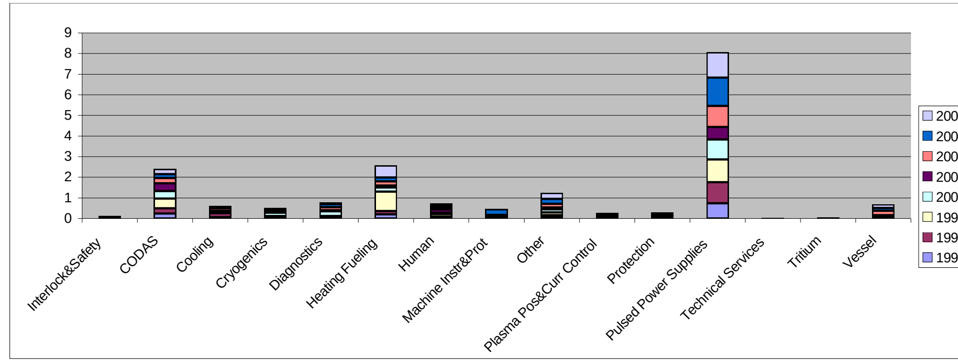
The present tokamaks availability shows already some criticality: e.g. at JET ≈3h/d (out 16h) are lost for minor issues on systems.

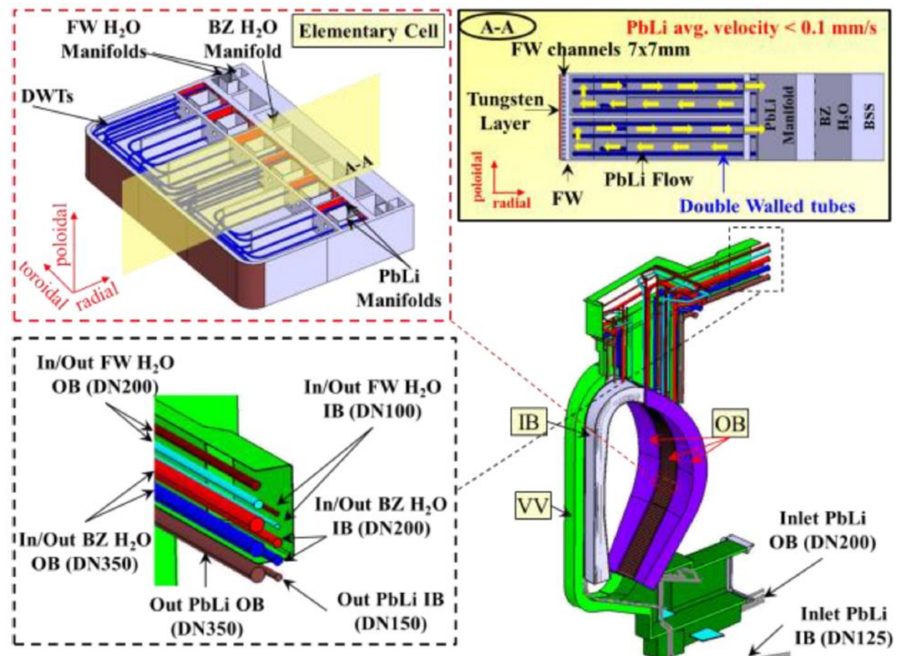
EU-DEMO has an availability objective of ~30% . Preliminary analyses show that such target is difficult to be reached because of

- Pulsed operation
- Huge number of complex systems ''first of kind'' components as, e.g. BB, with so many pipes and lot of welding working in harsh environment and with limited diagnostics and ISI
- Systems and components with a qualified life inferior to DEMO life
- Many active systems and components located in the tokamak building which accessibility is possible only with no operation and with strict radioprotection measures.

The experience of NPPs, in terms of qualification of components, diagnostics and test will be very important for DEMO.

Hour lost per malfunction, per system, per year at JET





WCLL BB

Synopsis and outlook

- DEMO has to demonstrate that electricity can be produced in a safe and reliable way. The entire project has to be oriented on safety and power provision to the grid.
- The design of main systems and buildings must advance in a progressive way taking into account all the interdependencies and considering two major objectives: to acquire a nuclear license with a wide operation domain and an adequate availability of the plant.
- The main operating challenges are relevant to plasma instabilities, huge tritium amount to manage, pulsed operation.
- The main maintenance challenges are relevant to the in-VV replacement of large components and to the high number of ex-VV systems and components particularly in nuclear buildings.
- The experience of NPP is considered at the maximum extent, in particular for the RH maintenance and for the operation, maintenance and ISI of similar NPPs-DEMO systems.
- ITER licensing, construction, commissioning and successful operation is the pre-condition for DEMO progress and represents the unique reference for operation and maintenance of specific large fusion systems.

As an overall, a simplification of DEMO plant is required in order to reduce the operating and maintenance challenges : relevant efforts are ongoing in the design of all systems.

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THANK YOU FOR YOUR ATTENTION

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