Nuclear Analysis in Support of ITER Blanket Modules Design

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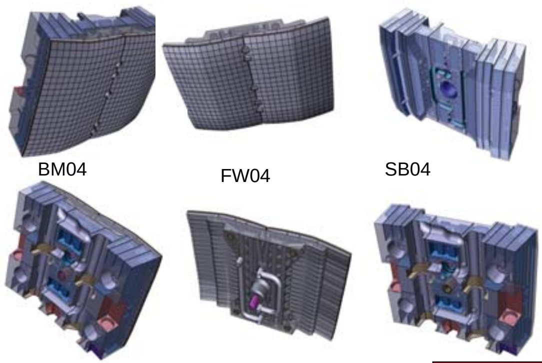
ITER Blanket Modules

- Provide main thermal and nuclear shielding of VV and external components
- BMs consist of a First Wall (FW) panel supported by a Shield Block (SB)
- FW is shaped to handle plasma heat loads
- BMs cover ~600 m^2 of inner VV wall
- BMs arranged into 18 poloidal rows with lowest IB module being BM01 and lowest OB module being BM18
- A total of 440 BMs, weighting ~4 tons each

FW Panels

- FW panel consists of array of fingers assembled onto a SS central support beam
- Each FW finger includes Be armor, CuCrZr heat sink, and SS316 structure with embedded water coolant
- Normal heat flux (NHF) FW panels have SS316 tubes embedded into CuCrZr
- Enhanced heat flux (EHF) FW panels employ CuCrZr rectangular or circular channels
- Dimensions and composition of FW panels are different for NHF and EHF types
- Thinner fingers with larger water content used in EHF FW panels
- Water content significantly higher in beam and steel support zones of NHF FW

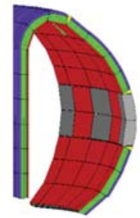


Nuclear Analysis

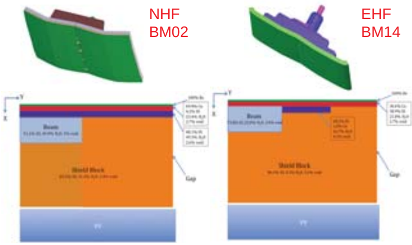
- Design of BMs is going through several iterations that include performing detailed CFD and EM analyses requiring accurate knowledge of nuclear heating with sufficient spatial resolution
- Performed 2-D neutronics to produce detailed nuclear heating profiles in each component separately (Be, Cu, SS, water) needed for thermal analysis Calculations were performed for 3 EHF and 6 NHF BMs
- Used a simplified 2-D radial build and material composition based on detailed CAD models
- Also determined profiles of cumulative dpa and He production in Cu and SS
- Assessed impact of various material compositions and configurations

Normalization of Results

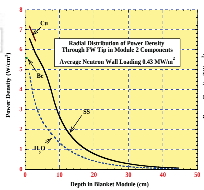
Blanket Module #	Average Neutron Wall Loading (MW/m^2)
1	0.270
2	0.430
3	0.565
4	0.567
5	0.433
6	0.270
7	0.264
8	0.336
9	0.380
10	0.418
11	0.544
12	0.629
13	0.693
14	0.728
15	0.736
16	0.713
17	0.625
18	0.514

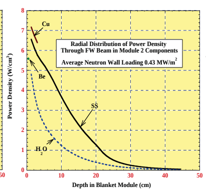


- Results for each BM normalized to corresponding neutron wall loading value at the associated poloidal location
- Assumed that modules are exposed to the full ITER average FW fluence of 0.3 MW-yr/m^2. With the average ITER neutron wall loading of 0.57 MW/m^2, this corresponds to 0.526 full power years (FPY) of operation

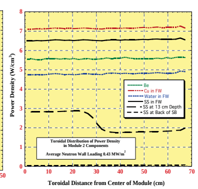


Radial Nuclear Heating Distribution through FW Finger Tip and Beam Regions of BM02

