2nd EU–US DCLL Workshop
November 14-15, 2014, UCLA

EU blanket design and R&D for DEMO

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PL of the Breeding Blanket Project

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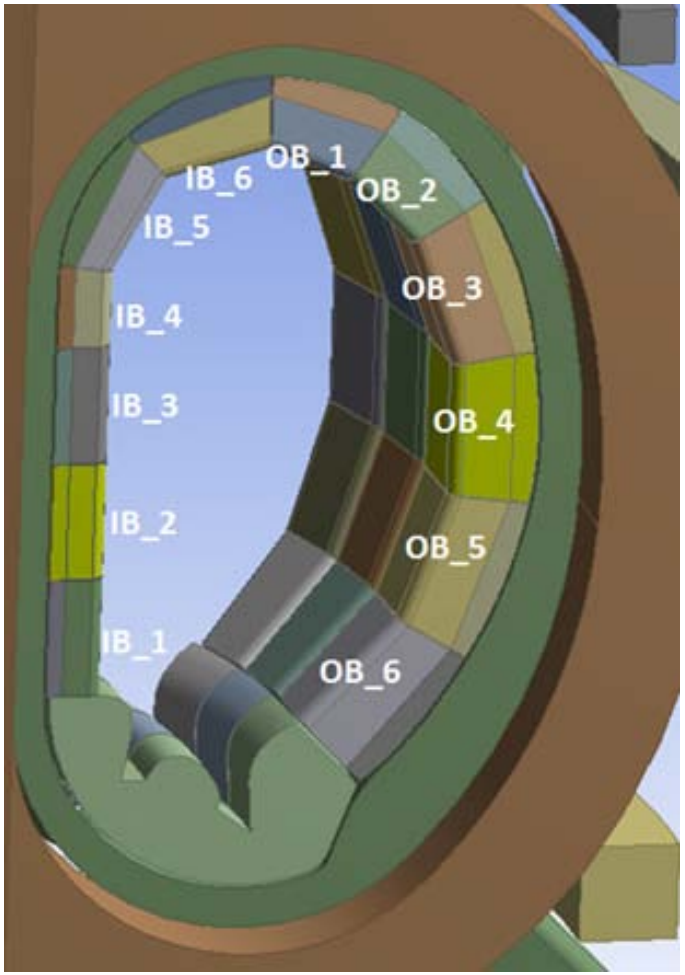
The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline

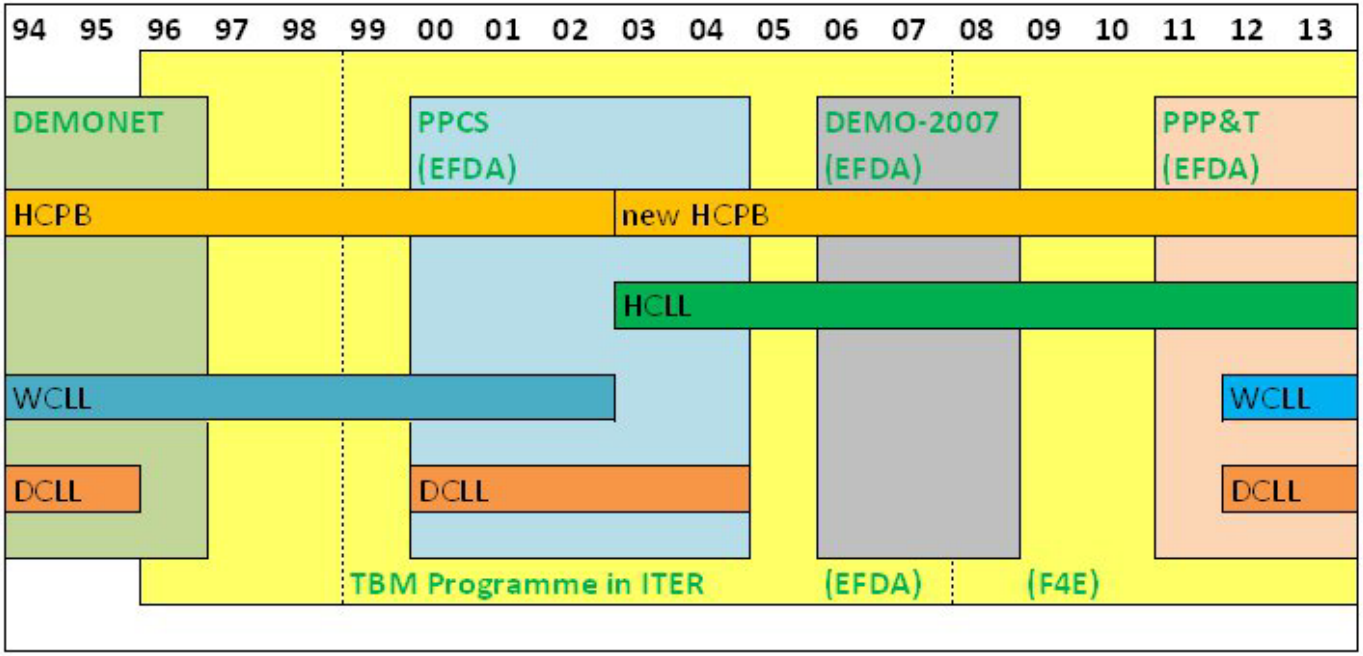
- Introduction
- The PPPT studies on Breeding Blanket (BB)
- Scope of the BB Project
- Major issues in the Design
- Organisation of the BB Project
- Design activities and planned R&D

Introduction: challenges of a Breeder Blanket for a fusion Reactor.

- ***T Production*** *to achieve the reactor self-sufficiency*
- *Thermo-hydraulic lay-out* ***for electricity production*** *(e.g. high temperatures, reduced uncertainties in the thermal loads)*
- *High neutron fluences (e.g. necessity of scheduled replacement ,* ***material withstand*** *under 14Mev-neutrons)*
- *Safety and licensing requirements (e.g. tritium control, design features to mitigate possible main accident, waste reduction)*



EU Blanket development

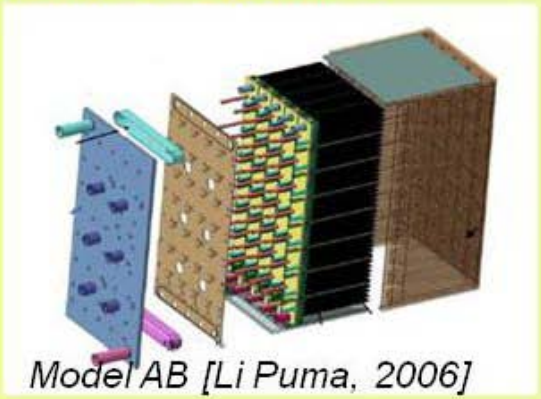


- HCPB: Helium Cooled Pebble Bed Blanket
- HCLL: Helium Cooled Lithium Lead Blanket
- WCLL: Water Cooled Lithium Lead Blanket
- DCLL: Dual Coolant Lithium Lead Blanket

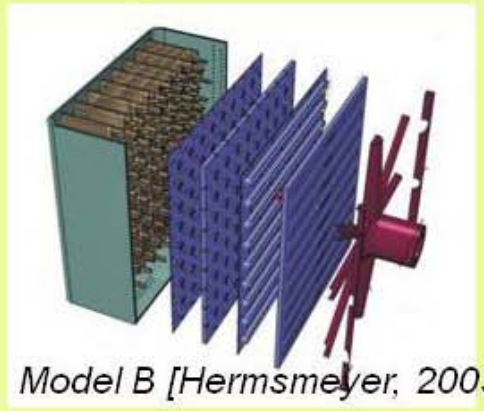
- EU is developing since the 80-ties blanket concepts based on liquid and solid breeder blankets.
- DEMONET specification were use in 1995 for the selection of concept to test in ITER.
- The Power Plant Conceptual Study (PPCS) considered plant model for a future Fusion Power Plant (FPP), assessing cost of energy and safety.
- In 2003 the HCLL replaced the WCLL. A new design architecture was proposed for the HCPB and HCLL. The two helium cooled blankets were selected for test the TBM programme.
- In the short DEMO-2007 study possible DEMO configurations were assessed for HCLL and HCPB.

