EUROfusion

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DEMO blankets needs from ITER TBM program

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Breeding Blanket Project

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Outline

- Introduction
- Connection between EU DEMO/FPP and TBM programme.
- Strategy and requirements driving the Breeding Blanket project in the EU PPP&T Studies.
- Expected inputs from the TBM to the DEMO programme.
- Conclusions

Introduction: origin of the EU TBM Programme

In EU TBM Programme und DEMO were always strongly tied.

In the past 20 years:

- DEMONET Studies (1992-1995): the main blanket concepts have been developed in this period (i.e. WCLL, HCPB, DCLL). Selection of DEMO concepts for ITER test.
- First DDD of the ITER TBMs (WCLL and HCPB) for the test in ITER (1995).
- Second DDD (1997) for the ITER TBMs (WCLL and HCPB)
- The Power Plant Conceptual Study (PPCS, 1999-2004) considered plant model for a future Fusion Power Plant (FPP), assessing cost of energy and safety (e.g. WCLL, HCPB, DCLL, HCLL).
- Third DDD (2003) for the ITER TBMs (HCLL and HCPB)
- Short DEMO study (2005-2008): possible DEMO design according to the PPCS results. Main focus: Maintenance System (multi-module segment in vertical maintenance).

And today:

- TBM Programme under F4E (2009 to now). HCPB and HCLL concepts as EU TBMs.
- PPP&T Studies (2011 to now). EU DEMO reactor based on EU Roadmap (2013). Started in 2011 under EFDA and since 2014 under EUROfusion Consortium.

Strategy and Requirements of the TBM Programme: limitations

Limitation in the TBM test in comparison to a DEMO component conditions:

1) Only <1 m^3 of device with <1 m^2 of surface in front of plasma (note: surface recessed to the ITER Shielding Blanket geometrical FW);
2) Still relevant neutron flux (0.78 MW/m^2, 65%), rad. surface heating (max. 0.5 MW/m^2, ~60-100%).
3) Low values according to pulse time (400 s, ~13%) and neutron fluence (1 dpa, 2-5%).

Strategy of testing developed in several studies [1-4], the main objectives can be summarised:

1) Development of tools (experimental and computational) to capitalise the experimental results in ITER and extrapolate this to DEMO.
2) Development of manufacturing technology with EUROFER
3) Create a precedent in the safety and licensing of blanket components
4) Integral test of processes, materials and technologies (at least for BOL conditions).

References:

[1] G. Shatalov, DEMO Blanket testing in ITER. Influence on reaching DEMO, Fusion Eng. Des. 56–57 (2001) 39–46.

[2] L.V. Boccaccini, U. Fisher, K. Kleefeldt, S. Malang, et al., Strategy for the blanket testing in ITER, Fusion Eng. Des. 61–62 (2002) 423–429.

[3] Y. Poitevin et al., The test blanket modules project in Europe : from strategy to the technical plan over next 10 years. Fusion Eng. Des. 82 (2007) 2164-2170.

[4] G. Aiello, L.V. Boccaccini, I.A. Maione, Assessment of the DEMO relevance of the ITER TBM, EFDA Report, WP11-DAS-IVCC-02.

EU TBM Programme und DEMO

For this EU TBMs are designed:

1) To reproduce selected conditions relevant for the blanket design (e.g. temperatures of materials and coolants, relevant velocity of coolants and T carries, multi-physic effects).
2) To use materials selected for DEMO (e.g. EUROFER, breeders, neutron multipliers).
3) To be adapted to different phase of ITER to maximise test possibilities (i.e. several TBM for a blanket concepts).
4) To reproduce relevant geometries and dimensions of typical DEMO concepts (in case of the EU TBM also the relevant architecture of DEMO 2003).
5) Auxiliary system designed to reproduced DEMO relevant conditions (e.g. temperatures, local mass flow, velocities fields) . Not high relevant for analogous systems in DEMO.

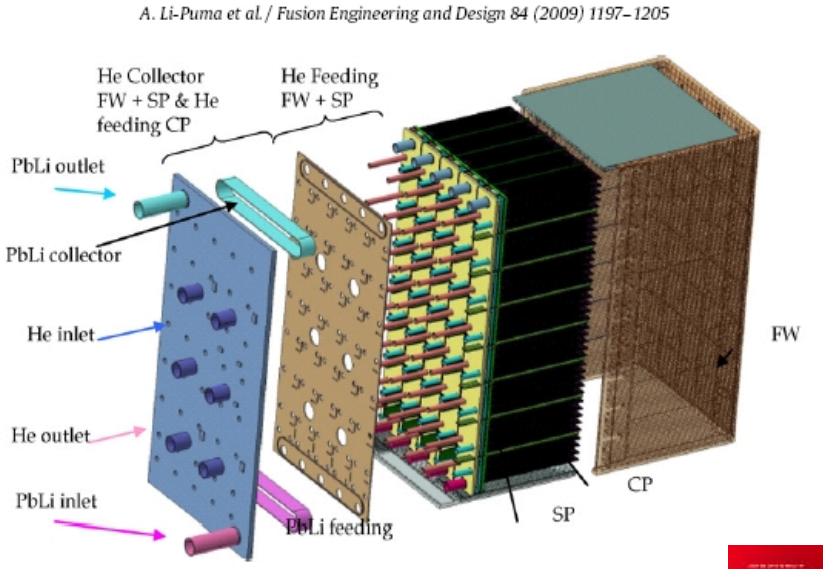
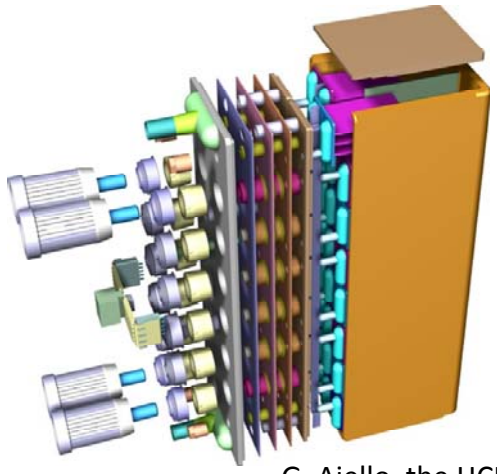


Fig. 2. Exploded view of a generic HCLL-DEMO-2007 blanket module.



