An Overview of the US Work to Complete the Design of Blanket Shield Modules 7, 12 and 13 for the ITER Project

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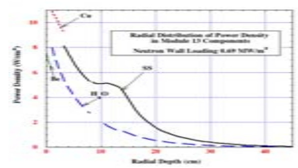
Part of the US contribution to the ITER project is Blanket Shield Modules (BSM) number 7, 12 and 13 comprising about 20% of the ITER First Wall. These modules are all in the upper half of the vacuum vessel. Starting from outlines of each style of module, general design rules contained in the ITER Design Description Document (DDD), design memos, and CATIA interface drawings, the US Team has worked to fill in the details of the internal water cooling passages, slits to control eddy currents, and methods for efficient and reliable manufacturing of the BSM. Our analysis begins with nuclear heating assessment of complex 3D structures containing water, copper, and steel carried out by the University of Wisconsin using a version of MCNP that connects directly to CATIA to get the geometry. Computational Fluid Dynamics (CFD) analysis of the coolant flow distribution and pressure drop in a shield module provides the basis for thermal transfer from the BSM to the coolant. The size and position of coolant passages are adjusted to optimize the heat transfer and eliminate hot spots. ITER specified major disruption (MD) and downward vertical disruption (VDE) events are used to calculate the currents induced in the BSM. In this modeling it is necessary to include the vacuum vessel and other BSM near the modules of interest. In order to benchmark our Electromagnetic Code against the one used for the DDD analysis, we calculated eddy currents and forces on all 18 BSM in a simplified model that matched the DDD analysis. The eddy current forces are used to determine the torque and net force on the BSM. These forces are compared to the load capacity of the mounts and adjustments made to eddy current control slits as needed. Dynamic analysis of the eddy current induced stresses on the BSM and mounts are performed using the ABAQUS code. Static thermal and pressure stresses are calculated using the temperature distributions from CFD analysis. The primary and secondary stresses are compared to the allowables specified in the ITER Structural Design Criteria to determine the suitability of the design to the ITER needs. Manufacturing processes are being created through a series of mockups and prototypes of sub-scale parts. This paper will describe the results of these analyses that have led to a Preliminary Design for the US contribution of BSM 7, 12 and 13.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

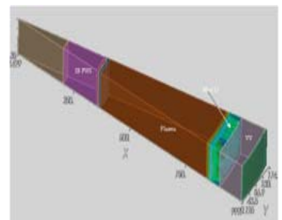
Neutron heating of BSM



Results from 1D neutron heating analysis of BSM13

1D analysis

Non-homogeneous slabs of material representing the composition of 6 zones in the BSM for rapid assessment of the heating

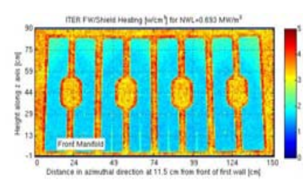


The 1D/3D hybrid model of SM13 in MCNP

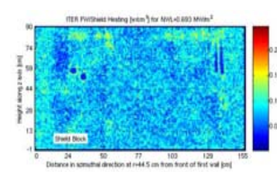
1D/3D hybrid analysis

Full 3D geometry in BSM but a cylindrical representation of the plasma to derive more accurate heating profiles in BSM. We found that the radial coolant holes do not cause increased heating behind a BSM.

Full 3D planned.

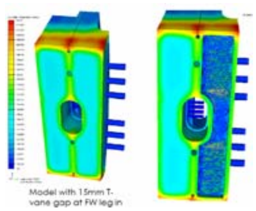


Nuclear Heating at the plasma side of SM13

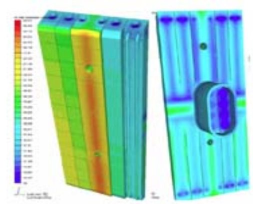


Nuclear Heating at the vessel side of SM13

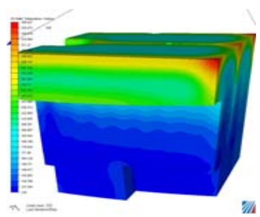
Heat Transfer and Fluid Flow Analysis



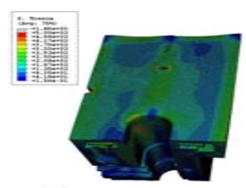
SM7 Temperature distribution (left) and fluid flow distribution (right)



Typical FW temperature distribution with 0.5 MW/m² plasma heating

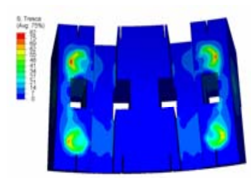


Temperature distribution in SM13

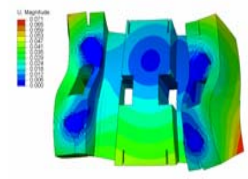


Thermal Stress in SM13

Stress and Deflection from static application of Electromagnetic Loads (SM7)



Stress near the mounts due to Major Disruption for SM7. The maximum load was applied statically.