EU TBM Programme

DEMO Programme

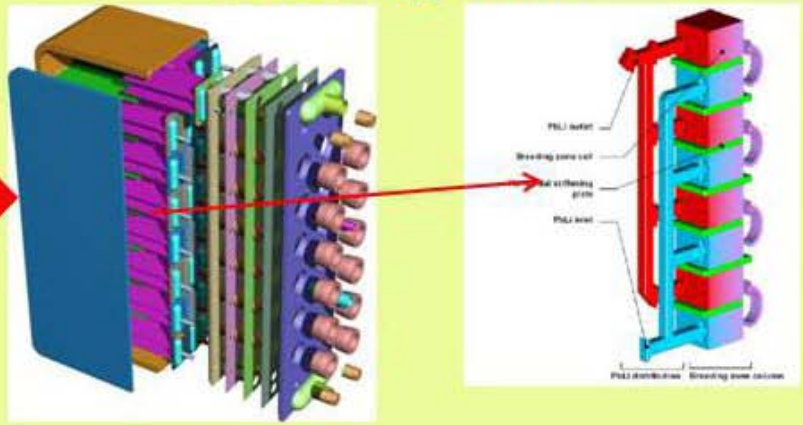


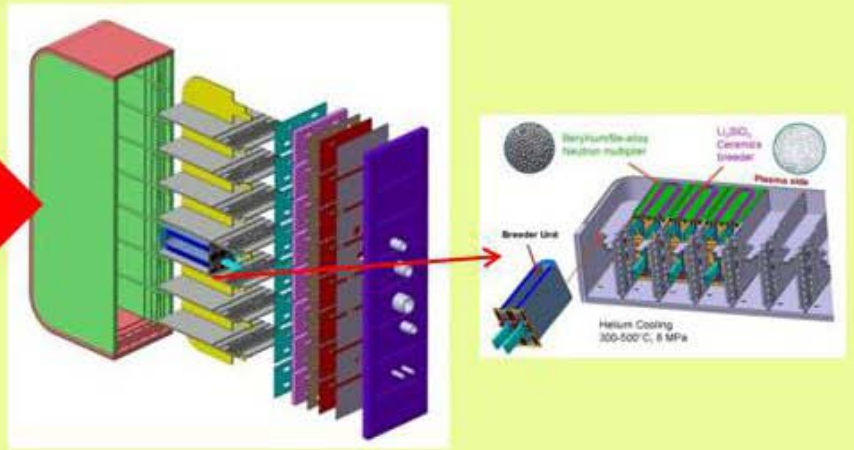
Model AB [Li Puma, 2006]



Model B [Hermsmeyer, 2003]

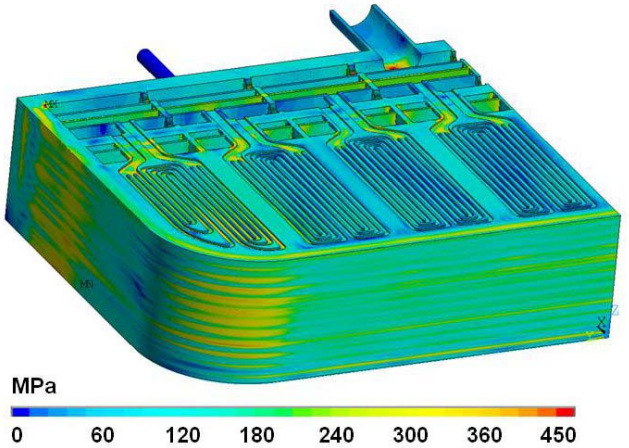
TBM Programme





EU TBM Programme

- **Conceptual design of the TBM.** This include neutronic, thermo-hydraulic and structural design, assessment under code and standard (RCC-MR(x) + SDC-IC). Relevant in direction to DEMO. Already in advance status for an ITER review meeting end 2014.
  G. Aiello (CEA) and al., HCLL TBM design status and development, Fusion Engineering and Design 86 (2011) 2129.
  F. Cismondi (KIT) et al., HCPB TBM thermo mechanical design: assessment with respect codes and standards and DEMO relevancy, Fusion Engineering and Design 86 (2011) 2228.
- **Manufacturing development for EUROFER TBM** structures (plates with cooling channels) and joint technology. Relevant in direction to DEMO. Large procurements started in 2012.
- **Material development, characterisation and procurement:** structural material (EUROFER), ceramic breeder pebbles (Li_4SiO_4 and Li_2TiO_3), beryllium pebbles (or Be-alloy), PbLi eutectic, coatings (PbLi corrosion protection, T-permeation). Objective is the test in ITER of DEMO relevant materials. PIE of large irradiation programme (e.g. HICU and HIDOBE) for solid breeder materials and Be are ongoing. R&D will start soon.

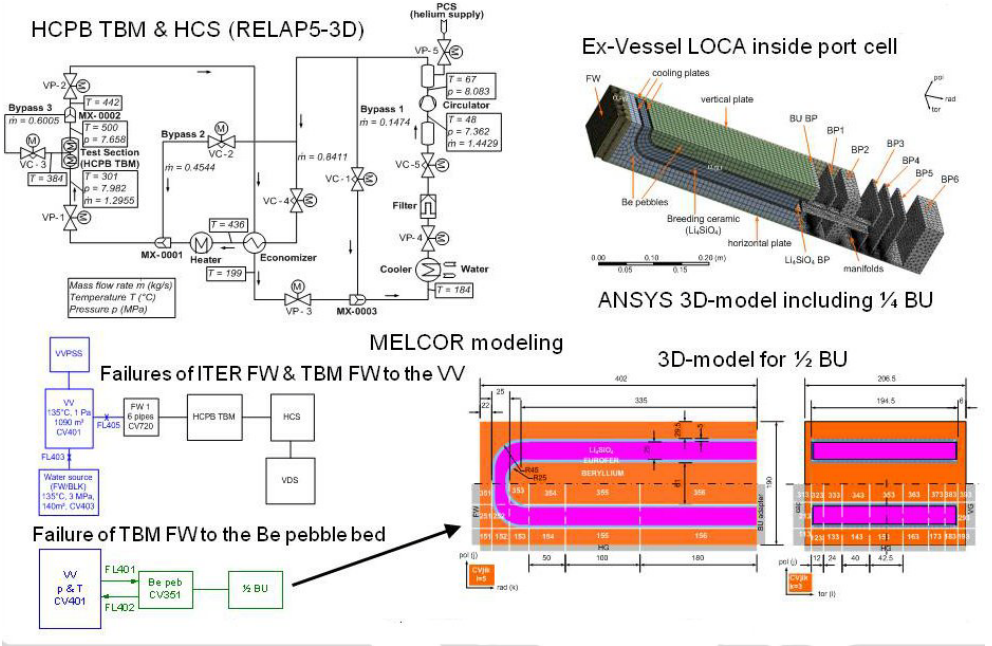


Primary and secondary von Mises stresses at flat top (asymptotical conditions). Cismondi, (KIT) 2011

1:3 FW mock-up: pre test ior diffusion welding. Rey, von der Weth, Neuberger (KIT), 2012.

EU TBM Programme

- **Predictive tools:** experimental and modelling programme to interpret TBM data and to extrapolate them to DEMO: neutronics, thermo-hydraulic, pebble bed thermo-mechanics, MHD, T transport, corrosion. R&D to be started.
- **Safety:** study of accidents related to the TBM operation. R&D ITER specific, but with interesting topics like interaction of water with Be or PbLi. Safety reporting for licensing authority ongoing.
- **Tritium recovery:** the T-auxiliary systems are mostly not relevant to DEMO systems but dictated by ITER and test specific requirements. Conceptual design in advanced status.
- **He cooling:** Feeding the TBM with Helium in the range of 300-500°C at 8 MPa. The circuit itself is not relevant for DEMO. Conceptual design in advanced status.
- **Diagnostics:** The requirements are mostly dictated by TBM test Programme. Few technologies to be used in DEMO.



RELAP 5, ANSYS and MELCOR models for combined ex-vessel LOCA analyses.

Xue Zhou Jin, Brad Merrill, Lorenzo Virgilio Boccaccini, Preliminary safety analysis of ex-vessel LOCA for the European HCPB TBM system, Fusion Energy and Design in print.