G. Aiello, the HCLL TBM

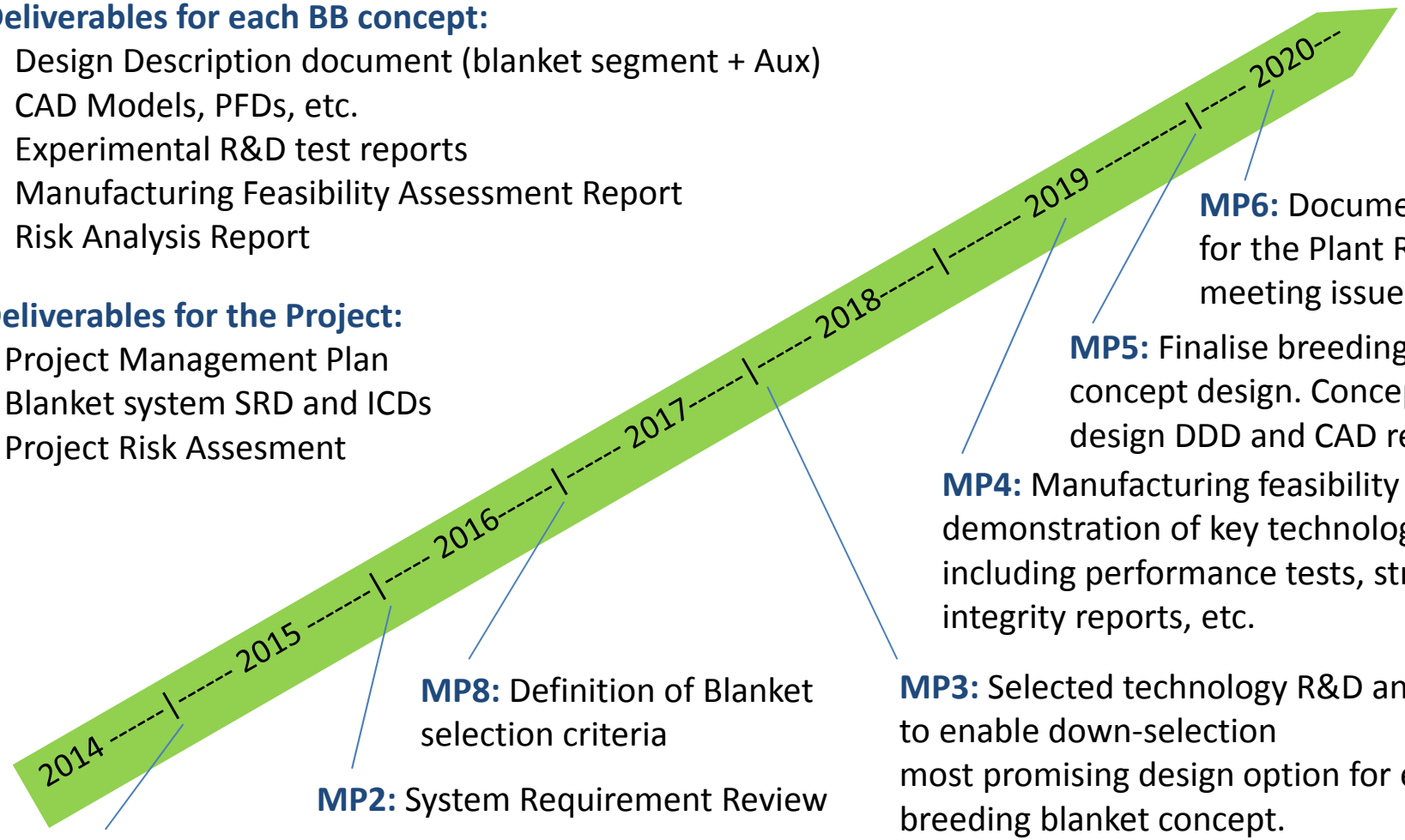
EU BB Milestones (2014-2020)

Deliverables for each BB concept:

- Design Description document (blanket segment + Aux)
- CAD Models, PFDs, etc.
- Experimental R&D test reports
- Manufacturing Feasibility Assessment Report
- Risk Analysis Report

Deliverables for the Project:

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



MP1: Establishment of project Requirements, blanket configuration and blanket Development Plan. Preliminary DDD and CAD released.

MP2: System Requirement Review

MP8: Definition of Blanket selection criteria

MP3: Selected technology R&D and testing to enable down-selection most promising design option for each breeding blanket concept. Consolidated DDD and CAD released.

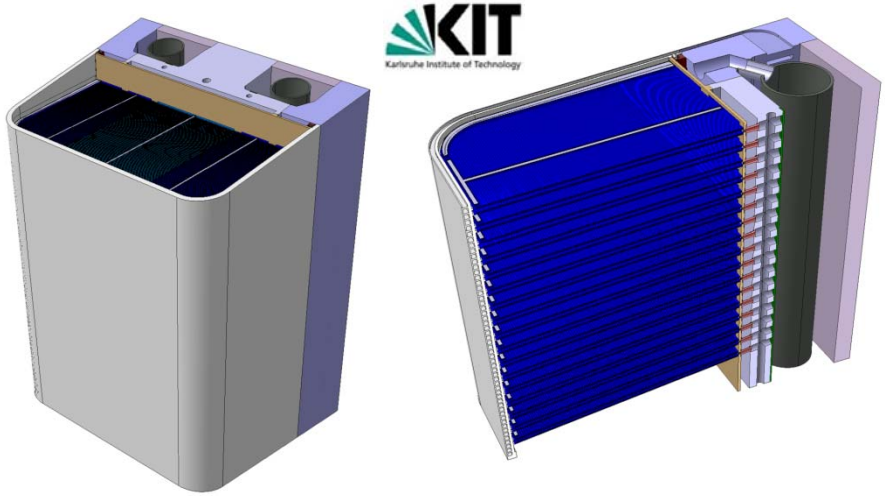
MP4: Manufacturing feasibility demonstration of key technologies, including performance tests, structural integrity reports, etc.

MP5: Finalise breeding blanket concept design. Conceptual design DDD and CAD released.