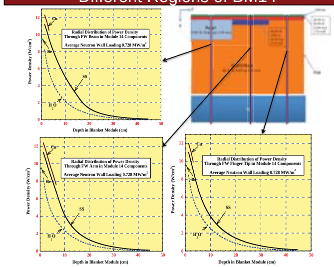




Toroidal Nuclear Heating Distribution in BM02



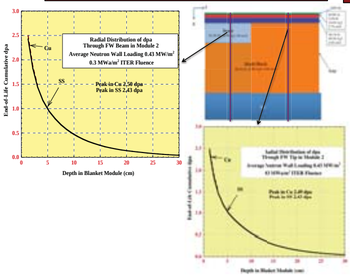
Radial Nuclear Heating Distribution through Different Regions of BM14



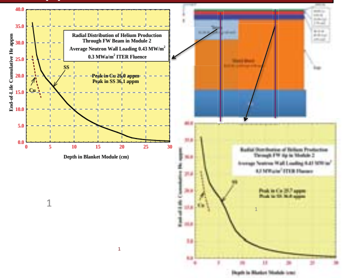
Observations and Comments on Nuclear Heating Results

- Only minor impact of the poloidal gap on nuclear heating at the front of module with local peaking for Be and water (dominated by neutron heating) and slight dip for Cu and SS (dominated by gamma heating)
- Local peaking for SS at edge of SB increases to ~1.75 at back of SB of OB BM14 with 15 mm gap compared to ~1.5 for IB BM02 with 10 mm gap
- Dominant effect on heating profiles is water distribution with higher SS heating (and slightly lower water heating) in beam and arm that have large water content
- At same radial depth through beam, heating in beam of EHF BM14 is larger by up to a factor of 1.3 than in adjacent SB due to large water content in beam. This increase is lower than in NHF BM02 (1.65) that has larger water content in beam

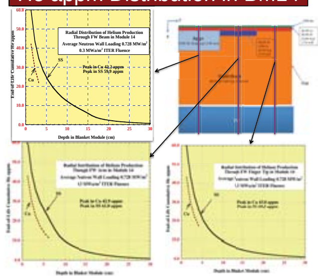
dpa Distribution in Module 02



He appm Distribution in Module 02



He appm Distribution in BM14

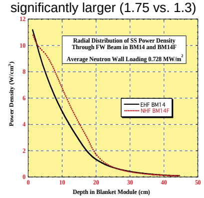


Observations and Comments on Radiation Damage Results

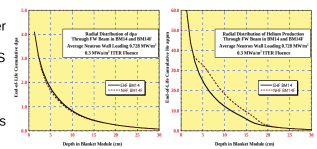
- Nearly uniform toroidal variation in the module
- Damage parameters drop radialy by an order of magnitude in ~15 cm
- At same radial location Cu and SS dpa values are comparable with ~3% higher values in Cu
- At same radial location SS helium values are higher than in Cu (by up to ~50%) due to existence of Ni and B in SS
- Higher SS He production values in regions with large water content (by ~35% for EHF BM14) due to production by low energy neutrons in Ni and B. This effect is not as pronounced as in NHF BM02 (~60%)
- End-of-life He production drops to 3 appm (limit for thin plate and tube rewelding) at a depth of ~20 cm implying that rewelding is possible only beyond that depth

Comparison between Nuclear Heating Profiles in NHF BM14F and EHF BM14

- Lower SS and Cu heating in Cu layer of fingers due to lower water content
- Much larger SS heating in FW SS support and FW beam due to nearly twice the amount of water
- Peaking in SS nuclear heating in beam compared to adjacent SB is significantly larger (1.75 vs. 1.3)



Comparison between Damage Parameters in NHF BM14F and EHF BM14



- Lower SS dpa in FW SS support and FW beam due to larger water content that yields softer spectrum
- Much larger SS helium production in FW SS support and FW beam due to nearly twice the amount of water that results in enhanced helium generation in B and Ni
- Peaking in SS He production in beam compared to adjacent SB is significantly larger (2.1 vs. 1.35)