Updated Neutronics and Shielding Analysis for FIRE

Mohamed Sawan
Fusion Technology Institute
The University of Wisconsin

NSO Engineering Studies Meeting
31May 2000
PPPL

Calculation Approach

University of Wisconsin-Madison

- FIRE operation schedule includes DD and DT pulses with different fusion powers and pulse widths
- Highest fusion power in DT pulses is 200 MW and the highest fusion power in DD pulses is 1 MW
- Worst case conditions for nuclear heating obtained during the 200 MW fusion power DT pulses
- In these pulses the average neutron wall loading is 3 MW/m^2 with values at OB miplane, IB midplane, and divertor being 3.6 MW/m^2, 2.7 MW/m^2, and 1.8 MW/m^2, respectively
- Nuclear heating profiles determined in the different components
- End-of-life magnet insulator dose and helium production in VV determined for a cumulative fusion energy of 5 TJ DT and 0.5 TJ DD
- Detailed radial build for FW/tiles, VV, and outer divertor plate used in the calculations
- Calculations performed for both the passively cooled and actively cooled FW/tiles design options

Calculation Approach
(Continued)

University of
Wisconsin-Madison

- At each poloidal location, the appropriate vacuum vessel radial build was used along with the corresponding neutron wall loading
- VV consists of 15 mm thick inner and outer facesheets
- Space between facesheets filled with shielding material and coolant. The composition is 60% SS, 40% water except in IB where 11% SS, 89% water is used because of the small thickness (2 cm)
- Cu TF coils are included in the model with Cu at 90% packing
- A SS304 coil case is used in OB with 4 cm front thickness and 6 cm back thickness
- Both IB and OB regions modeled simultaneously to account for toroidal effects

Impact of FW/Tiles Design Options on Nuclear Parameters

University of
Wisconsin-Madison

- Two design options are considered for the FW/tiles:
  Option 1 with passive cooling
  Option 2 with active water cooling
- Impact of design options on nuclear heating in the different components was assessed
- 1-D neutronics calculations performed using detailed radial build of the FW/tiles and divertor plates
- Calculations were performed for DT pulses with 200 MW of DT fusion power to determine the largest nuclear heating generated
- Nuclear heating results scale linearly with the fusion power
- For DD pulses with largest fusion power (1 MW), nuclear heating values are more than two orders of magnitude lower than values for 200 MW DT pulses
- Impact of design options on VV and magnet shielding was assessed

Radial Build of FW/Tiles and VV at Midplane

University of Wisconsin-Madison

- Radial build and composition of FW/tiles in inboard side

Option 1:	5 mm Be PFC (90% Be)
	43 mm Cu tiles (80% Cu)
	2 mm gasket (50% SiC)
Option 2:	5 mm Be PFC (90% Be)
	18 mm Cu tiles (80% Cu)
	2 mm gasket (50% Cu)
	25 mm water cooled Cu (80% Cu, 15% water)

- In outboard side same radial build is used except that the total thickness is increased to 100 mm in option 1

- Radial build of VV in the inboard region at midplane is:
  - 1.5 cm SS plasma side facesheet
  - 2 cm shielding (11% SS, 89% water)
  - 1.5 cm SS coil side facesheet
  - 1.5 cm thermal insulation (10% microtherm insulation)

- Radial build of VV in the outboard region at midplane is:
  - 1.5 cm SS plasma side facesheet
  - 51 cm shielding (60% SS, 40% water)
  - 1.5 cm SS coil side facesheet
  - 1.5 cm thermal insulation (10% microtherm insulation)

Radial Build of Outer Divertor Plate and VV in Divertor Region

University of
Wisconsin-Madison

- Detailed radial build of outer divertor plate used in analysis:

  5 mm W Brush (90% W)
  1 mm region where W rods are joined to Cu heat sink (84% W, 14% Cu, 2% void)
  19 mm heat sink made of Cu finger plates (78% CuCrZr, 20% water, 2% void)
  30 mm mechanical attachment between Cu finger plates and backing plate
  (47% CuCrZr, 48% SS316, 5% void)
  70 mm SS backing plate (84% SS316, 16% water)

- Radial build of VV in the divertor region is:
  - 1.5 cm SS plasma side facesheet
  - 9 cm shielding (60% SS, 40% water)
  - 1.5 cm SS coil side facesheet