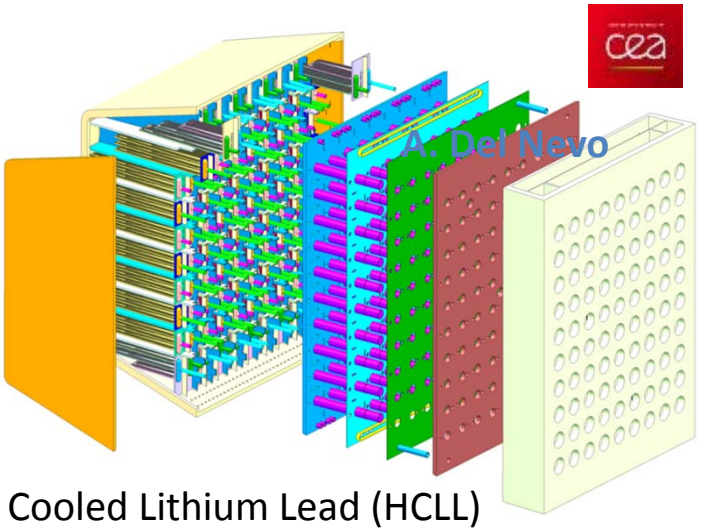
MP6: Documentation for the Plant Review meeting issued

MP7: End of the Plant Review Meeting

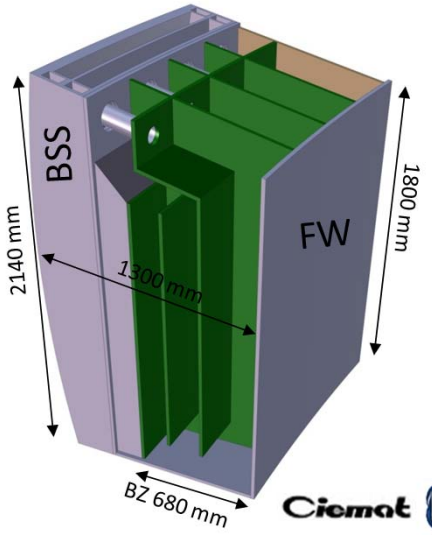
Blanket concepts considered in PPP&T



Helium Cooled Pebble Bed (HCPB)

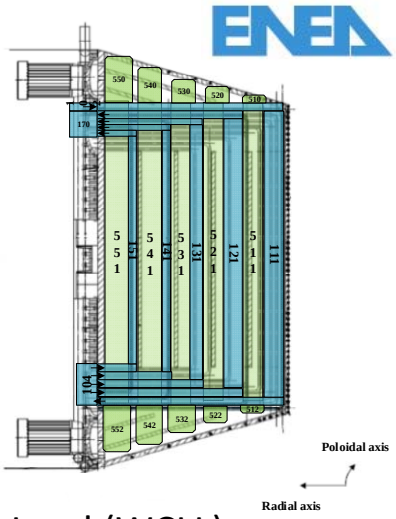


Helium Cooled Lithium Lead (HCLL)



Dual Coolant Lithium Lead (DCLL)

Concept	Breeder/ Multiplier	Coolant	T-Extraction	Other
HCPB	Ceramic Breeder / Beryllium	Helium	He low pressure purging	(Permeation barrier)
HCLL	PbLi	Helium	PbLi slow recirculation	(Corrosion-permeation barrier)
WCLL	PbLi	Water	PbLi slow recirculation	(Corrosion-permeation barrier)
DCLL	PbLi	Helium PbLi	PbLi fast recirculation	FCI of Allumina or SiC/SiC_f



Water Coolant Lithium Lead (WCLL)

Breeding Blanket Project

WBS in the Breeding Blanket Project:

- WP1: HCPB Blanket Design including Ceramic Breeder and Beryllium development and characterisation.
- WP2: HCLL Blanket Design
- WP3: WCLL Blanket Design including Water cooling technology
- WP4: DCLL Blanket Design including Flow Channel Insert development
- WP5: PbLi technology for HCLL, WCLL and DCLL.
- WP6: Tritium Technology
- WP7: Manufacturing Technology
- WP8: FW and Limiter technology
- WP9: System Engineering, System Modelling, Neutronic and EM analysis development.

Resources:

- In 2014-2018 about 260 ppy and 19 M€.

EU Research Unit involved:

- CCFE, CEA, CIEMAT, ENEA, IPP.CR, KIT, Wigner RCP.

Blanket Design evolution in PPP&T Studies

EU DEMO blanket design is evolving since DEMO 2007 driven by:

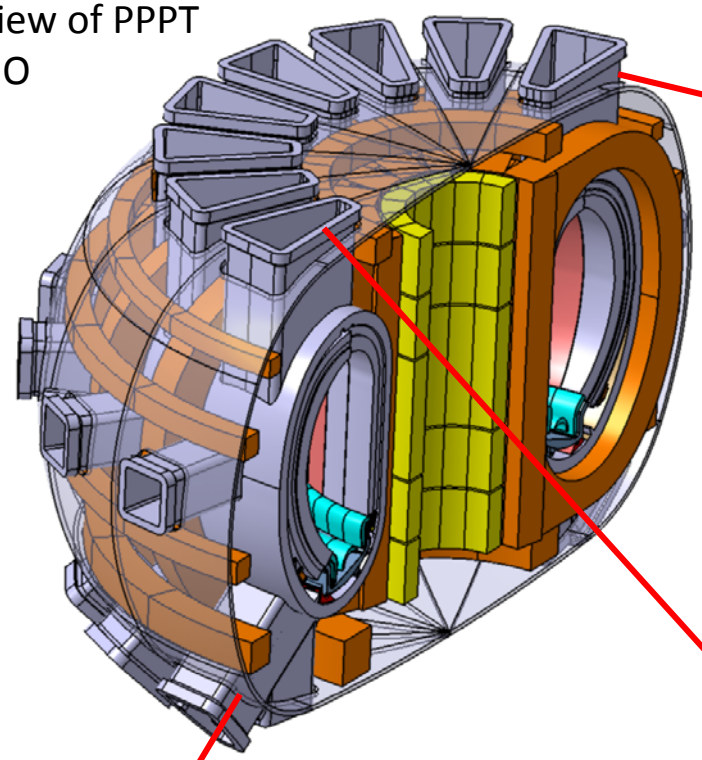
- Overall plant requirements: e.g. short timescale, plasma physic limitations (pulsed), T self sufficiency, production of relevant electrical energy, in-vessel Maintenance Systems.
- Integration in reactor (e.g. maintenance system, interface with other plant systems)
- Large uncertainties in the plasma load on FW (i.e. exhaust power)
- Evolving strategy of reactor safety (e.g. blanket safety functions and classification)
- Structural material requirements (e.g. temperature window, activation requirements, design rules)
- Optimisation of concept specific features.

