University of Wisconsin
Fusion Technology Institute

NUCLEAR CONSIDERATIONS FOR FIRE

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M.E. Sawan and H.Y. Khater
University of Wisconsin-Madison

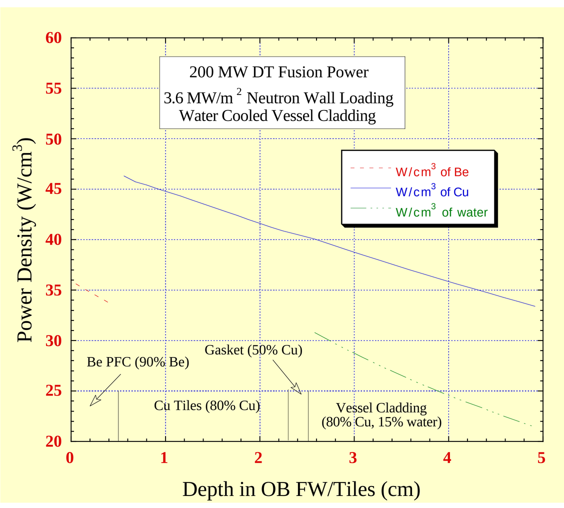
Background

- FIRE design is in pre-conceptual phase with different design options and operation scenarios being considered
- DT pulses with widths up to 20 s and fusion powers up to 200 MW produce a total of 5 TJ of fusion energy
- DD pulses with different widths and fusion powers up to 1 MW yield total fusion energy of 0.5 TJ
- A double walled steel VV with integral shielding adopted
- VV thickness varies poloidally from 5 cm in inboard region to 54 cm in outboard region
- The PFC include Be coated Cu FW and divertor plates made of tungsten rods mounted on water-cooled Cu heat sink

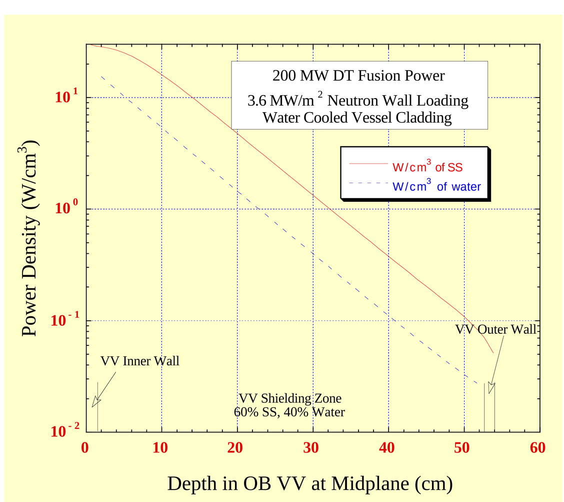
Peak Nuclear Heating (W/cm³) for 200MW DT Shots

	IB	OB
Be PFC	33.3	35.6
Cu Tiles	46.9	46.3
Gasket	40.6	40.6
Cooled Cu Vessel Cladding	40.2	40.1
H2O FWCoolant	27.6	30.9
SS Inner VV Wall	33.8	30.9
SS VV Filer	32.9	28.5
H2O VV Coolant	14.9	15.5
SS Outer VV Wall	30.3	0.07
Microtherm Insulation	9.8	0.02
SS Inner Coil Case	NA	0.038
Cu Magnet	19.5	0.019
SS Outer Coil Case	NA	$2.8x10^{-5}$

