NUCLEAR ANALYSIS OF ITER IN-VESSEL COILS

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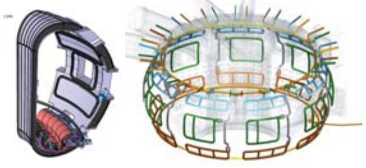
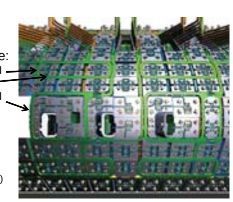
ITER In-Vessel Coils

IVCs used in ITER to provide control of Edge Localized Modes (ELMs) in addition to providing control of moderately unstable resistive wall modes (RWMs) and vertical stability (VS) of plasma





- ELM coil locations
  - Upper
  - Mid-plane
  - Lower
- Legs analyzed here:
  - 3 manifold poloidal
  - Toroidal
  - 2 manifold poloidal

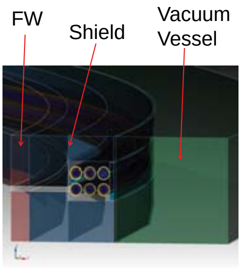
(View from outside)

- Results normalized for peak outboard neutron wall loading of 0.75 MW/m^2
- Cumulative end-of-life parameters calculated for the 0.3 MWa/m^2 total average FW fluence (based on 0.56 MW/m^2 average NWL that corresponds to 0.54 FPY

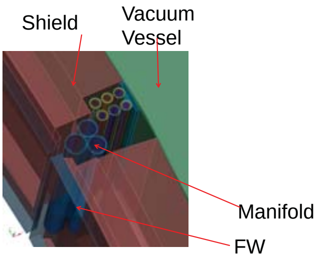
Radiation Effects

- A good review of radiation limits for normal-conducting magnets in fusion environments:
  - L.J. Perkins, "Materials Considerations for Highly Irradiated Normal-Conducting Magnets in Fusion Reactor Applications," J. of Nuclear Materials, vol. 122&123, pp. 1371-1375 (1984).
  - M. Sawan, H. Khater, and S. Zinkle, "Nuclear Features of the Fusion Ignition Research Experiment (FIRE)," Fusion Engineering & Design, vol. 63-64, pp 547 - 557 (2002).
- Main concerns:
  - Mechanical and structural degradation in ceramic insulation under long-term neutron fluence. Determined by swelling tolerance. Not issue for compacted powder
  - Resistivity degradation in ceramic under instantaneous absorbed dose rates (n+γ)
  - Resistivity increase in Cu conductor due to neutron induced transmutations
  - Mechanical and structural degradation in Cu (similar to considerations for ITER FW heat sink). Primary concern is low temperature embrittlement

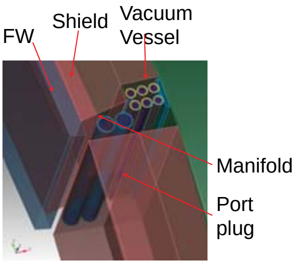
Toroidal Leg



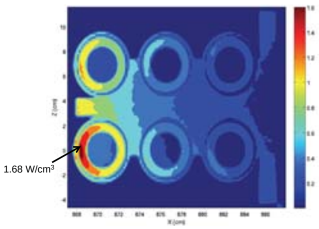
Poloidal Leg (3 manifolds)



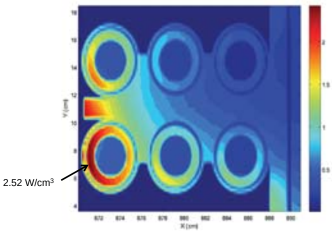
Poloidal Leg (2 Manifolds)



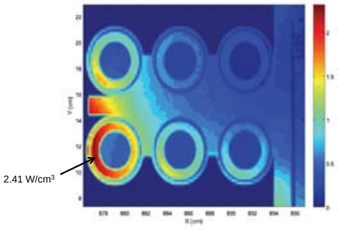
Nuclear Heating (W/cm^3)