- **Licensing process:** also if not completely comparable to the DEMO licensing, the experience developed in the TBM will be a precedent for blanket licensing in DEMO.

General Assumptions for PPPT Blankets

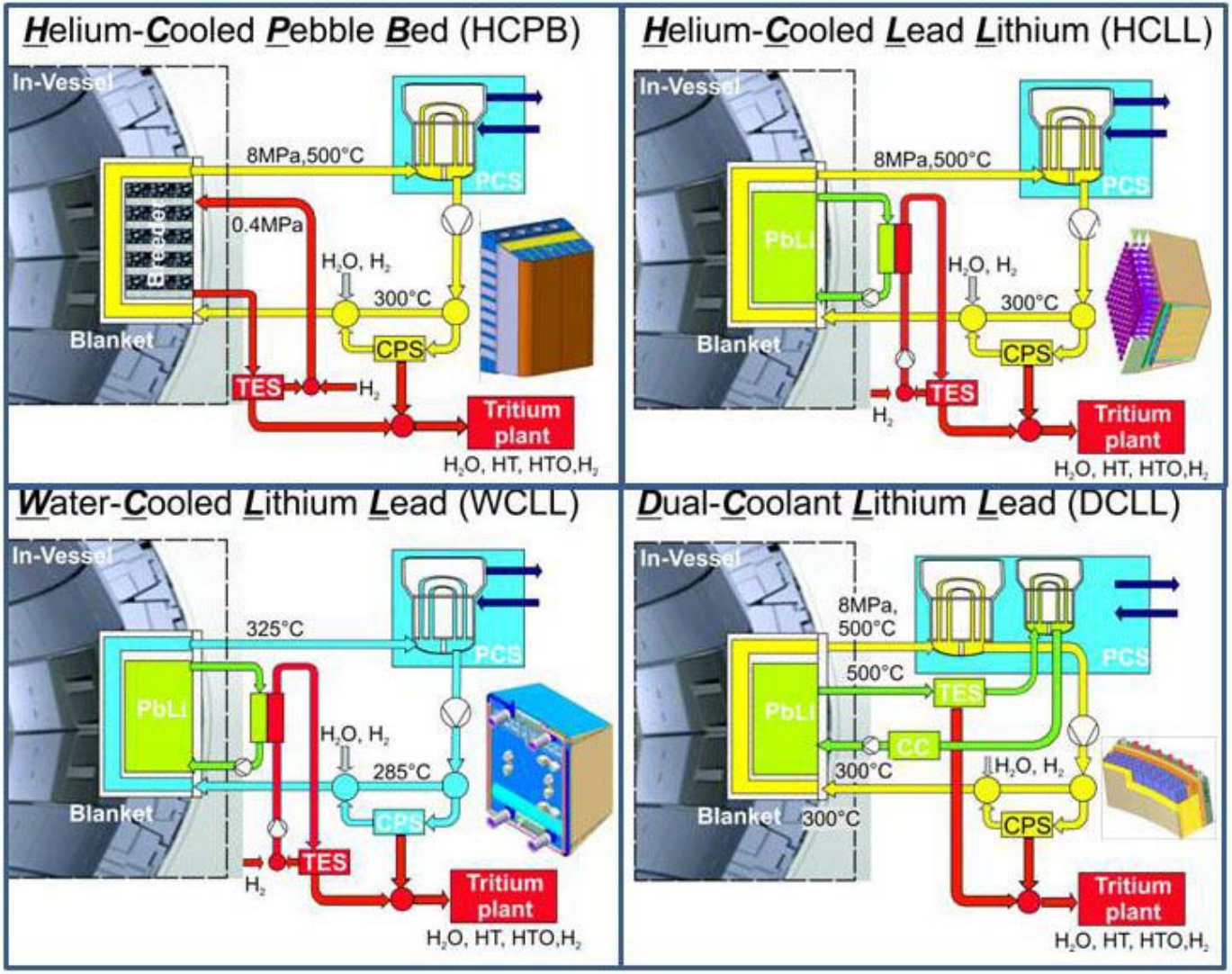
- "*DEMO shall be a **tokamak-class** nuclear fusion power plant capable of delivering several hundred megawatts of electrical energy to the grid during a fusion pulse" ;* "starting from 2050"
- DEMO shall *" **breed** the amount of **tritium needed to close its fuel cycle"***.
- "**Demonstrate** all the **technologies** for the construction of a **commercial** FPP, including an adequate level of availability."
- "***Implementation** of the **intrinsic safety features** of fusion"*.
- *" DEMO shall, wherever possible and appropriate, **utilise technology and benefit** from the experience that has been developed by the **ITER programme**."*
- *"The DEMO Programme shall employ **available resources and facilities** within the European Fusion Consortium".*
- *"**Industry shall be involved early** in the DEMO definition and design as well as R&D activities."*
- *"Europe should seek all the opportunities **for international collaborations**."*

Peculiarity of PPPT Studies

- **Strong integration study**: a configuration is managed during the project.
  - Development of complex requirements for each sub-systems
  - Complex interfaces

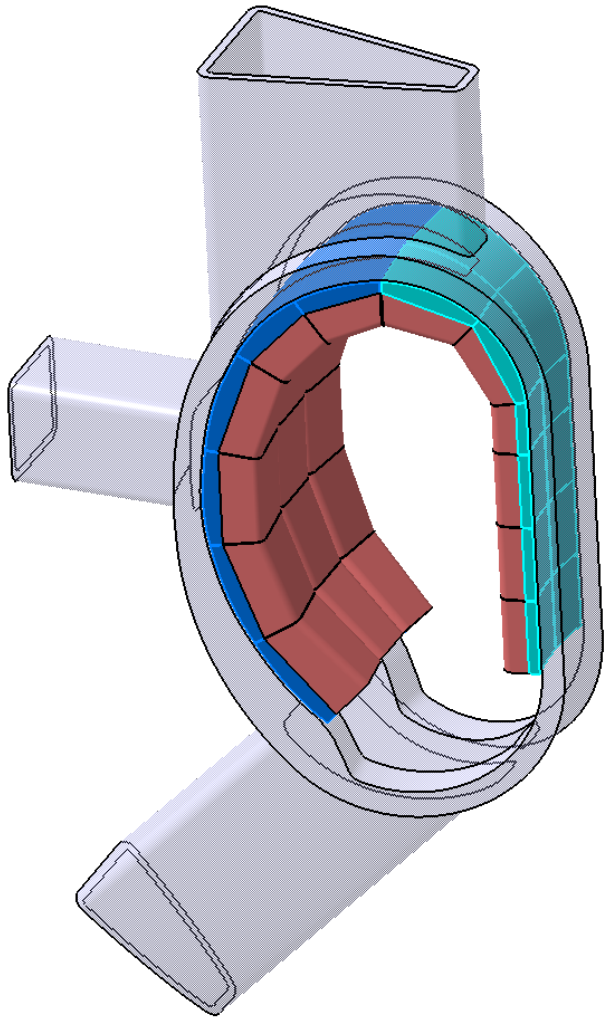
- **"Short" Time schedule**: decision to build in 2030
  - ITER physics: e.g. pulsed reactor ~2h
  - Use of technological available solution in short time scale (in technology, processes and materials).
  - "Low performances" in term of efficiency, avaliability, etc.
  - Possible high development risks.

EU Breeding Blanket Concepts



- **HCPB:** He as coolant (300-500°C @8 MPa), Li_4SiO_4 or Li_2TiO_3 as breeder and Be, both in form of a pebble bed, T extraction in blanket with purge gas
- **HCLL:** He as coolant (300-500°C @8 MPa), PbLi eutectic as breeder, T extraction from PbLi outside the reactor.
- **WCLL:** Water as coolant (PWR condition: 285-325°C @15 MPa), T extraction from PbLi outside the reactor.
- **DCLL:** He (~300-400°C @8 MPa) and PbLi (max <500°C) as coolant, PbLi eutectic as breeder, T extraction from PbLi outside the reactor, electrical insulating inserts.