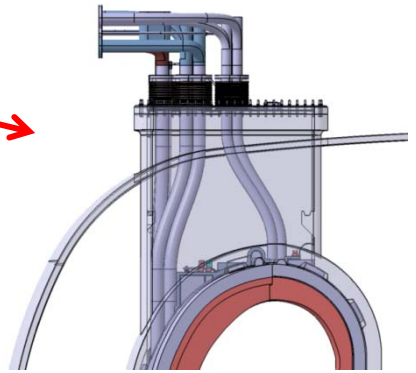
Issues in the design:

- Less margins allowed for Tritium Breeding Ratio
- Complicated thermo-hydraulic design suitable for energy production.
- Structural mechanic requirements related to TBM classification.

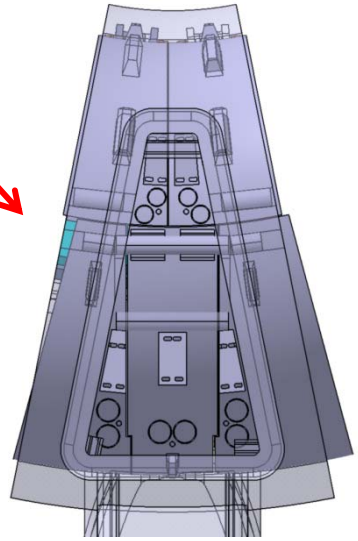
Maintenance System (1/2)

3D view of PPPT DEMO

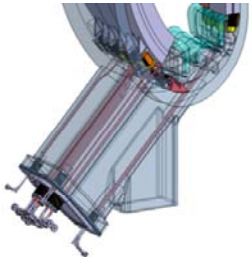




Vertical port for blanket maintenance and piping routing



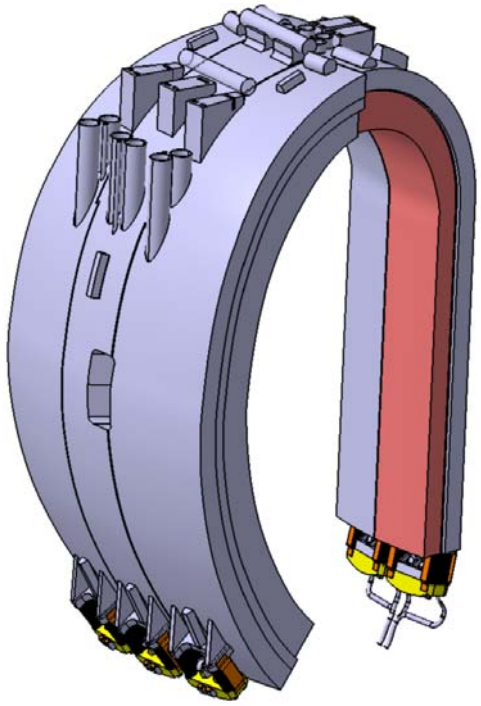
View from the vertical port of the blanket segments with piping access



Lower port for divertor maintenance and piping routing

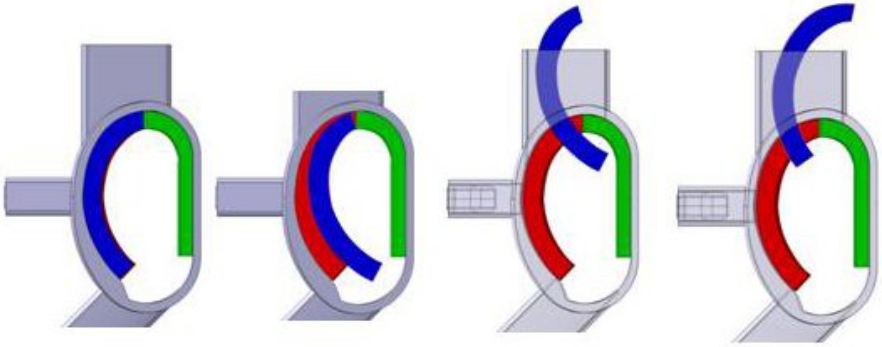
Daniel Iglesias et al., Blanket Segment Remote Maintenance, WP13-DAS07-T05

Maintenance System (2/2)

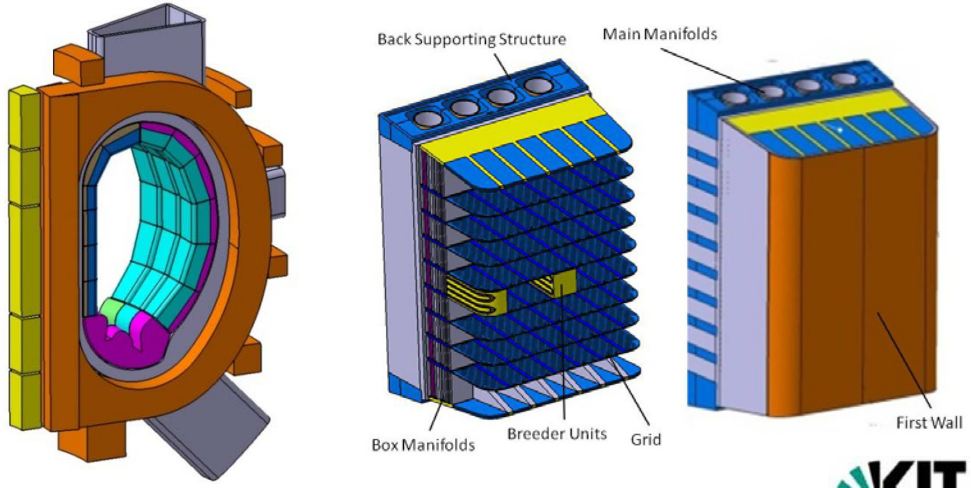


5 blanket segments (3 OB and 2 IB) for each 22.5°- sector (16 TF coils)

