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Nuclear Features of the Fusion Ignition Research Experiment (FIRE)

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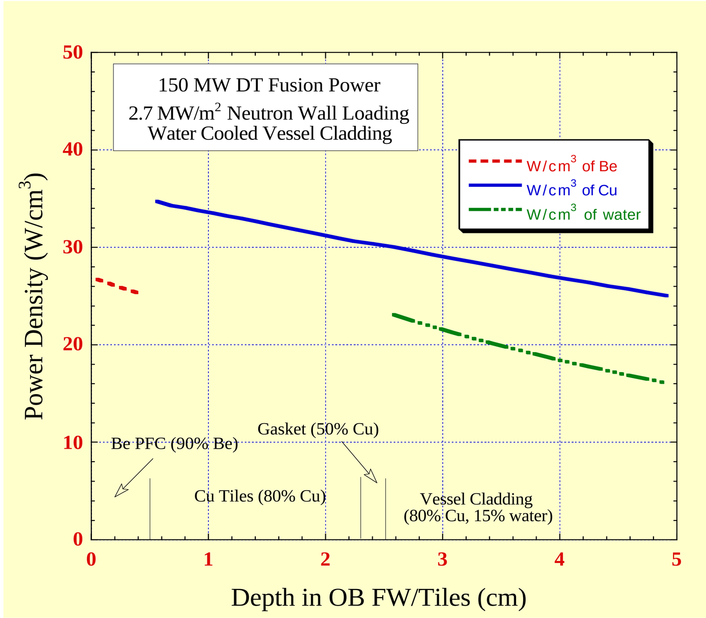
Background

- 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 150 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

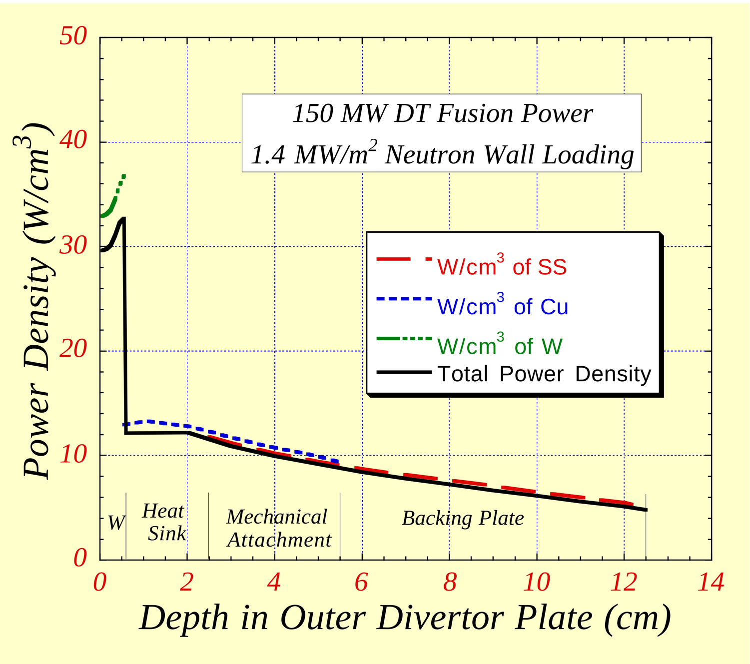
Peak Nuclear Heating (W/cm^3) for 150 MW DT Shots

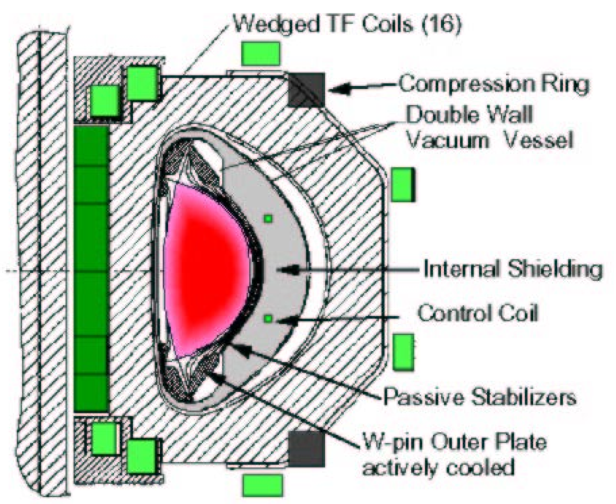
	IB	OB
Be PFC	25.0	26.7
Cu Tiles	35.2	34.7
Cu VV Cladding	30.2	30.1
H_2O Cladding Coolant	20.7	23.2
SS Inner VV Wall	25.4	23.2
SS VV Filler	24.7	21.4
H_2O VV Coolant	11.2	11.6
SS Outer VV Wall	22.7	0.053
Cu Magnet	14.6	0.014