Nuclear Heating in OB FW/Tiles

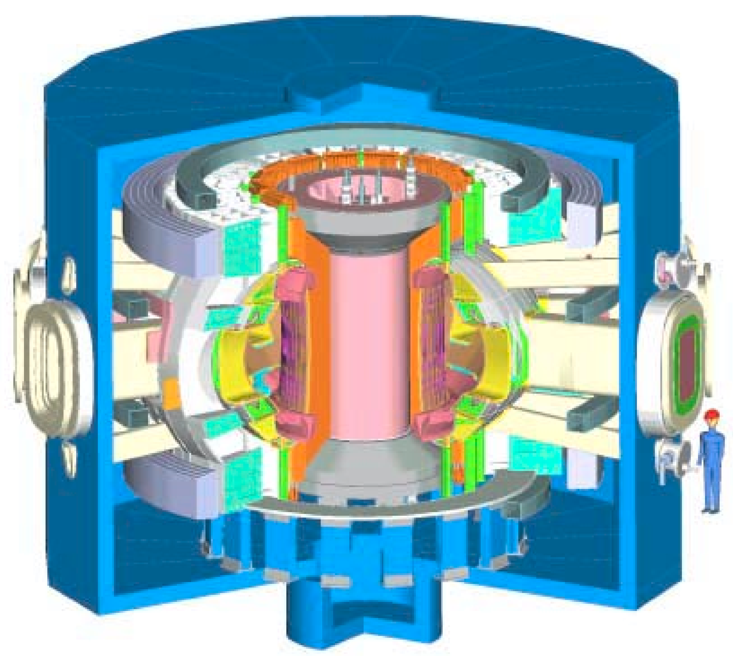


Nuclear Heating in VV Drops by an Order of Magnitude in ~18 cm

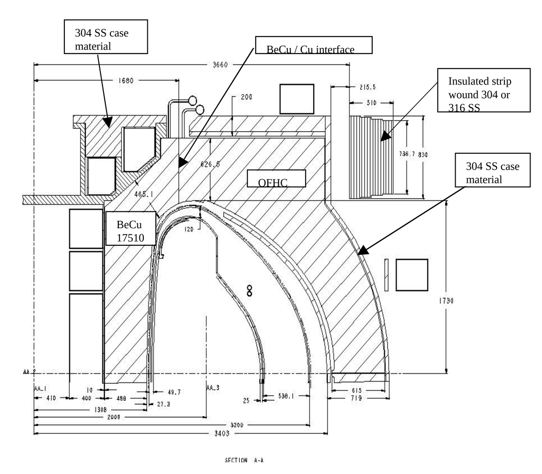


Total Magnet Nuclear Heating in 16 TF Coils for 200 MW DT Shots

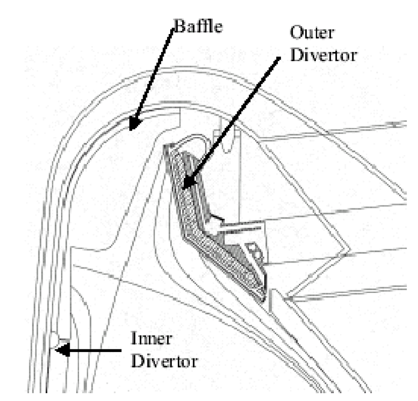
	Magnet Nuclear Heating (MW)
IB region	22.9
OB region	0.05
Divertor region	2.1
Total	25.05



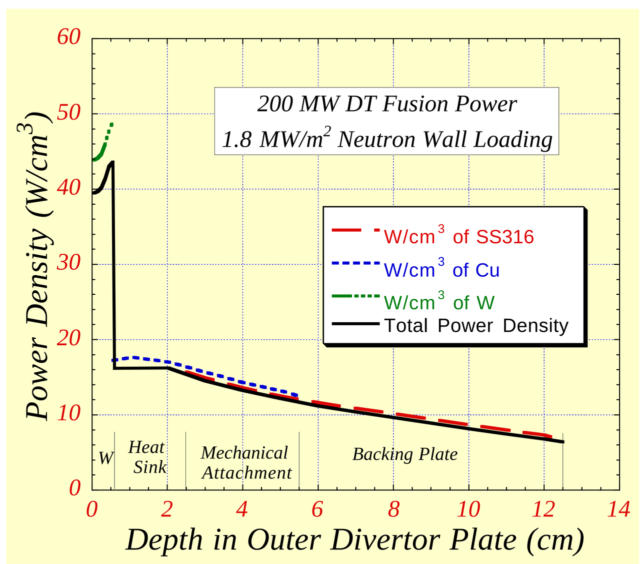
Cross Section of FIRE



FIRE Divertor



Relatively High Nuclear Heating in W PFC of Outer Divertor Plate



Cumulative Damage in FIRE Components is Very Low

Peak end-of-life cumulative radiation damage values in Cu components are < 0.05 dpa

Data on loss of ductility between 80 and 373 K and thermal creep for CuCrZr at temperatures up to 500° C are needed.