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

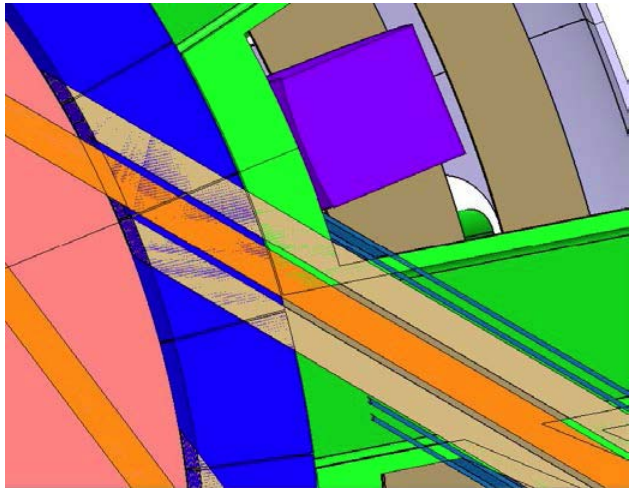


Example of kinematics for OB extraction

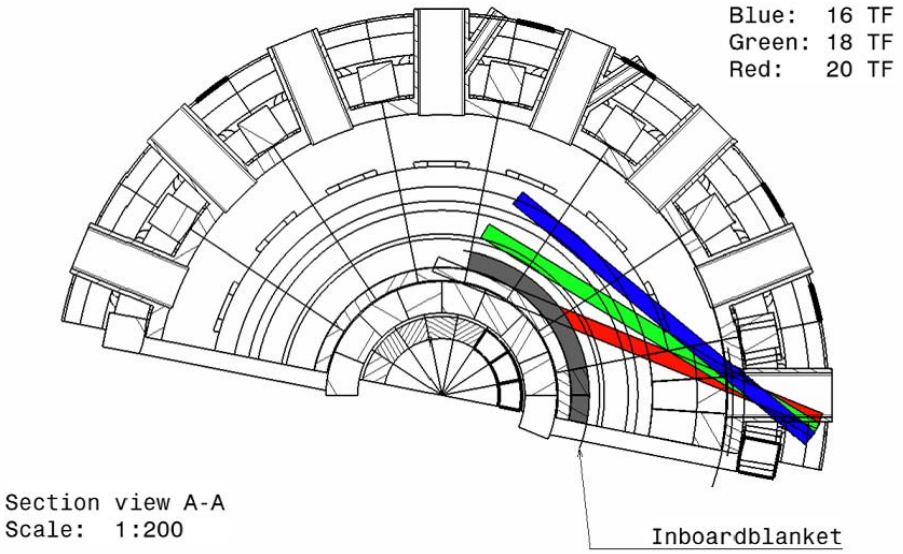


Multi Module Segment for DEMO
Prachai Norajitra et al., DDD 2014 for HCPB, EUROfusion report, D-112-01

Impact with/of other systems: e.g. NBI



NBI poloidal cross section detail with the beam (orange), HNB liner (brown) and vacuum vessel port duct shells (blue lines)

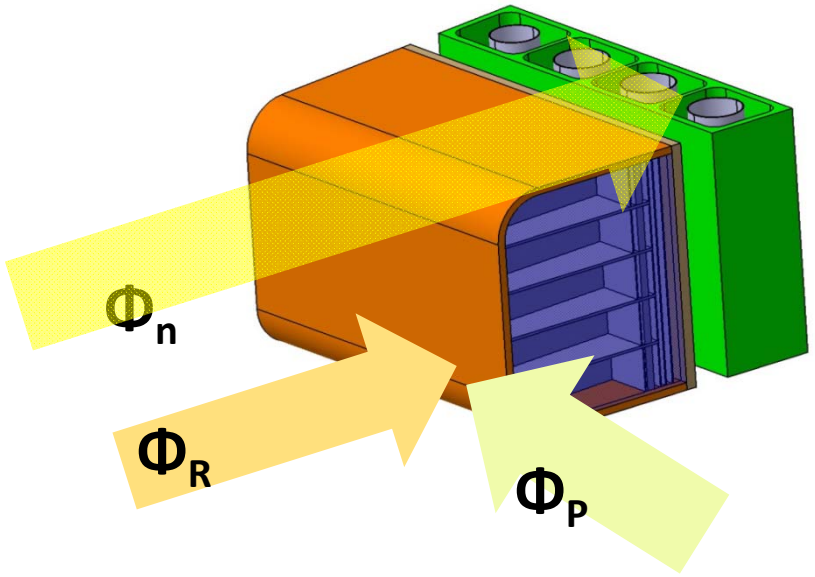


Several tangential radii with 16, 18 and 20 TF coils with assumed 700mm clearance for the port construction and shielding between beam and TF-coils and also 700mm beam width (as a rough first assumption).

From PPP&T H&CD, Th. Franke, 2013-2014

Similar issues with diagnostics and divertor

FW thermal Loading

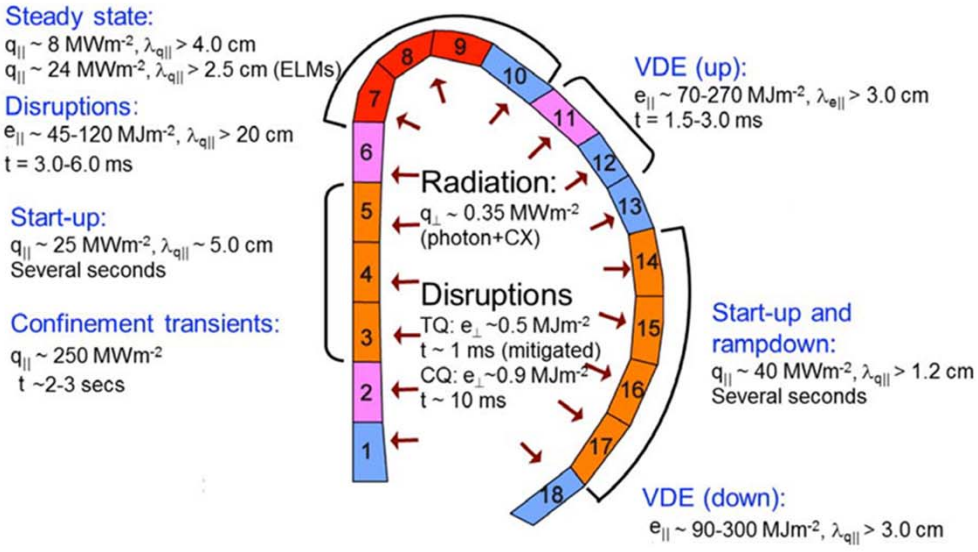


- The Breeding Blanket in DEMO is subjected to: neutronic volume heat load, surface heat from core irradiation and plasma flux interaction.
- The surface heating was considered caused mainly by core radiation (+ CX + some transients).
- Interaction with plasma flux only in short transients. FW protected from plasma erosion (~2 mm tungsten).
- The following table gives the load specification for the Outboard Blanket in equatorial position