PBS OF THE BB PROJECT



- Are also in the scope the following BB Auxiliary Systems:
  - **PbLi loops as breeder loops** in HCLL and WCLL.
  - For DCLL only. Mostly of the **PbLi Loop as PHTS** (heat exchanger excluded).
  - **Tritium Extraction System** with purge gas in Blanket for the HCPB.
  - **Tritium Extraction System** from PbLi loop outside the reactor (gas purging, vacuum permeator or others) for the HCLL, WCLL and DCLL.
  - **Limiter** if included in the design

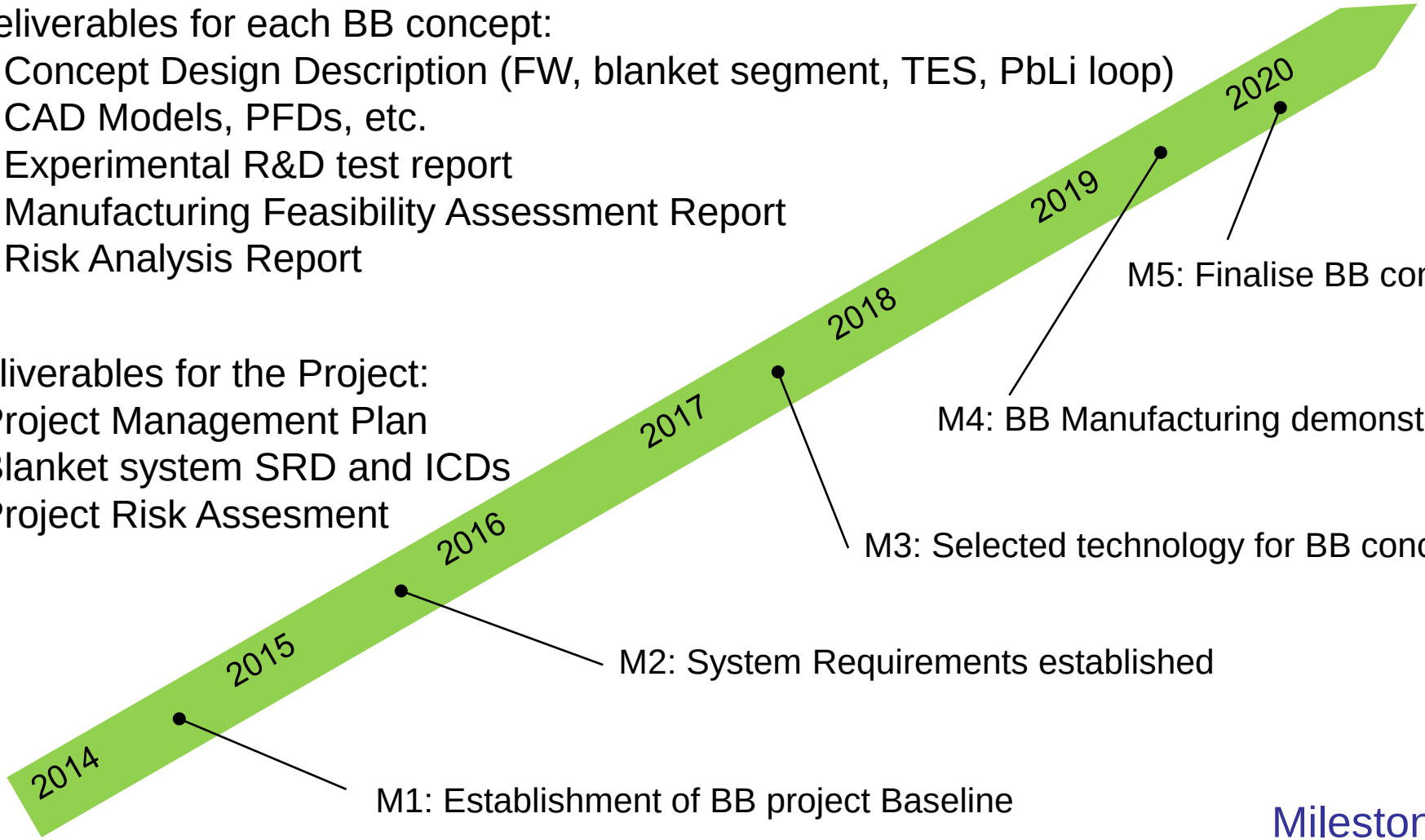
Major Milestones/Deliverables in 2014-2020

Deliverables for each BB concept:

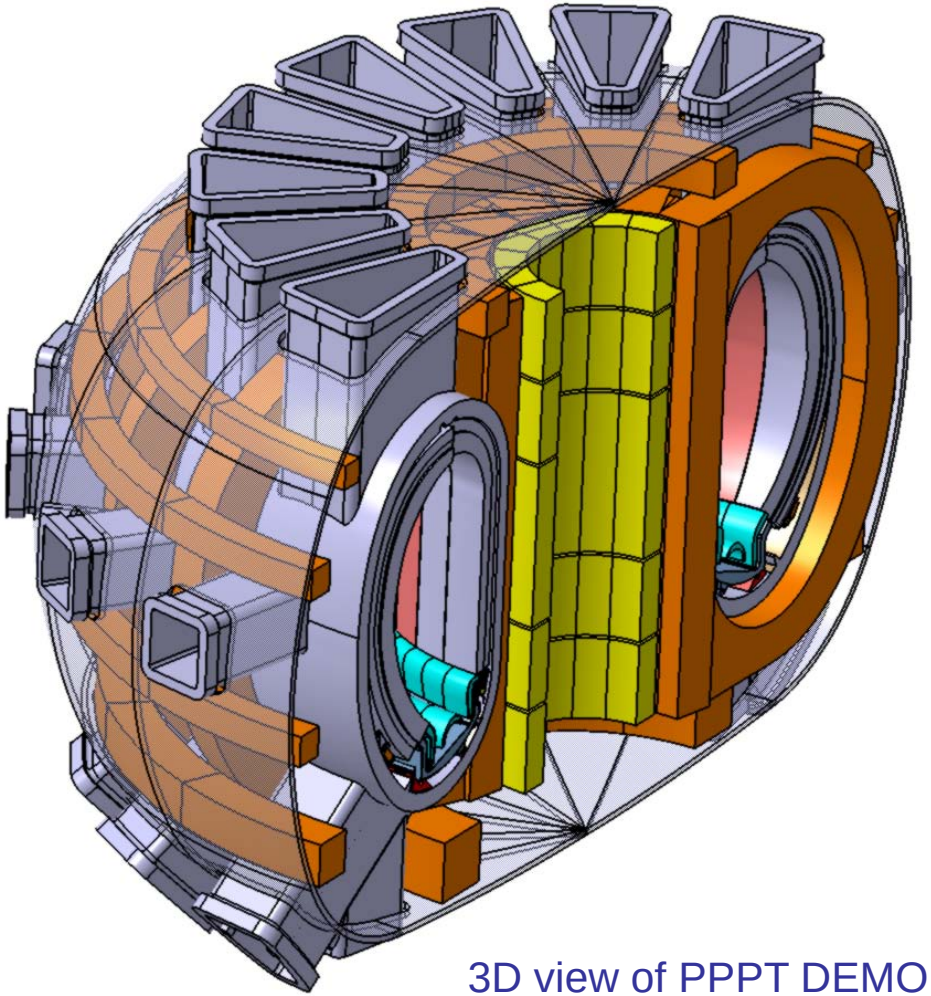
- Concept Design Description (FW, blanket segment, TES, PbLi loop)
- CAD Models, PFDs, etc.
- Experimental R&D test report
- Manufacturing Feasibility Assessment Report
- Risk Analysis Report

Deliverables for the Project:

- Project Management Plan
- Blanket system SRD and ICDs
- Project Risk Assesment

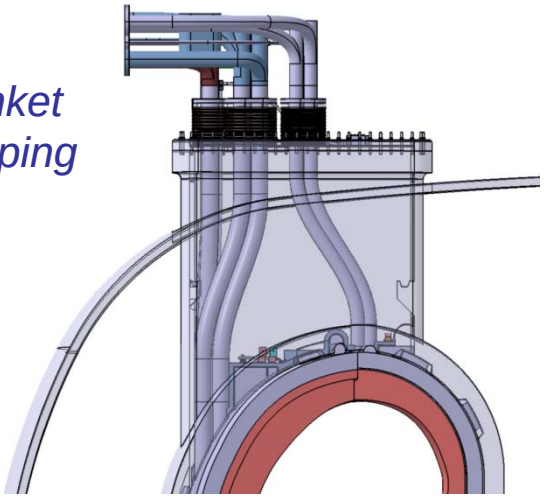


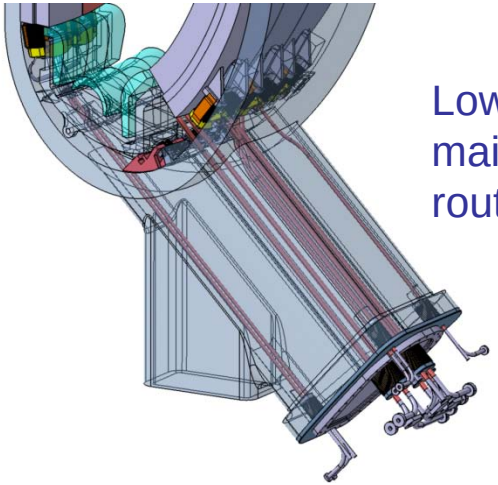
Maintenance System



3D view of PPPT DEMO

Vertical port for blanket maintenance and piping routing

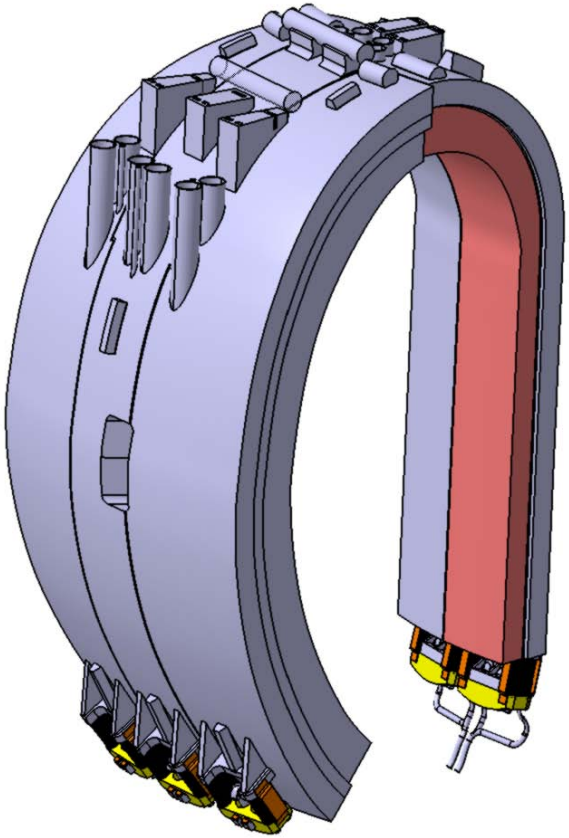




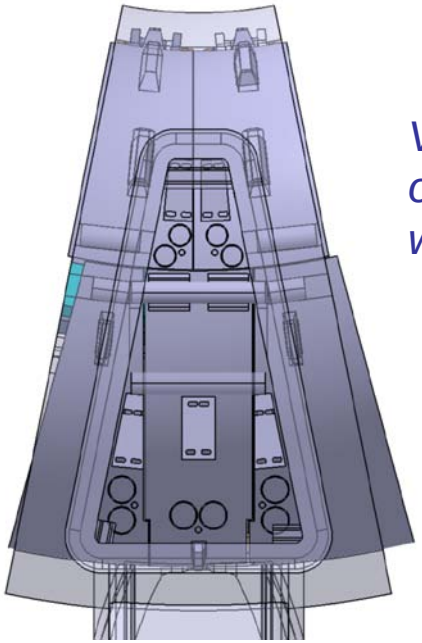
Lower port for divertor maintenance and piping routing

Daniel Iglesias et al., Blanket Segment Remote Maintenance, WP13-DAS07-T05 (CCFE)

Blanket Maintenance System

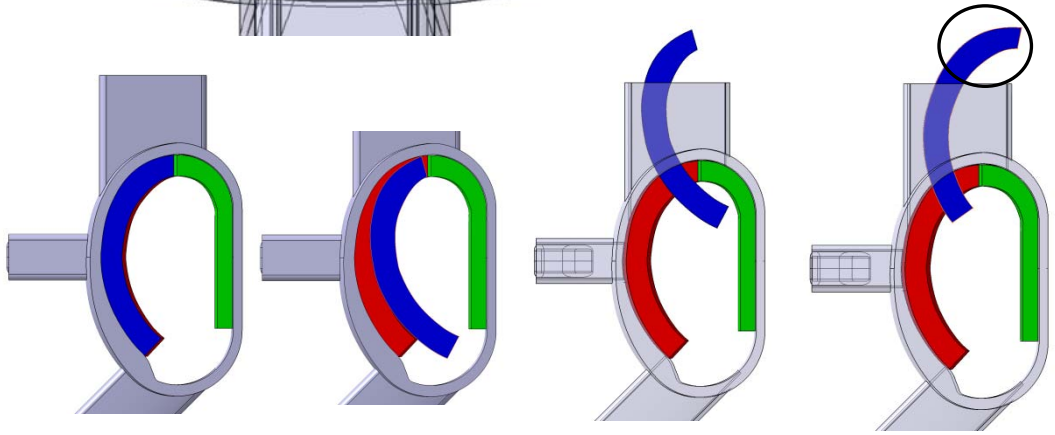


5 blanket segments (3 OB and 2 IB) concept



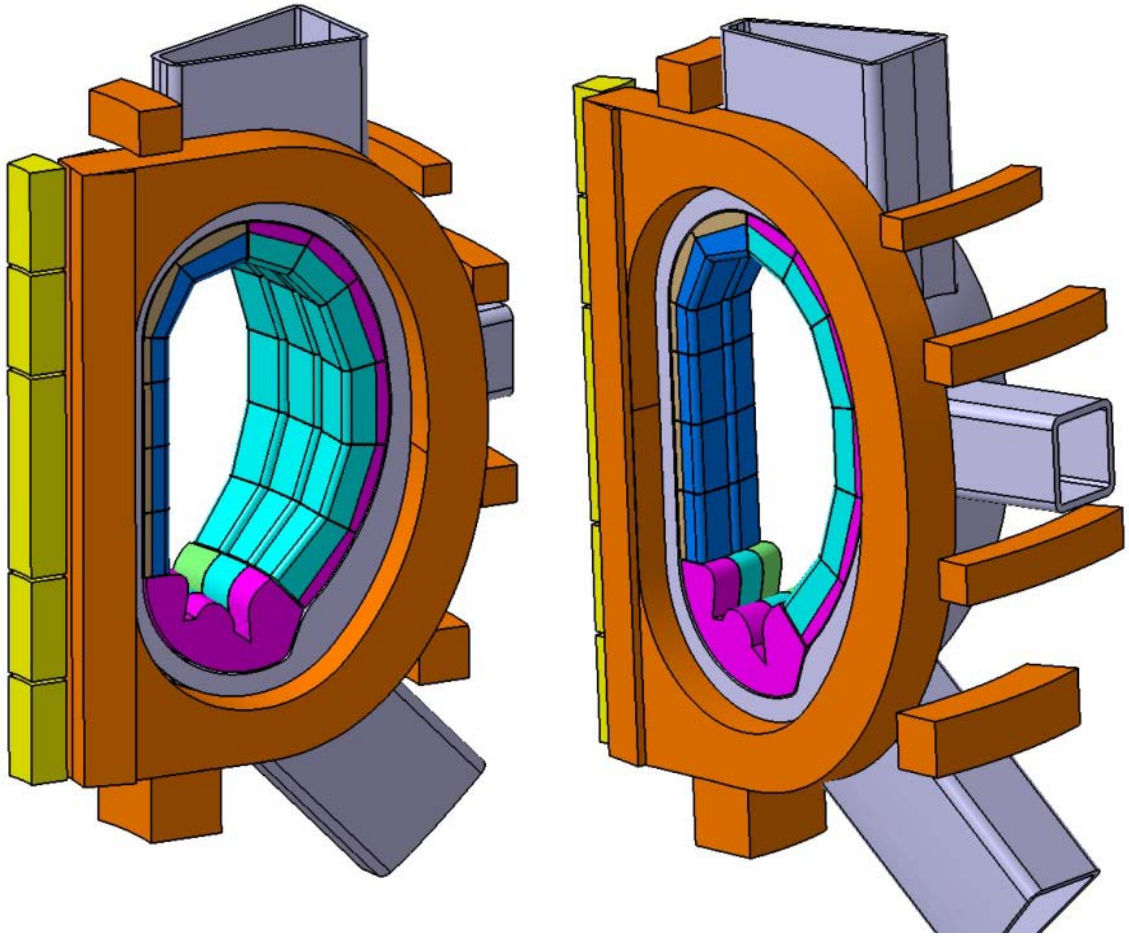
View from the vertical port of the blanket segments with piping access