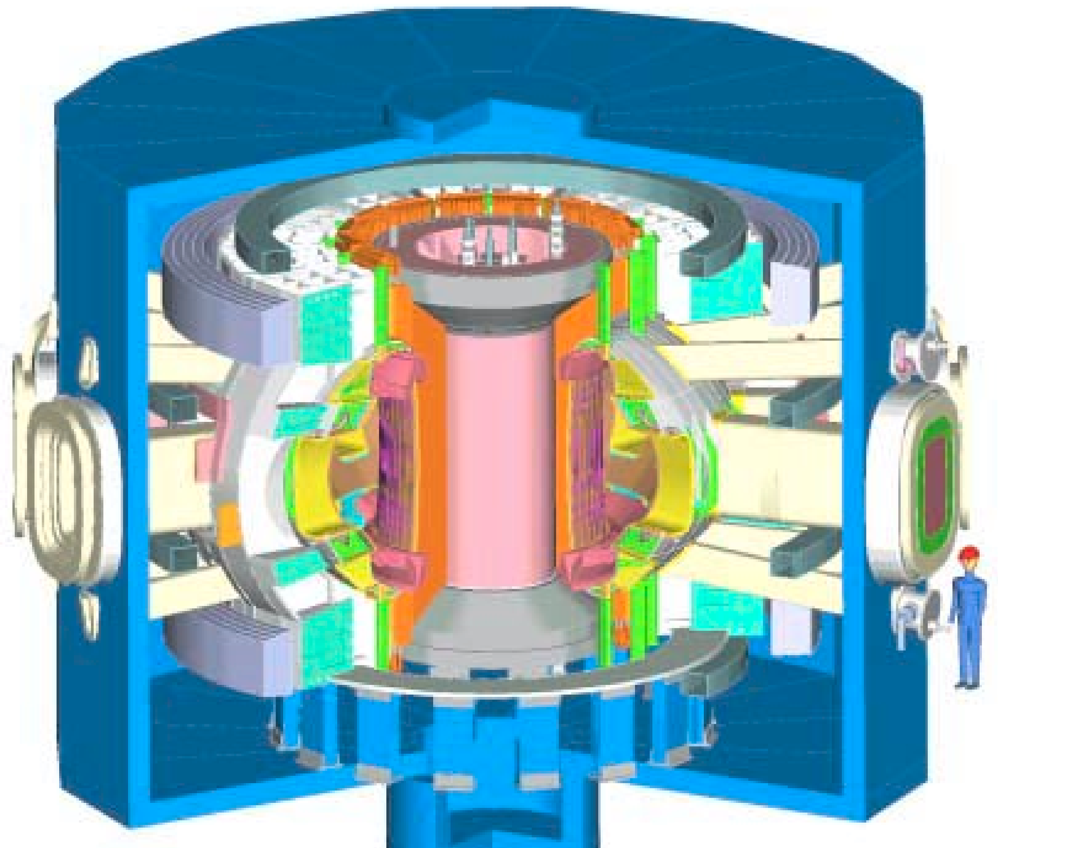
Nuclear Heating in OB FW/Tiles

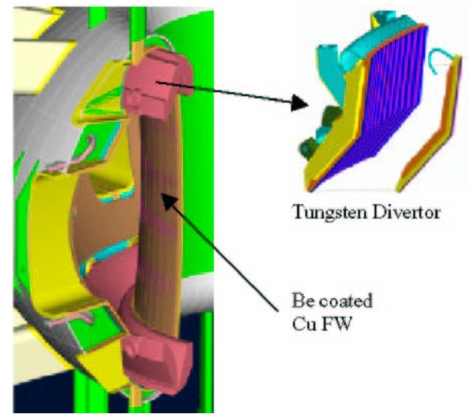


Relatively High Nuclear Heating in W PFC of Outer Divertor Plate









Total Magnet Nuclear Heating in 16 TF Coils for 150 MW DT Shots

	Magnet Nuclear Heating (MW)
IB region	17.2
OB region	0.04
Divertor region	1.6
Total	*18.84*

Cumulative Damage in FIRE Components is Very Low

	Total dpa
IB Tiles	0.0327
OB Tiles	0.0359
Divertor	0.0150
IB VV Cladding	0.0215
OB VV Cladding	0.0246
Magnet at IB	0.00666
Magnet at OB	7.54×10^{-6}
Magnet at Divertor	4.55×10^{-4}

R&D Needs:

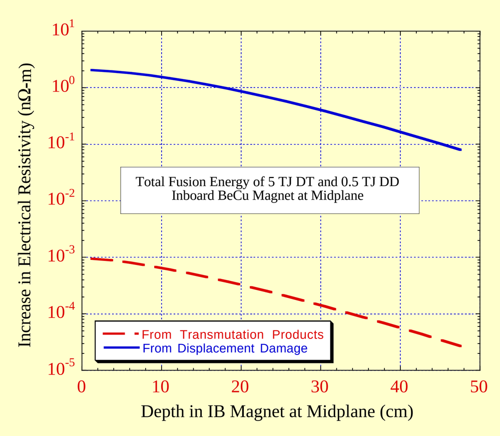
- Data on loss of ductility between 80 and 373 K with < 0.01 dpa
- Data on fatigue, fracture toughness and fatigue crack growth rate behavior
- Thermal creep data for CuCrZr at temperatures up to 500°C
- No need to perform irradiation creep measurements on Cu alloys for the low doses proposed in FIRE