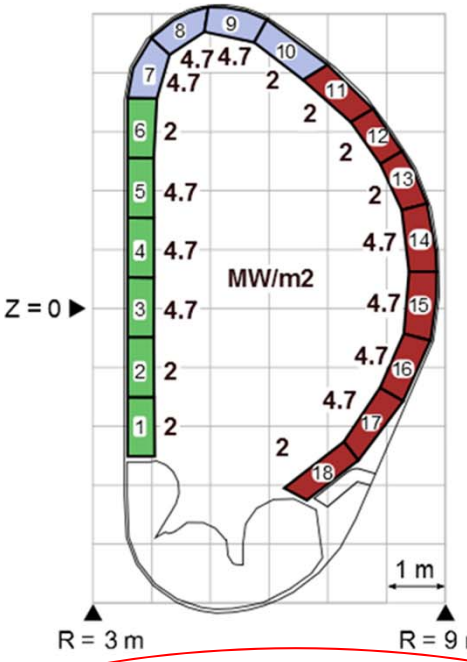
		DEMONET (1995-1999)	PPCS (2000-2004)	DEMO PPP&T (2011-2013)
Φ_n	Neutron wall load [Φ_n]	3.5 MW/m^2	2.5 MW/m^2	1.5 MW/m^2
Φ_R	Surface heat load [Φ_n]	0.5 MW/m^2	0.5 MW/m^2	0.5 MW/m^2
Φ_P	plasma interaction [Φ_n]	tbd (none)	tbd (2mm W layer)	tbd (2mm W layer)
	Pulse lengths	Steady state	SS or L-pulses (>8 h)	<2.5 h

FW thermal Loads: ITER Loads on FW

Physics Loads



Engineering Loads (q_{design})



- Peak factor values of 10, make impossible a design of the cooling system for energy production
- Value of heat flux >2MW/m^2 are at limit of the present technology (materials, performance, etc).

Two FW technologies →
- NHF: 2 MW/m^2
- EHF: 4.7 MW/m^2

In ITER !

R. Mitteau, "The ITER First wall design", 27th SOFT, 2012. Elaborated by German Perez (CCFE).

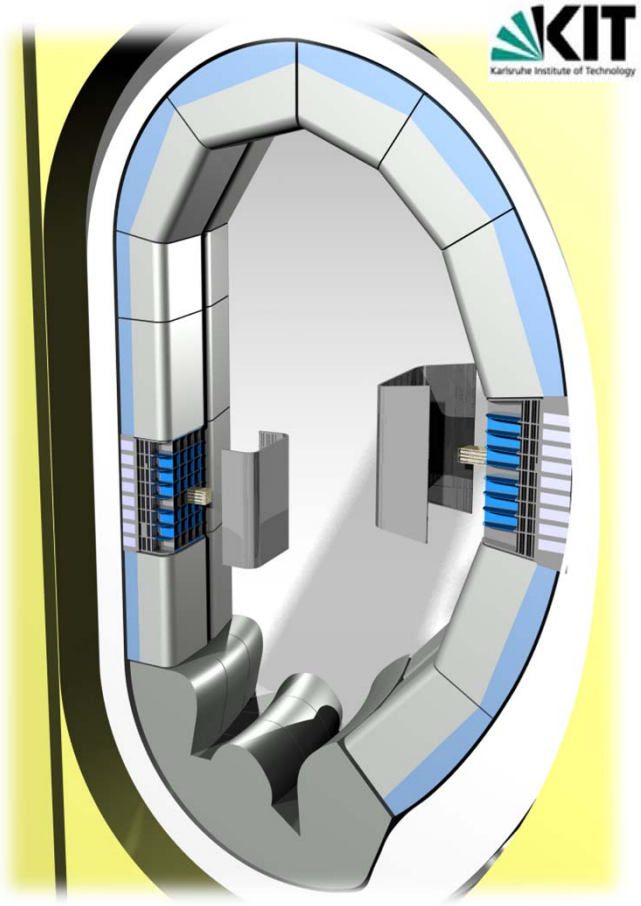
Breeding Blanket Design

In EURO*fusion* programme:

- Development and evaluation of blanket systems suitable for the EU DEMO-2050.
  - Short time schedule (decision to build in 2030)
  - Plasma physics limitations: probably a pulsed DEMO.
  - Use of materials available in short timeframe
- Development of a framework for Safety and Licensing (mainly in WPSAE)

From TBM Programme:

- First experience of design, development and qualification under nuclear environment of a breeding blanket design.
- First development of safety and Licensing framework (including classifications and design rules).



HCPB blanket segmentation for the DEMO Reactor (1 sector = 3 OB and 1 IB Segments) - status 2014.

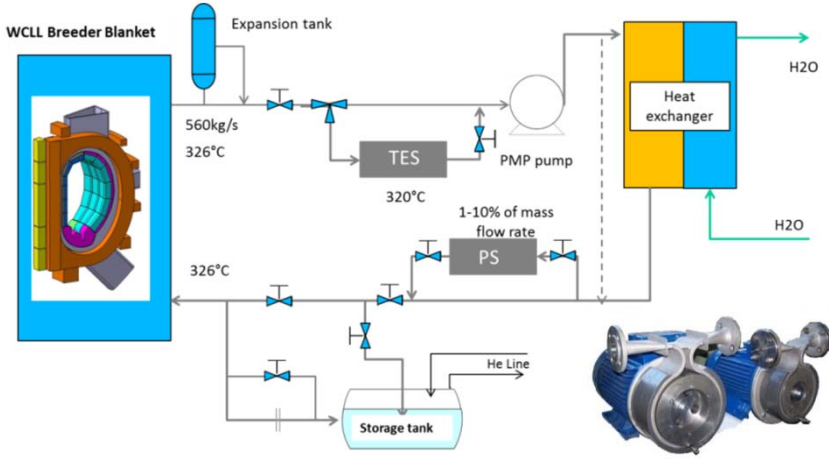
PbLi Technology

In EURO*fusion* programme:

- Design of PbLi loops, performance analyses and integration in reactor. Loop components development.
- Tools development and application of the MHD analysis to DEMO blanket geometries (design support).
- Corrosion control (e.g. development of coating).
- PbLi chemistry & impurity control.
- Reaction PbLi/steam.

From TBM Programme:

- Validation of tools for the capitalisation of results in preparatory experiments and eventually in TBM test (e.g. PbLi flow simulations, MHD and corrosion).
- Data bank of PbLi properties (e.g. Sievert constant).



Permanent Magnetic Pumps

- Eight Pumping System => 70kg/s per loop
  - ✓ 4 loops <=Inboard Module (4 Segments)
  - ✓ 4 loops <= Outboard Module (4 Segments)

	WCLL		
PbLi volume [m3]	5,21E+02		
PbLi weight [kg]	5,12E+06		
Recirculation/day	8	10	15
PbLi mass flow [kg/s]	448	560	804
PbLi mass flow segment [kg/s]	28	35	53
ΔT PbLi(out-in) max	211		
Pth [MW]	15	22	33

Preliminary lay-out of the PbLi Loop for the WCLL blanket – status 2014.