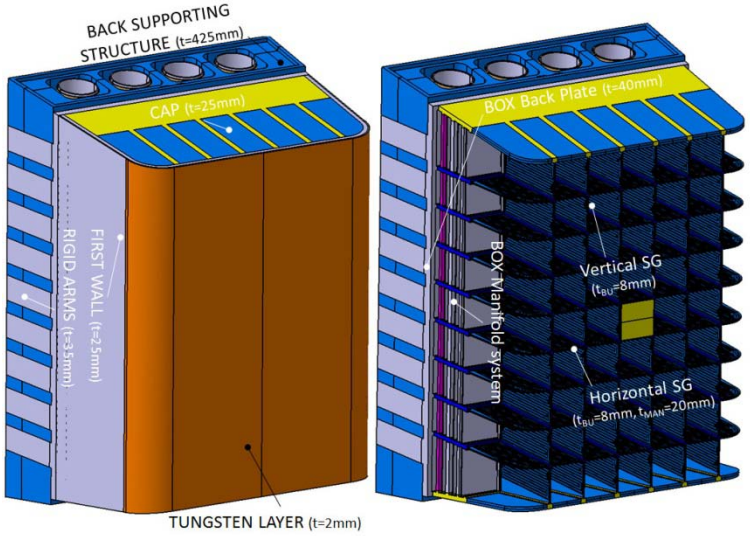
Example of kynematics for OB extraction



Daniel Iglesias et al., Blanket Segment Remote Maintenance, WP13-DAS07-T05 (CCFE)

Multimodule Segment



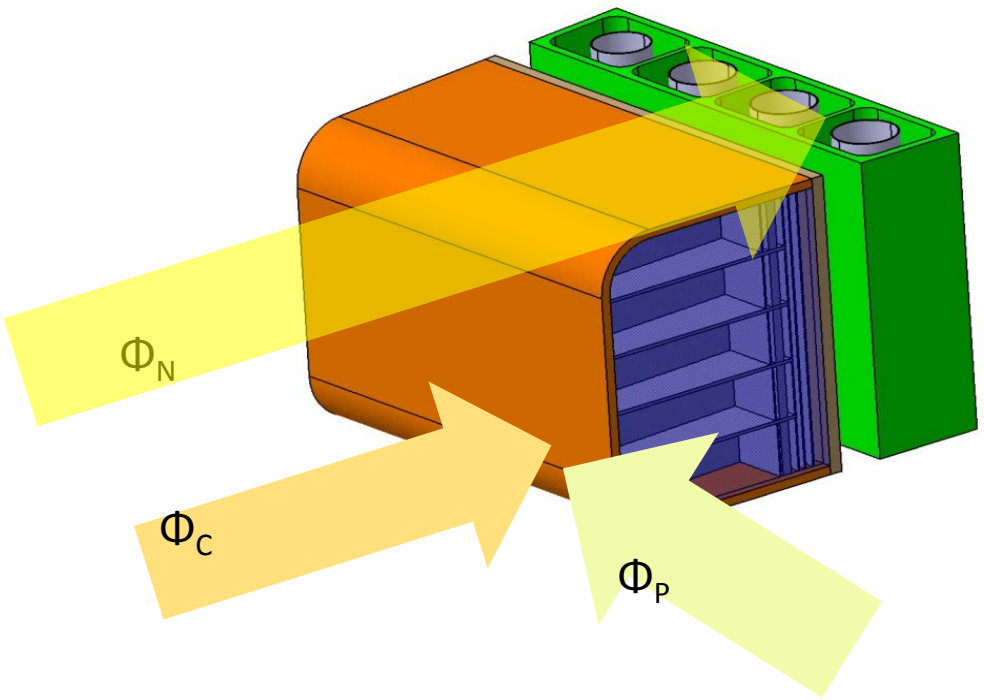


Example: HCPB blanket design of box adapted to a PPPT configurations.

Example of blanket sector segmentation for a PPPT Demo

Dario Carloni et al., Helium Cooled Blanket Design Development WP13-DAS-02-T04 (KIT)

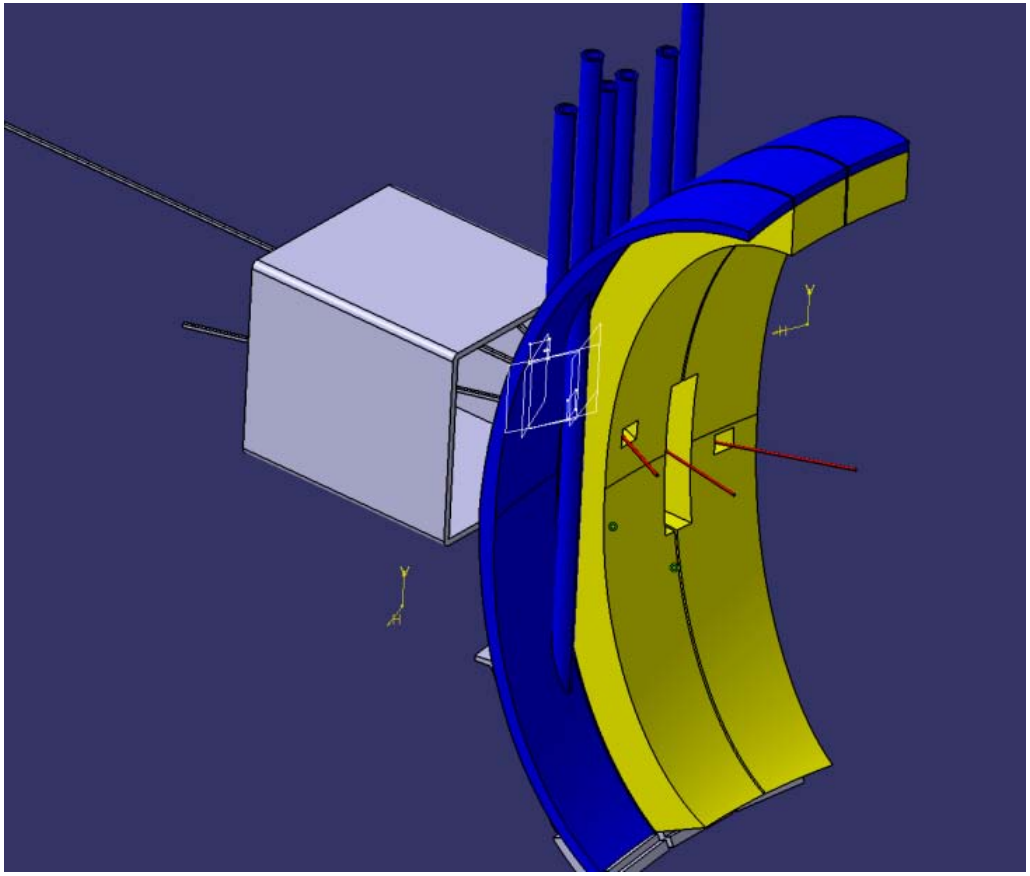
DEMO Thermal Loading



Φ_N	Neutron wall load	1.5 MW/m^2
Φ_C	Core irradiation	0.5-0.7 MW/m^2
Φ_P	plasma interaction	tbd

- The Breeding Blanket in DEMO is subjected to: neutronic volume heat load, surface heat from core irradiation and plasma flux interaction.
- In DEMO the dominant issue is the management of heat coming fro the plasma interaction. The present uncertainties lead to safety factors larger than 5 in ITER FW hydraulic design (~50% of FW designed for ~4.5 MW/m2).
- Present blanket FW are able to remove max ~1 (1.5) MW/m2 (mostly due to material limitations).
- In addition the erosion related to the plasma interaction requires FW protection layers (W).
- Requirements are requested soon **(end 2015 tbd)** as large changes could be required in the current design.