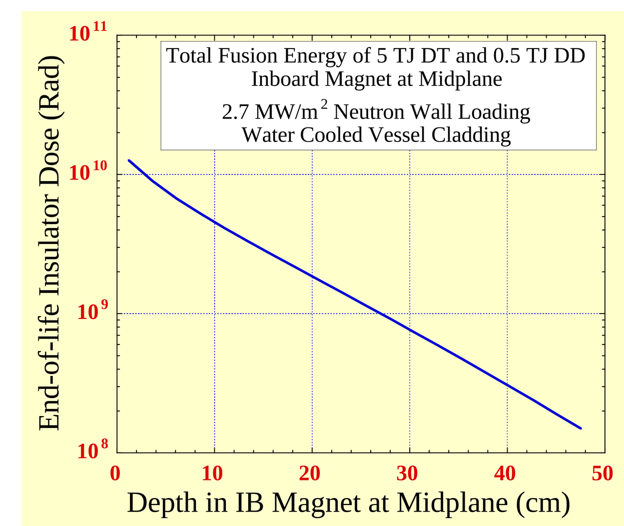
Peak end-of-life He Production in VV

	He appm
IB midplane	0.11
OB midplane	0.15
Divertor	0.016

- He Production in VV < 1 appm Allowing for Rewelding
- Contribution from DD shots very small (<0.15%)

Cumulative Peak Magnet Insulator Dose (5 TJ DT Shots and 0.5 TJ DD Shots)

	Dose (Rads)	% from DD Shots
IB midplane	$1.26x10^{10}$	13%
OB midplane	$1.26x10^{7}$	1.6%
Divertor	$9.80x10^{8}$	10%



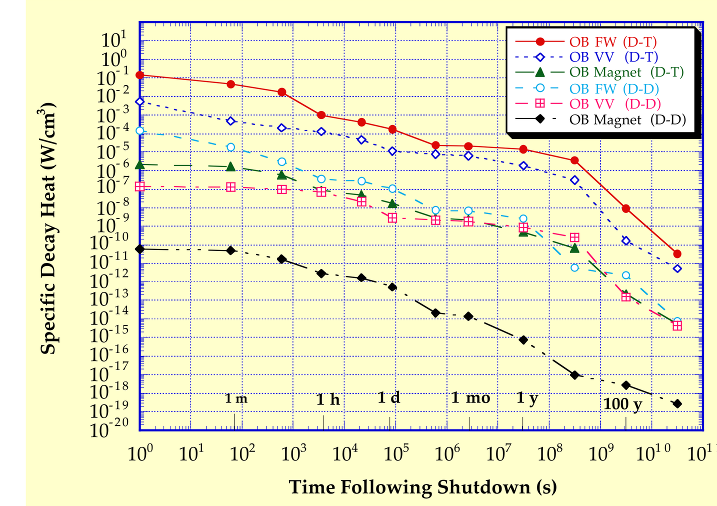
Insulator Lifetime Issues

- The commonly accepted dose limit for epoxies is 10^9 Rads (ITER)
- Polyimides are more radiation resistant
- Hybrids of polyimides and epoxies could provide radiation resistant insulators with friendly processing requirements
- In FIRE design with wedged coils and added compression ring, the TF inner leg insulation does not have to have significant bond shear strength
- Peak shear stresses occur at top and bottom of IB leg behind divertor. End-of-life dose to insulator at this location ~10^9 Rads
- Magnet insulation materials with radiation tolerance to $1.5x10^{10}$ Rads under FIRE load conditions need to be developed.