Peak Nuclear Heating (W/cm^3) in the Different Components at Midplane

University of Wisconsin-Madison

	Option 1 (Passively Cooled FW)		Option 2 (Actively Cooled FW)	
	IB	OB	IB	OB
Be PFC	34.7	36.8	33.3	35.6
Cu Tiles	44.9	43.6	46.9	46.3
Gasket	19.6	11.0	40.6	40.6
Cooled Cu FW	NA	NA	40.2	40.1
H2O FW Coolant	NA	NA	27.6	30.9
SS Inner VV Wall	35.9	19.6	33.8	30.9
SS VV Filer	37.5	20.6	32.9	28.5
H2O VV Coolant	17.5	11.1	14.9	15.5
SS Outer VV Wall	35.1	0.04	30.3	0.07
Microtherm Insulation	11.4	0.01	9.8	0.02
SS Inner Coil Case	NA	0.021	NA	0.038
Cu Magnet	23.1	0.010	19.5	0.019
SS Outer Coil Case	NA	1.5×10^{-5}	NA	2.8×10^{-5}

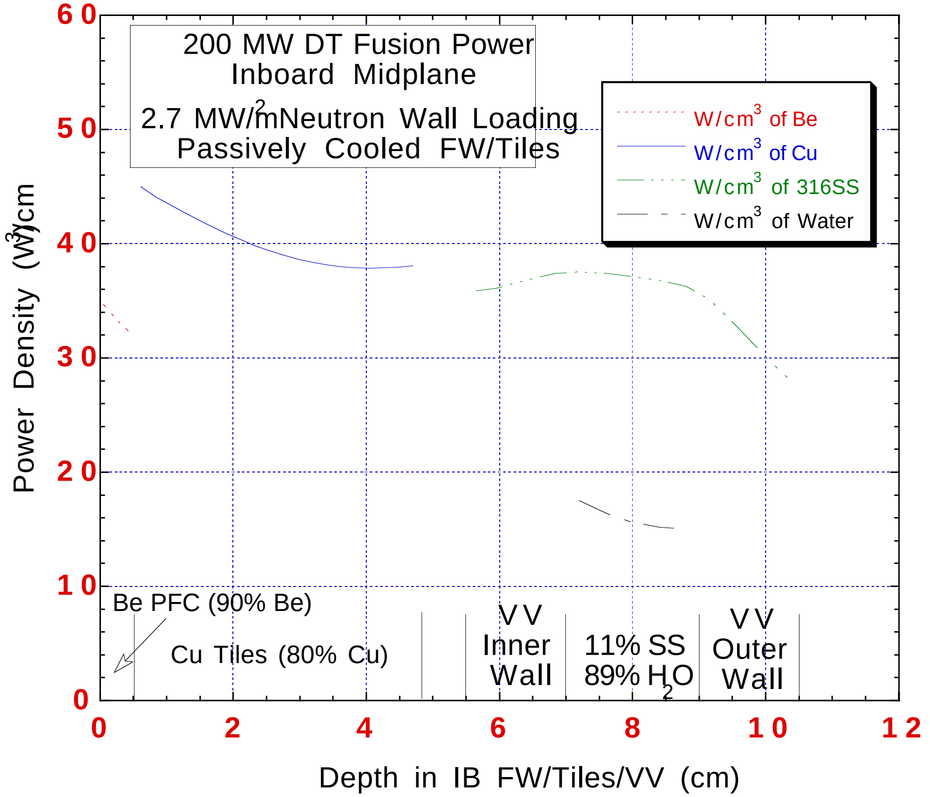
Impact of FW/Tiles Design Options on Nuclear Heating

University of Wisconsin-Madison

- Peak nuclear heating values in the FW/tiles are comparable for the two design options
- IB VV and magnet heating decreases by ~15% in option 2 because of the added water coolant in FW and using Cu in gasket in place of SiC
- OB VV and magnet heating increases by a factor of 1.5-2 in option 2 due to the 5 cm reduction in FW/tiles thickness
- The largest power density values in the magnet occur in the IB region at midplane with the minimum being in the OB region at midplane due to the 49 cm thicker VV