Tritium Technology

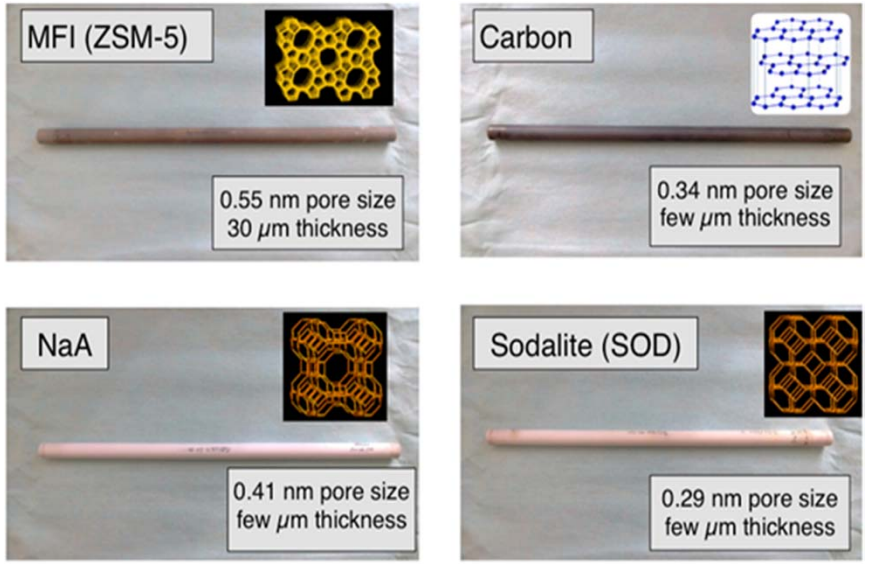
In EURO*fusion* programme:

- Design of Tritium extraction systems, performance analyses and integration in reactor.
- Development and application of T modelling tools for the analysis to DEMO blanket configurations.
- Development of advanced tritium extraction processes mainly based on continuous processes (e.g. PAV, membrane reactors).
- Development of permeation reduction technologies based on coating (LB blankets) or chemical control (SB blanket).

From TBM Programme:

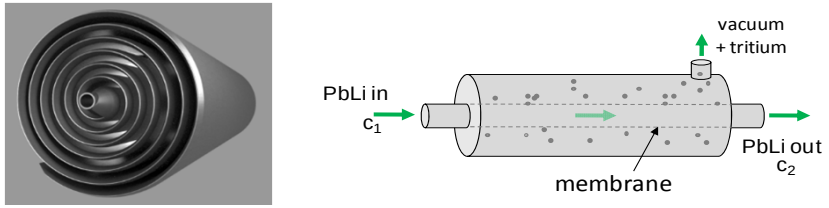
- Validation of tools for the capitalisation of results in preparatory experiments and eventually in TBM test (e.g. T transport modelling)
- Data bank on parameters (e.g. T transport coefficients) for T modelling.
- Development of gas/liquid contactor and molecular sieve technology for tritium extraction.

Label: LB: liquid breeder, SB: solid breeder, PAV: permeator against vacuum.



Zeolite and carbon membranes tested at ZIMT III facility to recover tritium from He purge gas.

KIT Karlsruhe Institute of Technology



Spiral shape Permeator Against Vacuum and drawing of the new PbLi loop for testing PAV.

Ciemat

Blanket manufacturing

In EURO*fusion* programme:

- Assessment of Blanket Segment manufacturing (FW, Breeder zone, small/large boxes, manifold systems, attachments to VV).
- Technology development with production of fabrication mock-ups (e.g. Double Wall Tubes for WCLL, W coating in FW)
- Test of mock-ups in helium and water facilities.

A fail-safe and cost effective fabrication route for blanket First Walls; Commin, L.; Rieth, M.; Dafferner, B.; Zimmermann, H.; Bolich, D.; Baumgärtner, S.; Ziegler, R.; Dichiser, S.; Fabry, T.; Fischer, S.; Hildebrand, W.; Palussek, O.; Ritz, H.; Sponda, A.; Journal of Nuclear Materials, Volume 442, Issue 1, p. 538-541

From TBM Programme:

- Qualification of key technologies (like plates with channels and welding assembly) suitable for integrated FW, breeder Zone and small boxes.

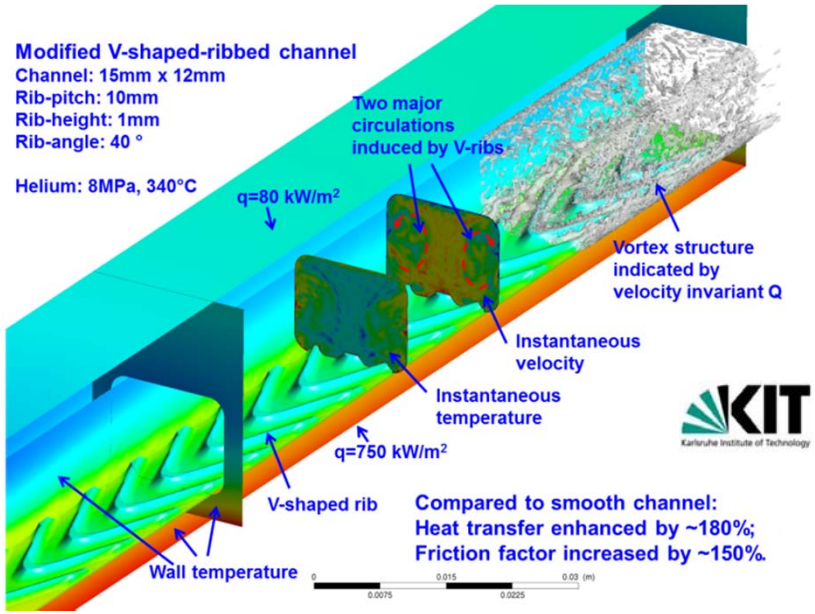
RVS-3 test loop

Research reactor LVR-15

FW/Limiter Technology

In EURO*fusion* programme:

- Development of engineering specifications for the FW in Fusion reactors (e.g. thermal load, plasma flux interaction).
- Design of not integrated components for FW and/or limiter applications.
- Studies of enhanced heat transfer configurations for FW/Limiter applications (e.g. helium channels with ribs).