Activation Analysis

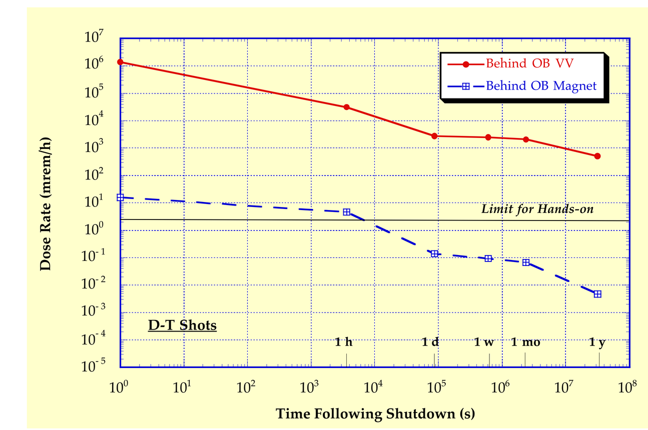
- Calculations performed for DT pulses with 200 MW of fusion power
- Four pulses per day with pulse width of 20 seconds and 3 hours between pulses
- Calculations also performed for DD pulses with 1 MW of fusion power
- Total fusion energy 5TJ DT and 0.5 TJ DD

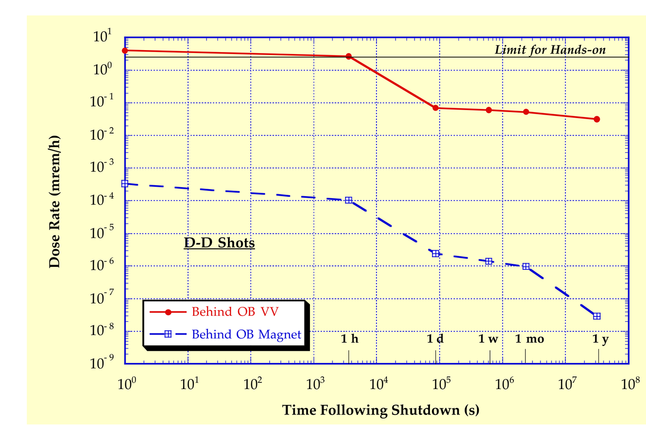
Activity and Decay Heat Values are Tolerable



- Low decay heat and activity at shutdown due to decay of short-lived radionuclides during the 3 hours between pulses
- Activity and decay heat generated following D-D shots are more than three orders of magnitude lower than the D-T shots

Biological Dose Rates at Midplane





- Following DT shots hands-on ex-vessel maintenance is possible with
  - The 110 cm long steel shield plug in midplane ports
  - The 20 cm shield at top of TF coil
- Following DD shots immediate access for maintenance is possible behind OB VV

All Components Qualify as Class C LLW

Zone	Fetter	10CFR61
IB FW	0.2 (^{108m}Ag)	0.022 (^{63}Ni)
IB VV	0.092 (^{108m}Ag, ^{94}Nb)	0.035 (^{94}Nb, ^{63}Ni)
IB Mag.	0.0002 (^{108m}Ag)	0.0011 (^{63}Ni)
OB FW	0.21 (^{108m}Ag)	0.024 (^{63}Ni)
OB VV	0.011 (^{108m}Ag, ^{94}Nb)	0.0032 (^{94}Nb, ^{63}Ni)
OB Mag.	$2.26x10^{-6}$ (^{94}Nb)	$2.56x10^{-6}$ (^{94}Nb, ^{63}Ni)
Divertor	0.034 (^{108m}Ag)	0.013 (^{94}Nb)

Conclusions

- Modest values of nuclear heating occur in FW, divertor, VV, and magnet
- End-of-life He production values imply that VV will be reweldable
- Critical issues for copper alloys include low-temperature embrittlement and high-temperature thermal creep
- Insulators with radiation tolerance up to ~ $1.5x10^{10}$ Rads under FIRE load conditions should be used
- Activity and decay heat values after shutdown are low
- Following DT shots hands-on ex-vessel maintenance is possible with the 110 cm shield plug in midplane ports and the 20 cm shield at top of TF coil
- All components would qualify for disposal as class C LLW according to both 10CFR61 and Fetter limits