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%)

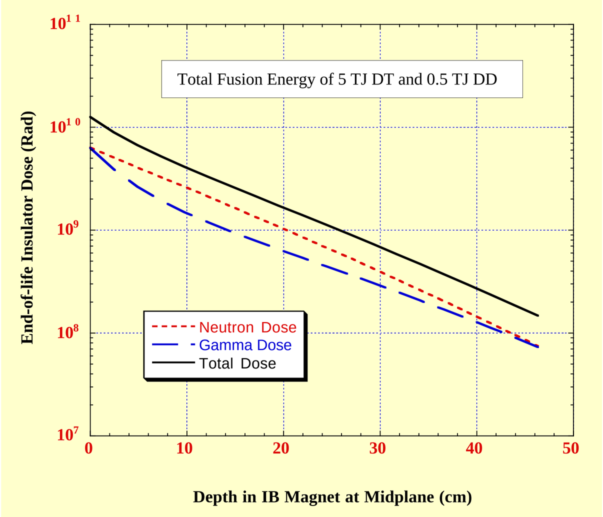
Radiation Induced Resistivity in Cu Coils is Small



- Total resistivity increase dominated by displacement damage
- Maximum increase in resistivity of BeCu at end-of-life varies from ~ 20% at start of pulse to ~ 7% at end of pulse
- Maximum increase in resistivity of OFHC copper at end-of-life varies from ~ 2.5% at start of pulse to ~ 0.3% at end of pulse

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

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



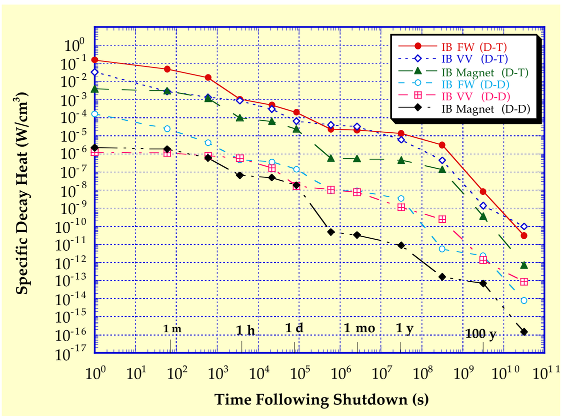
Insulator Lifetime Issues

- 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 $\sim 10^9$ Rads
- Magnet insulation materials with radiation tolerance to 1.5×10^{10} Rads under FIRE load conditions need to be developed

Activation Analysis

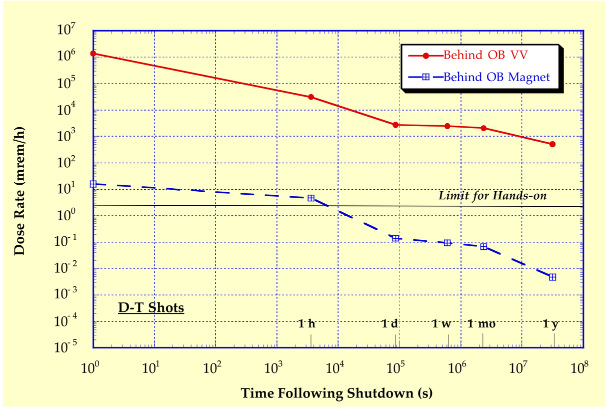
- Calculations performed for DT pulses with 150 MW of fusion power
- Four pulses per day with pulse width of 20 seconds and 3 hours between pulses
- Calculations also performed for DD pulses with 1 MW of fusion power
- Total fusion energy 5 TJ DT and 0.5 TJ DD

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

Feasibility of Hands-on Maintenance



- 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

Very Small Amount of ^{13}N and ^{14}C Produced in Nitrogen Gas

Location of Nitrogen Gas	Activity (Ci)	
	^{13}N	^{14}C
Between IB Magnet and IB VV	0.9	1.3×10^{-6}
Between OB Magnet and OB VV	1.1×10^{-2}	1.8×10^{-8}
Between OB Magnet and Cryostat	6×10^{-9}	5×10^{-11}

- Nitrogen gas exists inside the cryostat during shots and gets activated
- Largest amount of ^{13}N and ^{14}C generated in space between IB magnet and IB VV
- Since ^{13}N has a short half-life of 9.97 minutes, a nitrogen-holding system that allows for a significant decay of ^{13}N before releasing it to the environment is adopted in FIRE

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.	2.26×10^{-6} (^{94}Nb)	2.56×10^{-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 ~ 1.5×10^{10} Rads under FIRE load conditions should be used
- Radiation induced resistivity increase is 7-20% for the BeCu alloy and 0.3-2.5% for the OFHC copper
- 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
- Following a DT pulse activities of ^{13}N and ^{14}C are only 0.9 and 1.3×10^{-6} Ci from N gas activation
- All components would qualify for disposal as class C LLW according to both 10CFR61 and Fetter limits