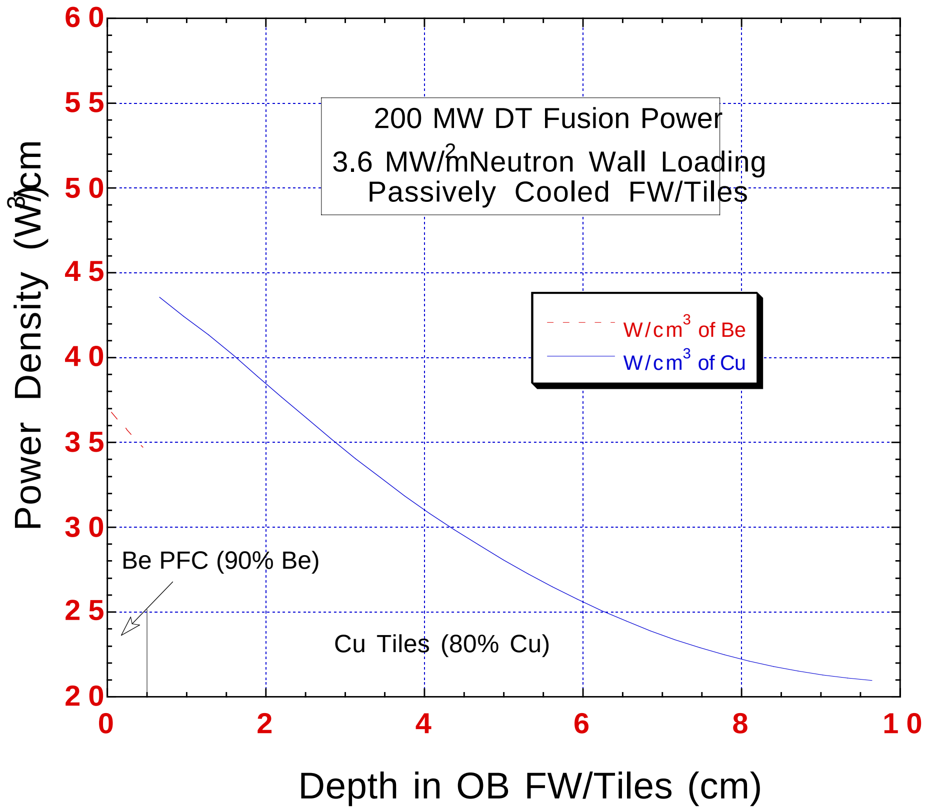
Nuclear Heating Distribution in the IB FW/Tiles/VV at Midplane

University of Wisconsin-Madison



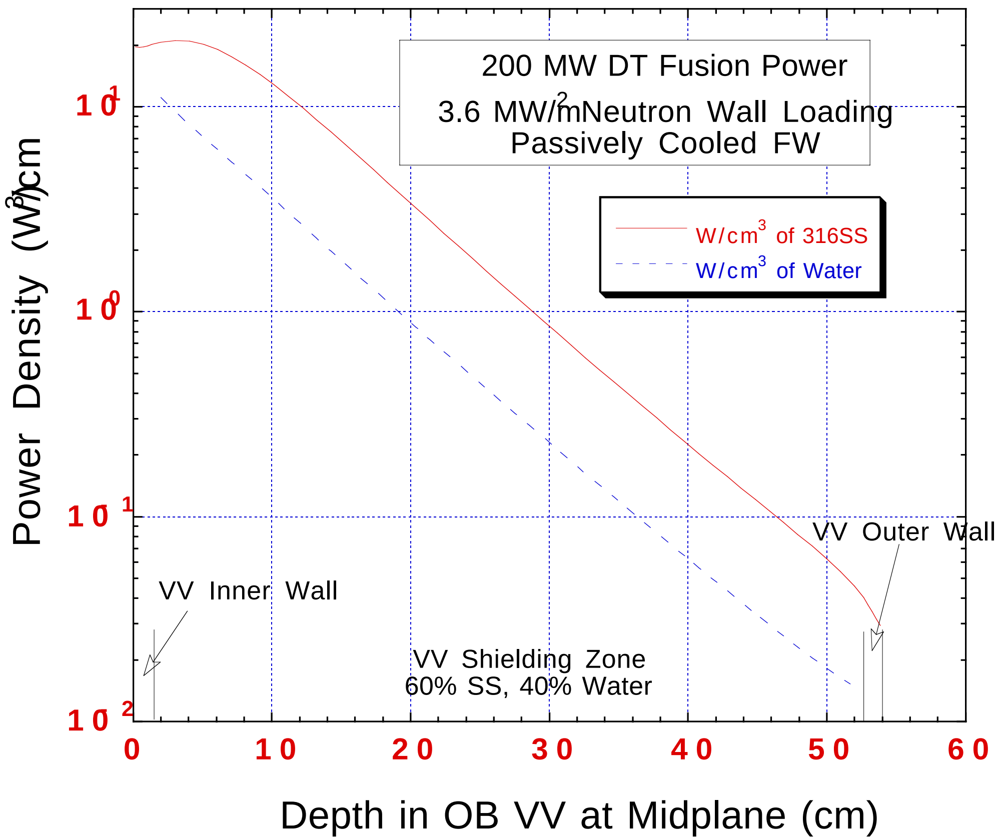
Nuclear Heating Distribution in the OB FW/Tiles at Midplane