H&CD Systems and Control Diagnostic

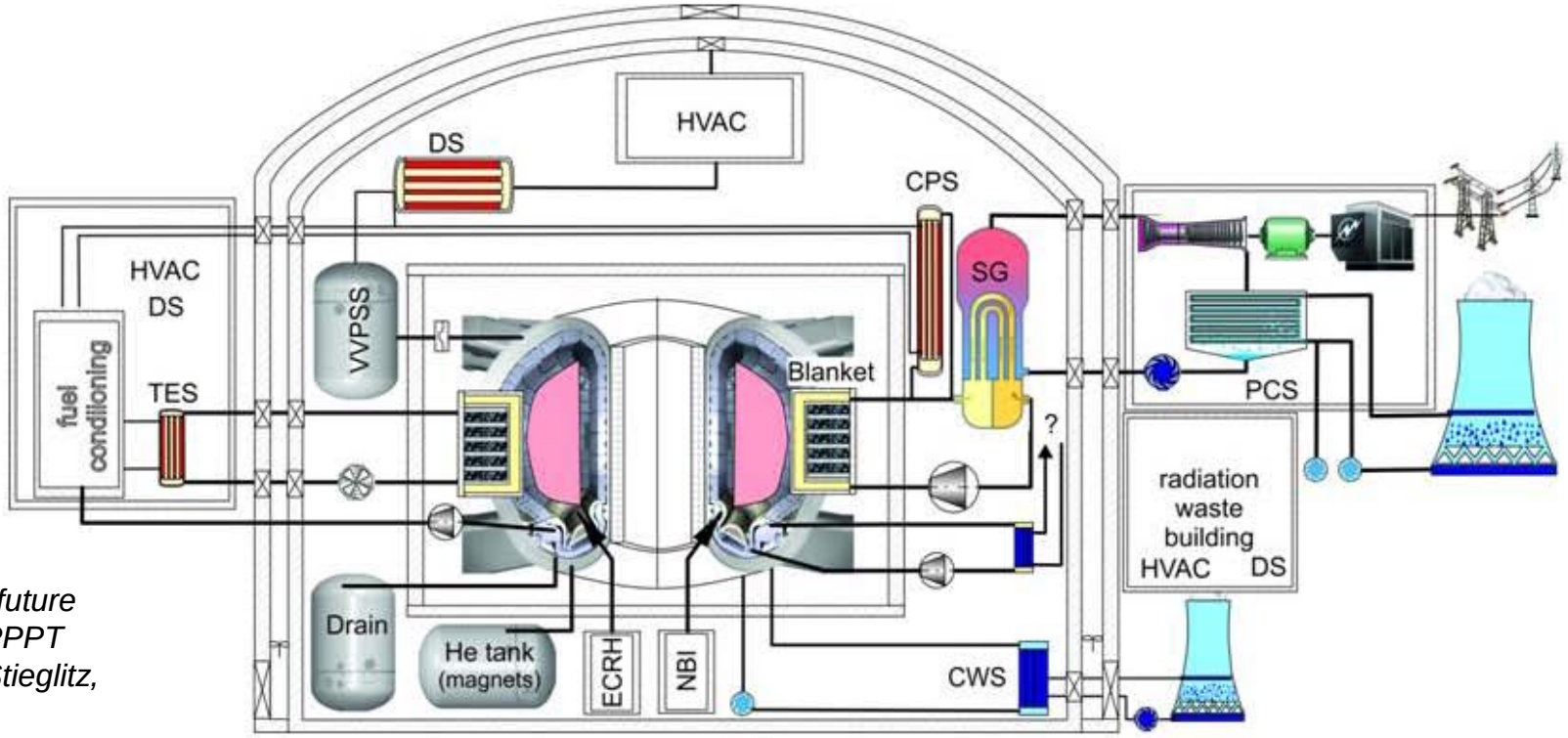


Conceptual study for the port openings into the outboard blanket segment.

- Several systems (e.g. **H&CD or Diagnostics**) use Vacuum Vessel Ports to accede to the inner part of the vacuum vessel.
  - Blanket components should allow opening and windows
  - Necessity to harmonise two different maintenance concepts.
- Large impact foreseen in the BB design and in the TBR.
- Input required soon **(end 2015)** because large changes could be required.