From TBM Programme:

- N/A (Integrated FW design and manufacturing already considered in blanket design and manufacturing WPs)

Von Mises stress distribution for a simplified WCLL model for level D analysis

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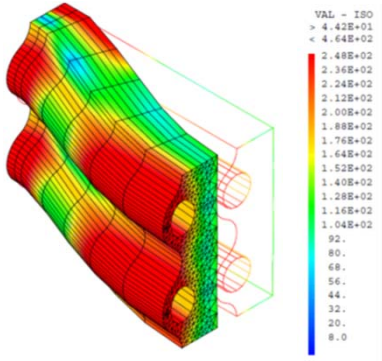
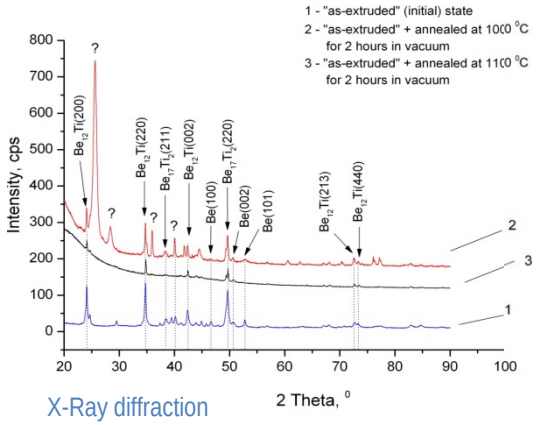


Solid Breeder Development (for HCPB)

In EURO*fusion* programme:

- Development and evaluation of advanced breeding ceramics for DEMO. Extension of their lifetime to reactor requirements.
- Pilot plant development aims for mass production of ceramic breeders.
- Development and evaluation of new Be/Be-containing (e.g. Be12Ti) materials.

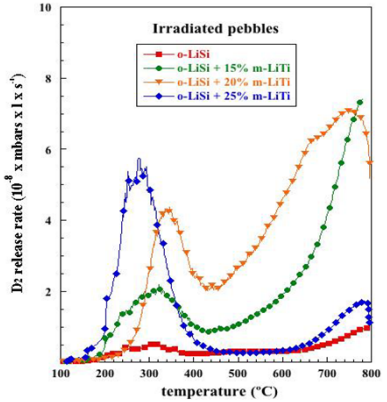


Fabrication and characterization of new Be-Ti beryllides.

From TBM Programme:

- Development of Validation of tools for the capitalisation of results in experiment and TBM test.
- Data bank on functional materials realised in EFDA/F4E contracts.
- Test of DEMO material in ITER TBM

Fabrication and characterization of Li_4SiO_4 (with 10-20% Li_2TiO_3)

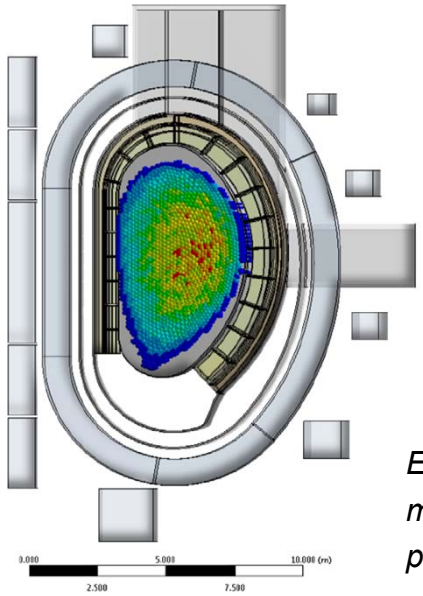


Thermally induced desorption experiments on Li_4SiO_4 + Li_2TiO_3 under γ-irradiation up to 4x106 Gy

Other Technologies

In EURO*fusion* programme:

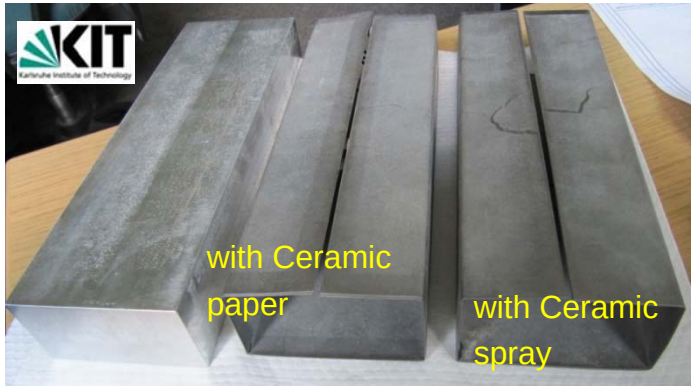
- Water technology (e.g. purification, corrosion) in WP3.
- Flow channel insert (FCI) development for DCLL in WP4.
- EM Calculations in WP9.
- Neutronics development (e.g. TRIPOLI, interface tools) in WP9.
- System code models for blanket systems (e.g. for PROCESS) in WP9.



EM Analysis on mechanical effects of plasma disruptions

From TBM Programme:

- N/A for Water and FCI
- Validation of Neutronics and EM models, tools and database.



Flow channels manufacturing for DCLL Design

Conclusions

TBM and DEMO Programme are in EU strong tied. TBM design is derived from DEMO/FPP studies and TBM results are to be used to confirm DEMO design.

Recent evolution of the PPP&T DEMO plant is driven by requirements coming from DEMO general objectives (e.g. T selfsufficiently, electrical energy production) and integrated engineering (e.g. Maintenance systems, interface with other components).

Results of the TBM programme that can be used in EUROfusion-BB:

- As the Roadmap foresees the blanket selection at the end of 2020, only results of the design and R&D related to the TBM preparatory programme (not the TBM ITER test) are at the moment integrated in the programme.
- These results includes:
  - Safety and licensing framework for blanket as nuclear component.
  - Predictive tools in several key fields (EM, PbLi breeder cycle modelling, Helium coolant and purge modelling, neutronics) to capitalise and extrapolate data form integral experiments.
  - Diagnostics and measurement systems necessary in the R&D programme
  - Manufacturing technologies with EUROFER
  - Development and characterisation of functional materials
- The consideration of TBM in-pile results in the time frame 2021-2030 (preparation to the construction start in 2030) have not be analyses as far.
- Results of the TBM Programme doesn't exhaust the needs for Blanket Development in PPP&T. In particular the qualification of materials requires a dedicate irradiation programme.