University of Wisconsin-Madison



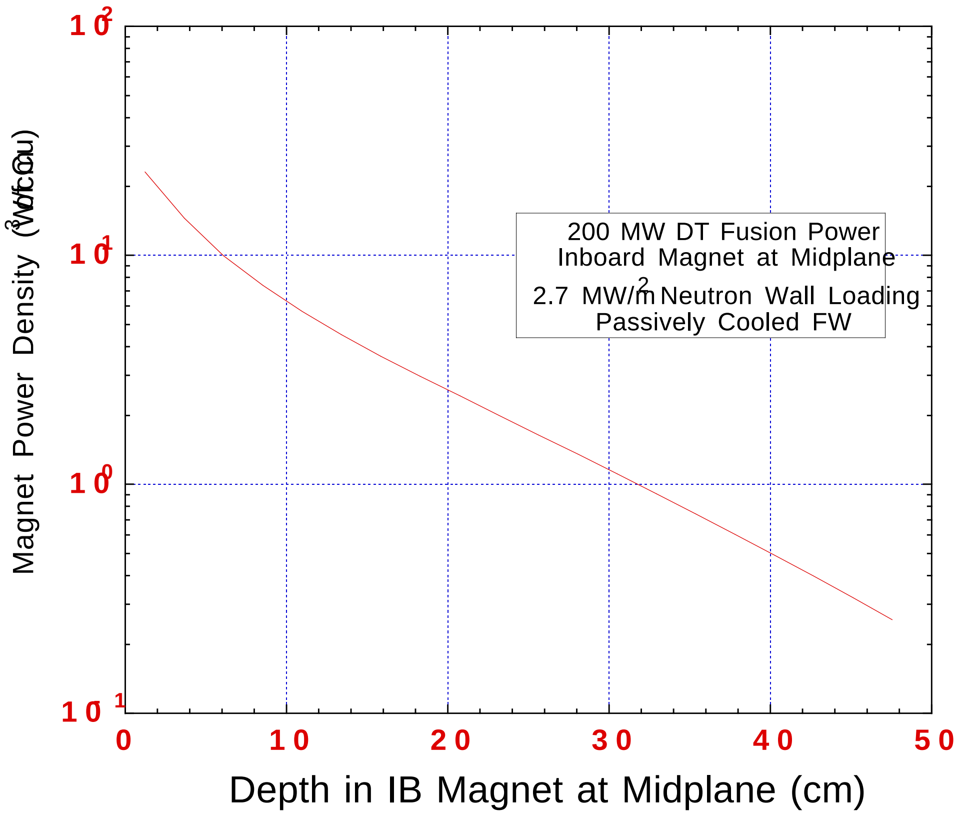
Nuclear Heating Distribution in the OB VV at Midplane