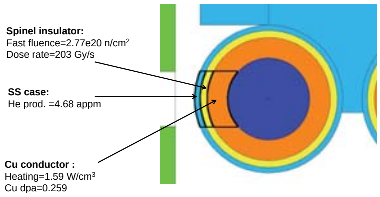
Nuclear Heating (W/cm^3)



Nuclear Heating (W/cm^3)



Peak Parameters

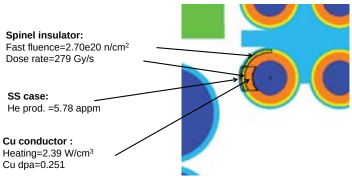


Spinel insulator:
Fast fluence=2.77e20 n/cm^2
Dose rate=203 Gy/s

SS case:
He prod. =4.68 appm

Cu conductor :
Heating=1.59 W/cm^3
Cu dpa=0.259

Peak Parameters

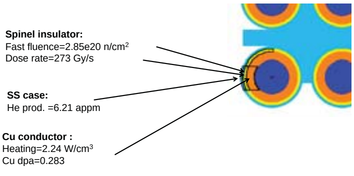


Spinel insulator:
Fast fluence=2.70e20 n/cm^2
Dose rate=279 Gy/s

SS case:
He prod. =5.78 appm

Cu conductor :
Heating=2.39 W/cm^3
Cu dpa=0.251

Peak Parameters



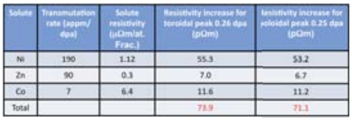
Spinel insulator:
Fast fluence=2.85e20 n/cm^2
Dose rate=273 Gy/s

SS case:
He prod. =6.21 appm

Cu conductor :
Heating=2.24 W/cm^3
Cu dpa=0.283

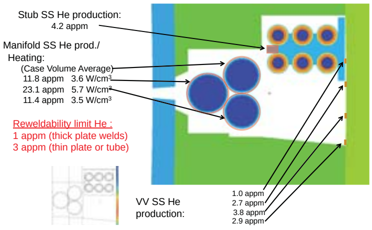
Peak Cu Resistivity Increase

- Increase in electrical resistivity of copper results from displacement damage (production of defects and dislocations) and solute transmutation products
  - $\rho_{10200\ OFHC\ Cu}$ ~16 nΩm at 293K
- At high doses, the displacement damage component approaches rapidly a constant saturation value due to displacement cascade overlap effects with a saturation value of 1-4 nΩm depending on purity and Cu alloy
  - Expected only to be a second order consideration since most effects could be annealed by baking out at 200-300° C
- Transmutation products are Ni, Zn, Co that build up as impurities with time resulting in changing conductor resistivity



Solute	Transmutation rate (appm/dpa)	Solute resistivity (μΩm/at. Frac.)	Resistivity increase for toroidal peak 0.26 dpa (pΩm)	esistivity increase for oloidal peak 0.25 dpa (pΩm)
Ni	190	1.12	55.3	53.2
Zn	90	0.3	7.0	6.7
Co	7	6.4	11.6	11.2
Total			73.9	71.1

He Production in SS



Stub SS He production:
4.2 appm

Manifold SS He prod./ Heating:
(Case Volume Average)
11.8 appm 3.6 W/cm^3
23.1 appm 5.7 W/cm^3
11.4 appm 3.5 W/cm^3

Reweldability limit He :
1 appm (thick plate welds)
3 appm (thin plate or tube)

VV SS He production:
1.0 appm
2.7 appm
3.8 appm
2.9 appm

Conclusions

- IVCs exposed to severe nuclear environment compared to TFC
- Manifolds and gaps increase nuclear parameters in poloidal legs
- Cumulative dose in compacted powder ceramic insulator is not a concern
- Impact of instantaneous dose rate of ~280 Gy/s on electrical resistivity of insulator needs to be assessed
- Modest Cu resistivity increase is expected
- Low temperature embitterment is a concern for Cu and depends on operating temperature and possible annealing
- Nuclear heating results should be used as input for thermal analysis to determine temperature profiles
- Excessive he production at local spots in VV, manifolds, and coil SS jacket will not allow re-welding