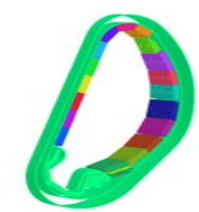


Deflection of SM7 due to static application of Major Disruption EM load (maximum value). Display magnified by 1000.

Summary of thermal stress analisis

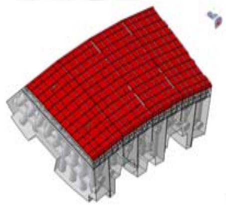
Analyses	Max Temp °C	Sm at Max Temp, MPa	Acceptable S_m Level	Acceptable Stress Level, MPa
SM 13 Corner Thermal	340	109	$3S_m$	327
SM 13Corner Pressure	340	109	S_m	109
SM 13 Mid Thermal	311	113	$3S_m$	339
SM 7 Corner Thermal	290	116	$3S_m$	348
SM 7 Corner Pressure	290	116	S_m	116

Model/ Material	Max Temp °C	Sm at Max Temp, MPa	Acceptable S_M Level	Acceptable Stress Level MPa
FW13 SS316LN-IG	305	114	$3S_m$	342
FW 13 CuCrZr	224	104	$3S_m$	312
FW 13 Be(S-65C)	262	75	$3S_m$	225
FW7 SS316LN-IG	203	129	$3S_m$	387
FW 7 CuCrZr	186	118	$3S_m$	354
FW 7 Be(S-65C)	229	78	$3S_m$	234

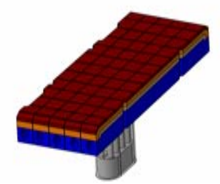


10° sector model of all 18 SM for electromagnetic analysis

Catia Design Results

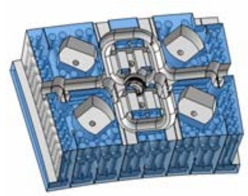


Blanket Shield Module 7 (BSM7)



Typical First Wall (FW) Panel

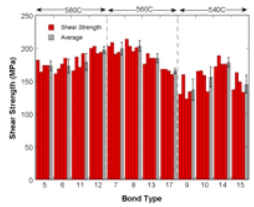
Blanket Shield Module 13

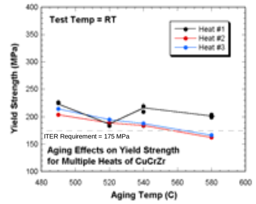


Shield Module 12 showing internal details

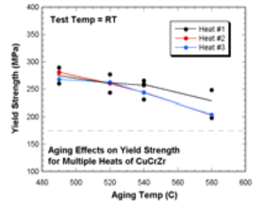
Fabrication Mockup of FW finger

Summary of FW joining R&D





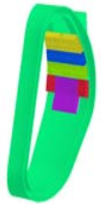
- High strength joints between Be and Cu are being made by Hot Isostatic Pressure methods.
- Water quenching improves the Cu strength after Be tile joining.

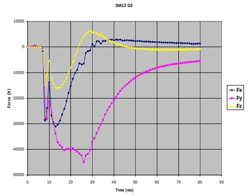


Electromagnetic Analysis of Disruptions

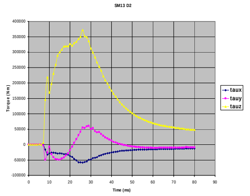
20° sector model of SM6, 7 and 8

20° sector model of SM11, 12, 13 and 14 with port shield module





Net Force on SM13 during Major Disruption



Torque on SM13 during Major Disruption

Results shown for Major Disruption with 36 ms linear current decay.

Conclusions

•The 3D structure in the FW and SM must be modeled accurately to get accurate predictions of the nuclear heating.

•The smallest segment of the SM that can be modeled for fluid flow analysis is 1/8.

•Thermal stress in the FW and SM are within the design allowables for the baseline configuration.

•Disruption analysis should be done on a 20° segment of the machine because the effects of the ports are important

•It is necessary to water quench the Cu alloy to 316LN structure after bonding to assure meeting ITER strength requirements

•We have completed Conceptual Design of BSM 7, 12, and 13.