University of Wisconsin-Madison



Radial Variation of Nuclear Heating in IB Magnet

University of Wisconsin-Madison



Nuclear Heating in Divertor Region

University of Wisconsin-Madison

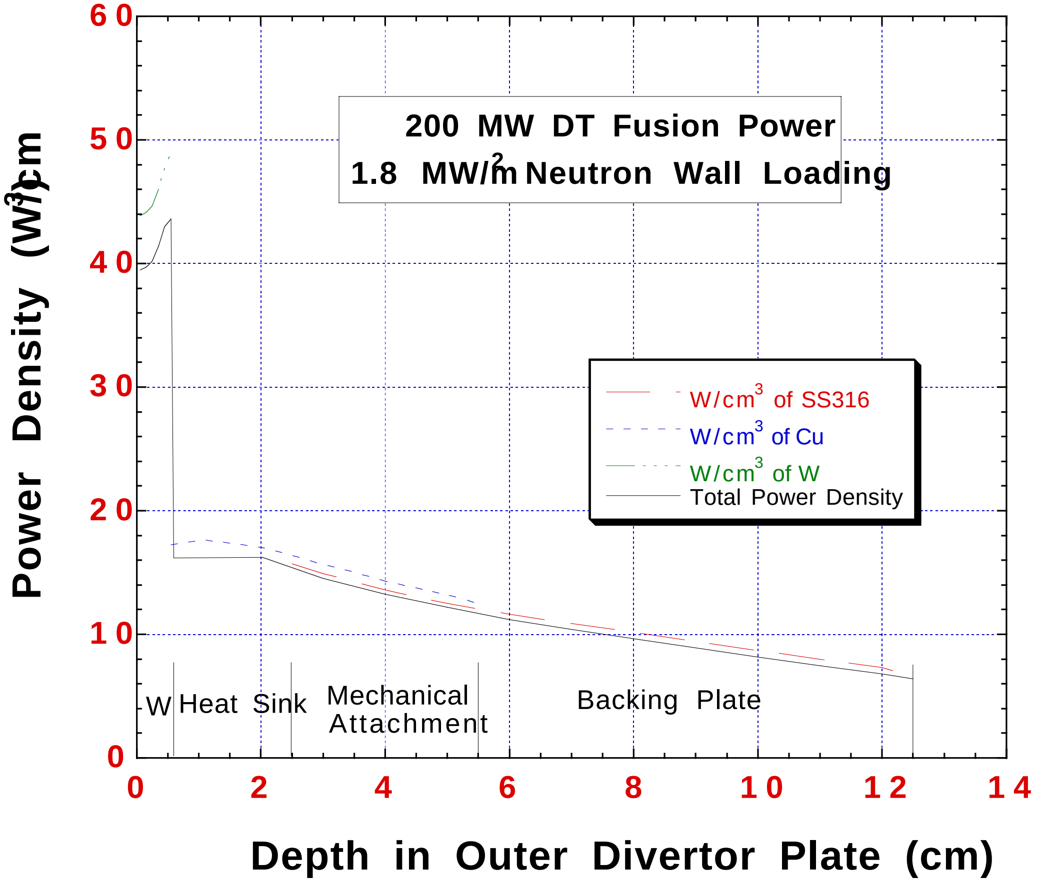
- Peak nuclear heating calculated in the different components at top/bottom of machine

	Nuclear heating (W/cm^3)
W divertor PFC	49.0
Cu divertor heat sink	17.2
SS divertor structure	14.9
SS VV	6.7
Magnet	1.7

- Relatively high nuclear heating deposited in W PFC

Nuclear Heating Distribution in Outer Divertor Plate

University of Wisconsin-Madison



Total Magnet Nuclear Heating

University of Wisconsin-Madison

- Total nuclear heating in the 16 TF coils for 200 MW DT fusion power was estimated based on the results of the 1-D calculations

- Variation of neutron wall loading and shielding thickness was taken into account

- Total heating is dominated by contribution from the lightly shielded IB legs

	Magnet Nuclear Heating (MW)	
	Option 1	Option 2
IB region	27	22.9
OB region	0.03	0.05
Divertor region	2.1	2.1
Total	29.13	25.05

- Total magnet heating decreases by 14% in option 2 compared to option 1 because of the added water coolant in FW and using Cu in gasket in place of SiC

Peak end-of-life He production (appm) in VV

University of
Wisconsin-Madison

	Option 1	Option 2
IB midplane	0.13	0.11
OB midplane	0.07	0.15
Divertor	0.016	0.016

- Contribution from DD shots is very small (<0.15%)
- Peak VV He production occurs in the IB for option 1 and in OB for option 2
- IB VV He production decreases by 15% in option 2 because of the added water coolant in FW and using Cu in gasket in place of SiC
- OB VV He production increases by a factor of ~2 in option 2 due to the 5 cm reduction in FW/tiles thickness
- Reweldability of VV is not a concern with both FW/tiles design options

Magnet Insulator Dose

University of
Wisconsin-Madison

- The dose rate to the magnet insulator in the TF magnet was calculated at different poloidal locations
- The dose rate was determined at the front layer of the magnet winding pack
- Because of the minimal shielding provided by the thin VV in the IB region, the peak value occurs in the IB side at midplane
- Dose rate decreases as one moves poloidally from IB midplane to OB midplane
- Neutron contribution is 50% at front and 30% at back of IB leg and varies from 40% at front to 30% at back of OB region