D. Straußß, EFDA Task WP11-DAS-RH-06

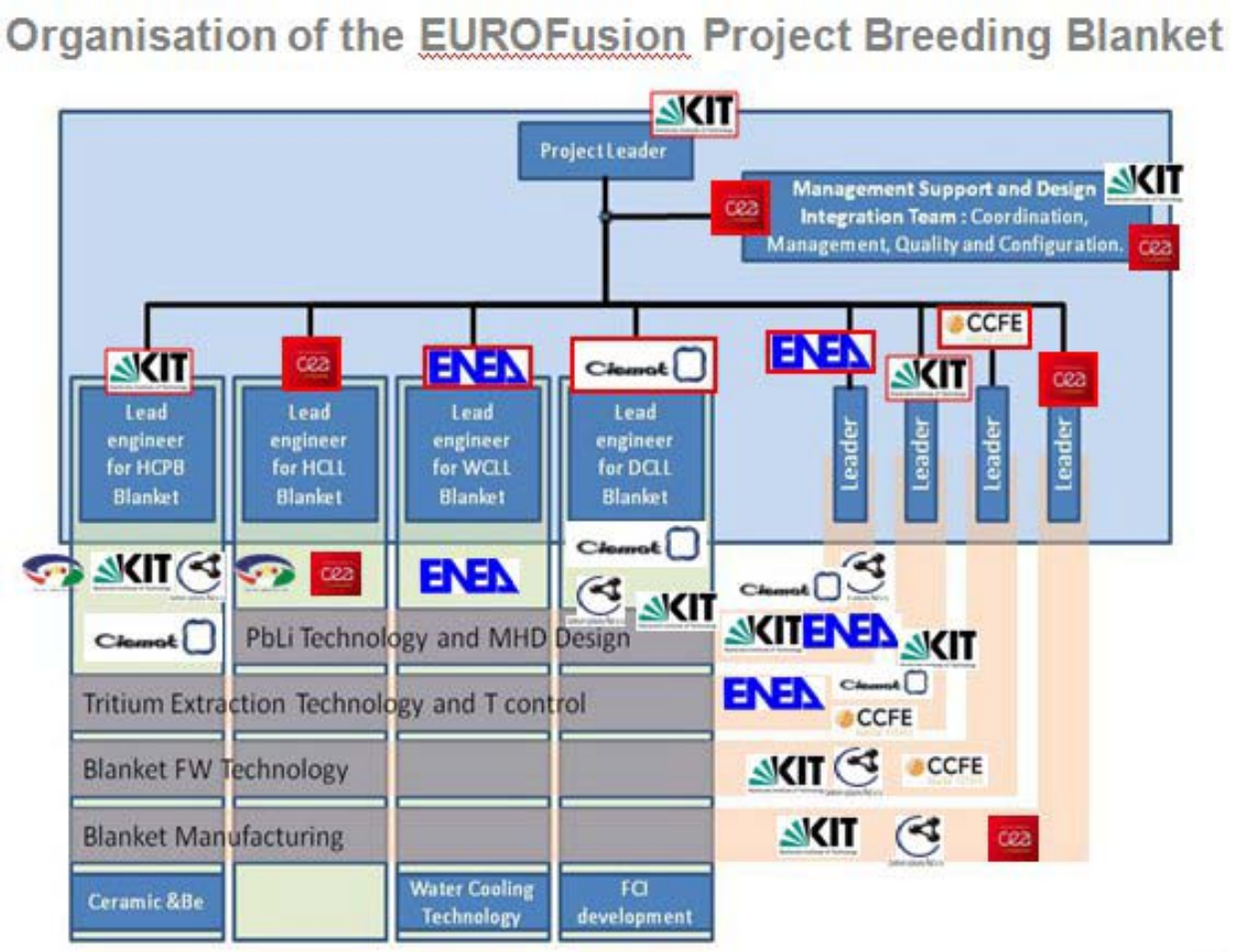
Other important Issues



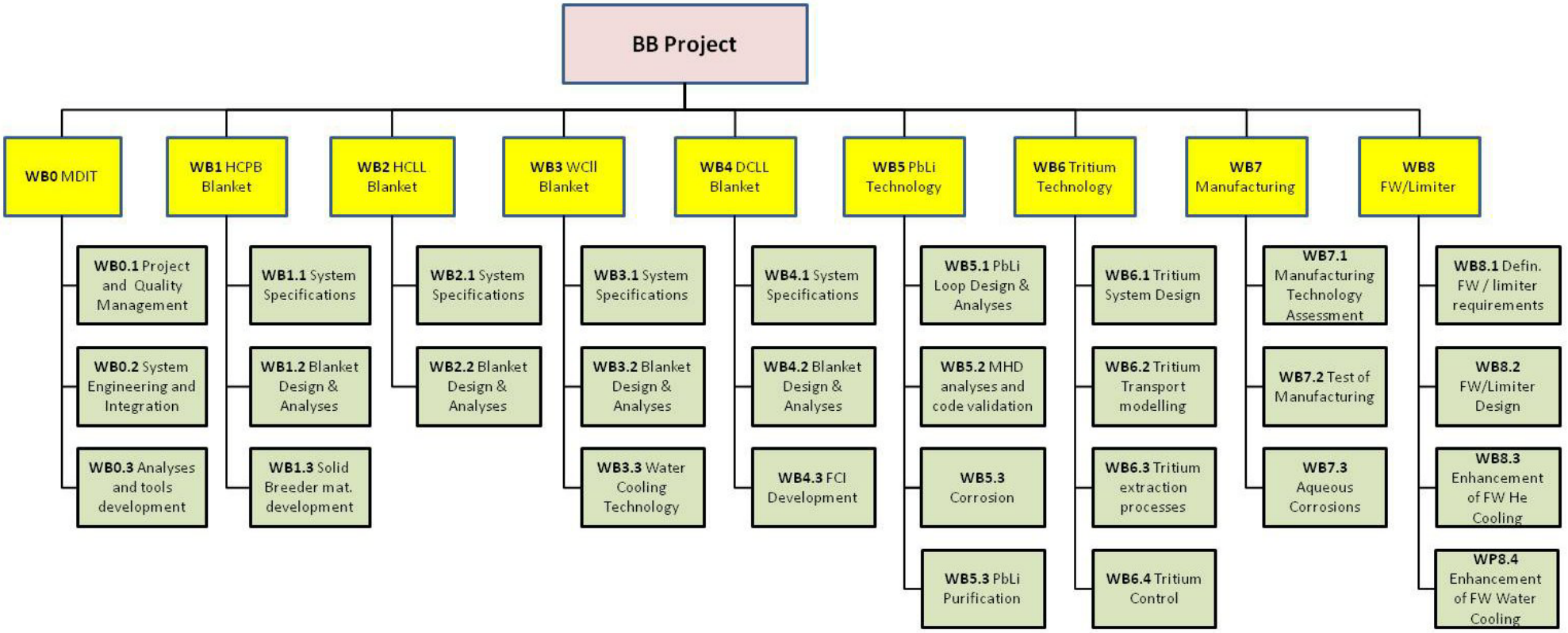
View of a possible future safety concept of PPPT fusion DEMO (R. Stieglitz, SOFT 2014)

- **Structural materials** (extension of EUROFER temperature windows).
- **Waste reduction**
- **Safety Characteristics** (e.g. Implementation of safety functions)

Breeding Blanket Project



BB Project Work Breakdown Stucture



PbLi Technology

- PbLi Loop Design & Analyses
  - Conceptual Design of HCLL/WCLL/DCLL LiPb-Loop with auxiliaries [ENEA,IPP-CR]
  - Component Development for HCLL/WCLL [ENEA]
- MHD Analyses and code validation
  - Computations of 3D MHD effect [CIEMAT, KIT]
  - MHD experiment at low velocity: code validation [KIT]
  - MHD experiment at high velocity: code validation [KIT]
- Corrosion
  - Development and characterisation of anti-permeation/anti-corrosion coating [CIEMAT, ENEA, KIT]
  - Coating Irradiation [CIEMAT,IPP-CR]
  - Compatibility tests of high velocity LiPb channels [
- PbLi Chemistry & Purification
  - Purification of PbLi loops (HCLL/WCLL/DCLL) [IPP-CR]
  - PbLi-Water Reaction [ENEA]

Tritium Technology

- Tritium System Design
  - HCPB, HCLL/WCLL and DCLL TES Conceptual Design [CIEMAT, ENEA, KIT]
- Tritium Transport Modeling
  - T System Analyses for BB [CIEMAT]
  - Development of Blanket T Transport models for HCPB, HCLL/WCLL and DCLL BB [CIEMAT, ENEA, KIT]
- Tritium Extraction Processes
  - Tritium Extraction from He purge gas with membrane: small scale with tritium and medium scale without T [ENEA, KIT]
  - Tritium Extraction from low velocity PbLi: small scale with tritium using VST or GLC [KIT]
  - Tritium Extraction from high velocity PbLi: small scale with/without tritium and medium scale without T using PAV [CIEMAT,ENEA,KIT]
- Permeation Control
  - Permeation Test on coatings (for PbLi) with tritium [KIT]
  - Permeation Test on coatings (for PbLi) under irradiation [CIEMAT]
  - Permeation Test on natural oxide layers using He chemistry control (with tritium) [CCFE]
  - Permeation Test on irradiated coatings anti permeation barriers [CCFE]

Manufacturing Technologies

- Manufacturing Technology assessment
  - Assessment of Manufacturing Technologies for Blanket development: HCPB, HCLL, WCLL and DCLL [CEA,KIT]
- Test of Manufacturing
  - Test of manufactured sub-components (FW, BZ mock-ups) in Helium facilities (300-500°C Helium) [KIT]
  - Test in Water facility at PWR conditions [IPP-CR]
- Aqueous Corrosion
  - Corrosion test of EUROFER in Water at PWR conditions [IPP-CR] .

FW/Limiter Development

- Definition of FW/Limiter Requirement
  - System requirements definition [CCFE]
- FW/Limiter Design
  - Design And Development [CCFE]
- Enhancement of FW He Cooling technology
  - Study of enhanced cooling channel geometries using experimental validation [KIT]
  - Optimization of HCPB DEMO FW cooling channels [KIT]
- Enhancement of FW Water Cooling technology
  - Channel Design and Analyses [IPP-CR]
  - Experimental validation of FW heat transfer enhancement techniques [IPP-CR].

Other R&D Tasks

- (Solid) Breeder Materials development [only for the HCPB]
  - Ceramic Breeder Production & Characterisation [KIT]
  - Ceramic Breeder Pilot Plant Development [KIT]
  - Ceramic Breeder Characterisation: irradiation effects [CIEMAT]
  - Ceramic Breeder Characterisation: chemical compatibility [CIEMAT]
  - Be Production & Characterisation [KIT]

- Water Cooling Technology [only for the WCLL]
  - Corrosion,Water Radiolisis,Water Chemistry Control [ENEA]

- FCI Design and R&D [only for the DCLL]
  - FCI Development [CIEMAT]
  - Support and Technology Transfer in FCI Development [KIT]

CONCLUSIONS

- Starting from 2014, the EU activities in BB (design and R&D) have been organised around a Project as integrant part of the developemnt of the PPPT DEMO.

- In 2014 an organisation, an integrated Programme and financial framework have been set up for the whole PPPT Programme and for the BB Project

- Four Blanket are part of the BB Project and will be investigated in the next years. The helium cooled blankets (HCPB and HCLL) with an advanced R&D programme and with their test in ITER. R&D for the Water cooled concepts, in particular the WCLL, has been restarted to clarify the issues in term of material compatibility, safety and T coolant purification. The DCLL is also under assessment as possible transition to more advanced liquid blanket concepts. However, in an PPPT DEMO only a low temperature version could be developed in time.