The ITER Blanket System Design Challenge

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Blanket Effort Conducted within BIPT



- Include resources from Domestic Agencies to help in major design and analysis effort.
- Direct involvement of procuring DA's in design
 - Sense of design ownership
 - Would facilitate procurement

Blanket System Functions

Main functions of ITER Blanket System:

- Exhaust the majority of the plasma power.
- Contribute in providing neutron shielding to superconducting coils.
- Provide limiting surfaces that define the plasma boundary during startup and shutdown.





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Slide 4

Blanket System in Numbers

Number of Blanket Modules: Max allowable mass per module: Total Mass:	440 4.5 tons 1530 tons		
		First Wall Coverage:	~600 m²
		Materials:	
- Armor:	Beryllium		
- Heat Sink:	CuCrZr		
- Steel Structure:	316L(N)-IG		
Max total thermal load:	736 MW		
Cooling water conditions:	4 MPa and 70°C		

Impact of Interface Requirements on Blanket Design

 Interface requirements impose challenging demands on the blanket in particular since the blanket is in its final design phase whereas several major interfacing components are already in procurement.

• Such demands include:

- Accommodating plasma heat loads on FW
- Maintaining acceptable load transfer to the vacuum vessel
- Providing sufficient shielding to the vacuum vessel and TF coils
- Accommodating the space allocations for in-vessel coils and manifolds
- These are highlighted in subsequent slides as part of the blanket design description.

Inboard Module Shape and Size Optimized for Neutron Shielding of VV and TF Coil

- The blanket is a major contributor to neutron shielding of the coils and vacuum vessel.
- E.g. the integrated heating in the toroidal field coil needs to be maintained to <14 kW.
- To that aim, two blanket-related modifications were introduced compared to CDR profile:
 - a flat inboard profile
 - an addition of 4 cm to mid-plane radial thickness
 - a reduction of the vertical gaps between inboard SB's from 14 to 10 mm.
- This is estimated to result in a TF coil nuclear heating in the range 13-14 kW. More detailed 3-D neutronics analyses are planned to confirm this.



 A reduction of the thickness of BM 1 also results in a corresponding reduction in the EM loads on the VV, consistent with the vacuum vessel load specifications, as discussed later

Design of First Wall Panel Impacted by Accommodation of Plasma Interface Requirements



Slide 8

First Wall Shaping at Different Locations



First Wall Panels: Design Heat Flux

• 218 Normal heat flux panels \rightarrow EU

Poloidal

• 222 Enhanced heat flux panels \rightarrow RF, CN



4.7

4.7

4.7

2

Z = 0 ►

MW/m2

1 m

R = 9 m

First Wall Finger Design



Shield Block Design





- Slits to reduce EM loads and minimize thermal expansion and bowing
- Poloidal coolant arrangement.
- Cooling holes are optimized for Water/SS ratio (Improving nuclear shielding performance).
- Cut-outs at the back to accommodate many interfaces (Manifold, Attachment, In-Vessel Coils).
- Basic fabrication method from either a single or multiple-forged steel blocks and includes drilling of holes, welding of cover plates of water headers, and final machining of the interfaces.

Shield Block Attachment

Shield Block #1



- 4 flexible axial supports
- Keys to take moments and forces
- Electrical straps to conduct current to vacuum vessel
- Coolant connections

Flexible Axial Support









- 4 flexible axial supports located at the rear of SB, where nuclear irradiation is lower.
- Compensate radial positioning of SB on VV wall by means of custom machining.
- Adjustment of up to ±10 mm in the axial direction and ±5 mm transversely (on key pads) built into design of the supports for custom-machining process.
- Cartridge and bolt made of high strength Inconel-718
- Designed for 800 kN preload to take up to 600 kN Category III load.

Shear Keys Used to Accommodate Moments from EM Loads



Keys in Inboard and Outboard Modules

- Each inboard SB has two inter-modular keys and a centering key to react the toroidal forces.
- Each outboard SB has 4 stub keys concentric with the flexible supports.
- Bronze pads are attached to the SB and allow sliding of the module interfaces during relative thermal expansion.
- Key pads are custom-machined to recover manufacturing tolerances of the VV and SB.
- Electrical isolation of the pads through insulating ceramic coating on their internal surfaces.



Shield Block and Attachment Designed to Respect Pre-Defined Load from Vacuum Vessel load Specifications

- Optimizing blanket design (radial thickness and slitting) to reduce EM loads based on the following analysis:
 - DINA analysis of disruptions and VDEs
 - Eddy and halo analysis to obtain superposition of wave forms
 - Dynamic analysis of BM structural response using ANSYS (NIKIET)
- For example, results for BM 1 under a downward VDE (load category II) for gaps of 0.375 mm at side of intermodular key pads and 0.75 mm at side of toroidal centering key pads, and with a friction coefficient of 0.4.
 - The axial loads are compatible with those in the VV load specifications (500 kN)



Example Analysis of Inter-Modular Key

- Analysis of the inter-modular keys indicate stresses above yield (~172 MPa at 100°C) in the case of Category III load.
- Limit analysis then performed to check margin.



Limit Analysis of Inter-Modular Key

 Reasonable load factors of 1.5 for the pads and 1.9 for the neck of the key are obtained based on limit analysis under Category III load with 5% plastic strain.



Eddy Forces Applied



Interface with Blanket Manifold and ELM Coils

- A multi-pipe manifold configuration has been chosen, with each pipe feeding one or two BM's
 - Higher reliability due to minimization of welds and utilization of seamless pipes.
 - Superior leak localization capability due to larger segregation of cooling circuits.
 - Elimination of drain lines.
 - Reasonable cost (well-established technologies)
- Three sets of in-vessel ELM control coils per outboard sector to control ELMs by applying an asymmetric resonant magnetic perturbation to the plasma surface.





Multi-pipe Manifold

Configuration

Supporting R&D

- A detailed R&D program has been planned in support of the design, covering a range of key topics, including:
 - Critical heat flux (CHF) tests on FW mock-ups.
 - Experimental determination of the behavior of the attachment and insulating layer under prototypical conditions.
 - Material testing under irradiation.
 - Demonstration of the different remote handling procedures.
- A major goal of the R&D effort is to converge on a qualification program for the SB and FW panels.
 - Full-scale SB prototypes (KODA and CNDA).
 - FW semi-prototypes (EUDA for the NHF FW Panels, and RFDA and CNDA for the EHF First Wall Panels).
 - Qualification tests include: He leak test, pressure test, FW heat flux test

Mock-Ups and Prototypes Are Being Manufactured as Part of the Qualification Programs



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Summary

- The Blanket design is extremely challenging, having to accommodate high heat fluxes from the plasma, large EM loads during off-normal events and demanding interfaces with many key components (in particular the VV and IVC) and the plasma.
- Substantial re-design following the ITER Design Review of 2007. The Blanket CDR and PDR have confirmed the correctness of this re-design.
- Effort now focused on finalizing the design work .
- Parallel R&D program and formal qualification process by the manufacturing and testing of full-scale or semi-prototypes.
- Key milestones:
 - Final Design Review in spring 2013.
 - Procurement to start in late 2013.