Cumulative Peak Magnet Insulator Dose

University of Wisconsin-Madison

	Option 1	Option 2	% from DD Shots
IB midplane	1.47×10^{10}	1.26×10^{10}	13%
OB midplane	6.97×10^{6}	1.26×10^{7}	1.6%
Divertor	9.80×10^{8}	9.80×10^{8}	10%

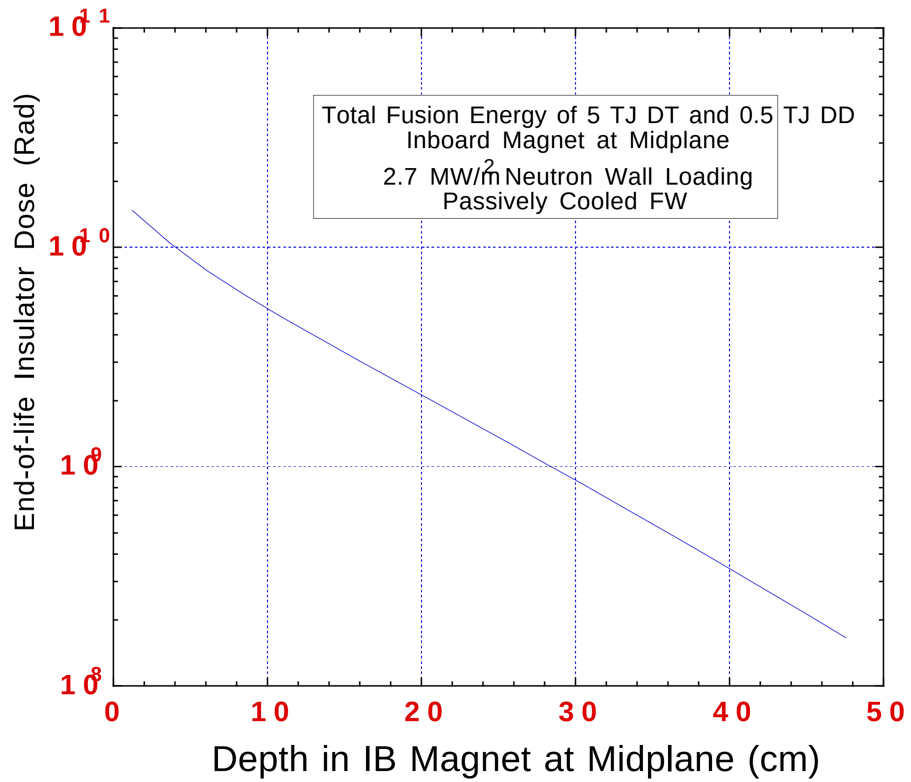
- The insulator dose at front surface of magnet peaks in the IB side at midplane and decreases as one moves poloidally to the OB midplane due to increased shielding by VV

- Relative contribution from DD shots decreases as one moves poloidally from IB midplane to OB midplane due to increased attenuation of DD neutrons compared to attenuation of the high energy DT neutrons

- The peak cumulative insulator dose decreases by 14% in option 2 compared to option 1 because of the added water coolant in FW and using Cu in gasket in place of SiC

Insulator Dose Distribution in the IB Magnet at Midplane

University of Wisconsin-Madison



- Peak end-of-life insulator dose drops to 10^{10} Rads behind the front 4 cm layer of the coil

Conclusions

University of Wisconsin

- Modest values of nuclear heating occur in FW, divertor, VV, and magnet
- Radiation damage values are very low and will not limit the lifetime of the chamber components
- The end-of-life He production values imply that the VV will be reweldable
- Peak IB VV and magnet heating and damage decreases by ~15% with actively cooled FW/tiles because of the added water coolant in FW and using Cu in gasket in place of SiC
- Total nuclear heating in the 16 TF coils during a 200 MW DT pulse is ~29 MW for passively cooled FW/tiles and ~25 MW for actively cooled FW/tiles
- Nuclear heating during DD shots is at least two orders of magnitude lower than in DT pulses
- DD shots contribute 13% of the peak end-of-life magnet insulator dose
- Insulators that have radiation tolerance up to ~ 1.5×10^{10} Rads should be used