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Impact of Tritium Removal and He-3 Recycling on Structure Damage Parameters in a D-D Fusion System

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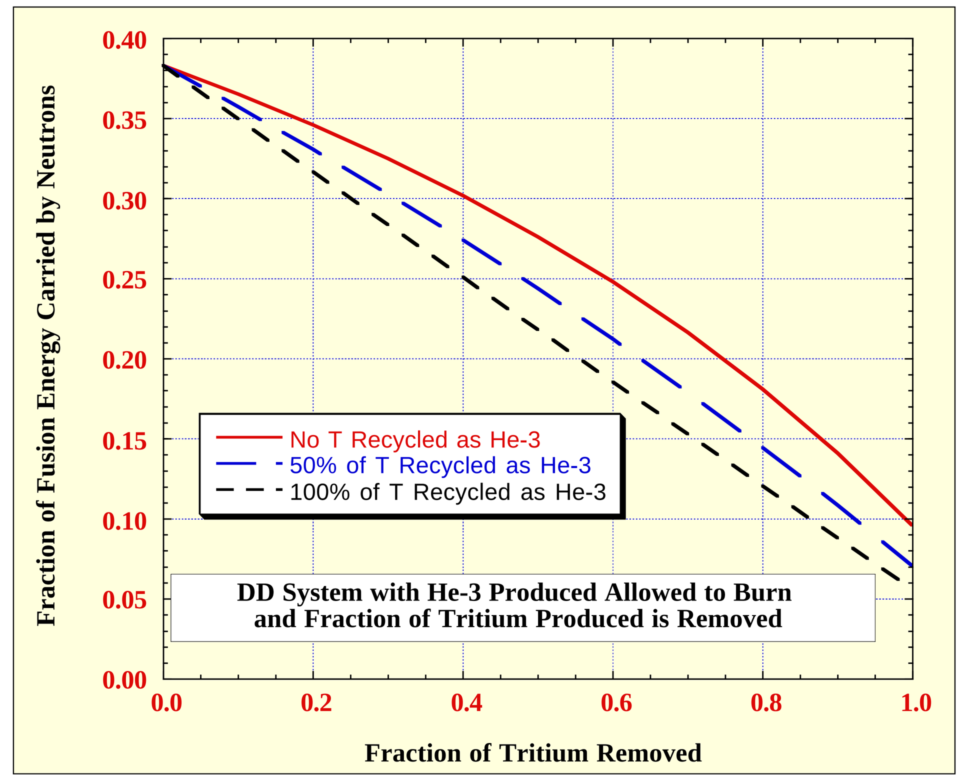
Background

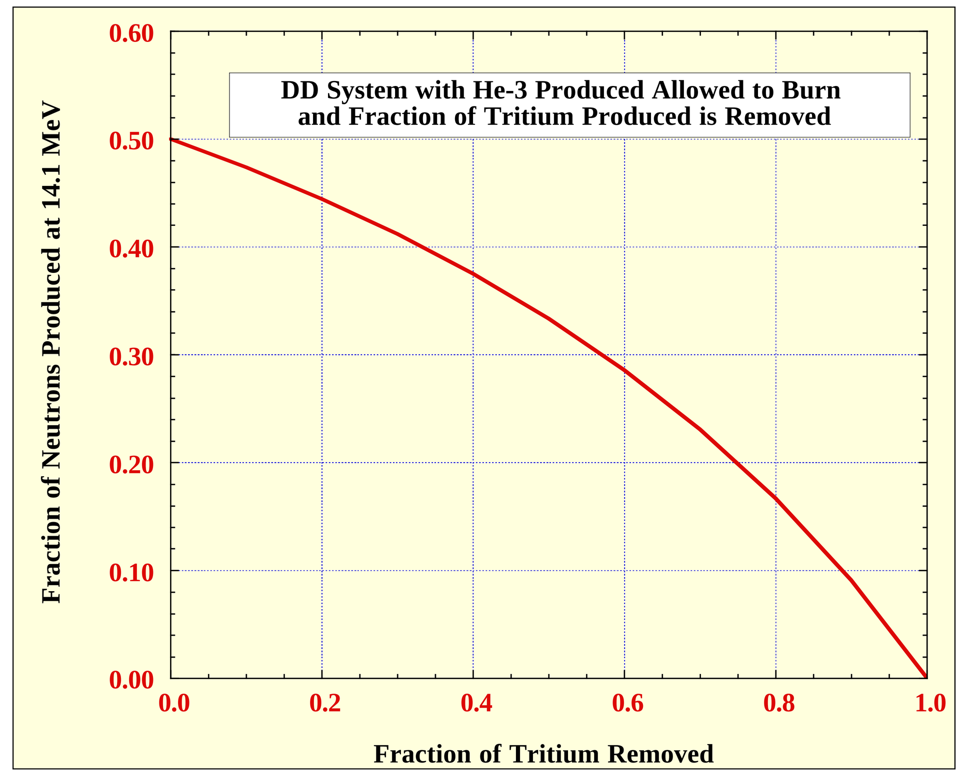
- In a catalyzed D-D system with all produced He-3 and tritium allowed to burn, equal numbers of DD and DT neutrons are generated and neutrons carry 38.3% of the fusion energy. Produced DT neutrons could lead to considerable structural radiation damage limiting lifetime of chamber components
- Several conceptual designs were presented in the past for catalyzed D-D commercial fusion plants [e.g., WILDCAT, SATYR]
- We propose developing large D-D magnetic fusion power plants where amount of tritium allowed to burn is systematically lowered, resulting in a reduced fraction of fusion energy carried by DT neutrons. If part of tritium removed is allowed to decay and is recycled as He-3, further reduction in fraction of energy carried by neutrons can be achieved
- We assessed impact on peak damage parameters in candidate first wall/blanket/shield structural materials. The results are compared to those in a D-T system with the same fusion power wall loading

Description of Analysis

- Structural material candidates considered
  - The vanadium alloy V4Cr4Ti
  - The ferritic steel alloy 9Cr-2WVTa
  - The SiC/SiC composite
- Blanket included in model to account for neutron backscattering
- Three candidate breeding blankets considered
  - $Pb_{83}Li_{17}$ cooled SiC/SiC
  - Li Cooled vanadium alloy
  - Water cooled ferritic steel (FS) with Li_2O ceramic breeder
- Peak radiation damage parameters determined also for a water cooled FS shield in the D-D system
- Damage parameters calculated are atomic displacement rate, helium production rate, hydrogen production rate and total transmutation or burnup rate
- For comparing results to those in a D-T system, we normalized to same fusion power that corresponds to a peak neutron wall loading of 4 MW/m^2 in a D-T system

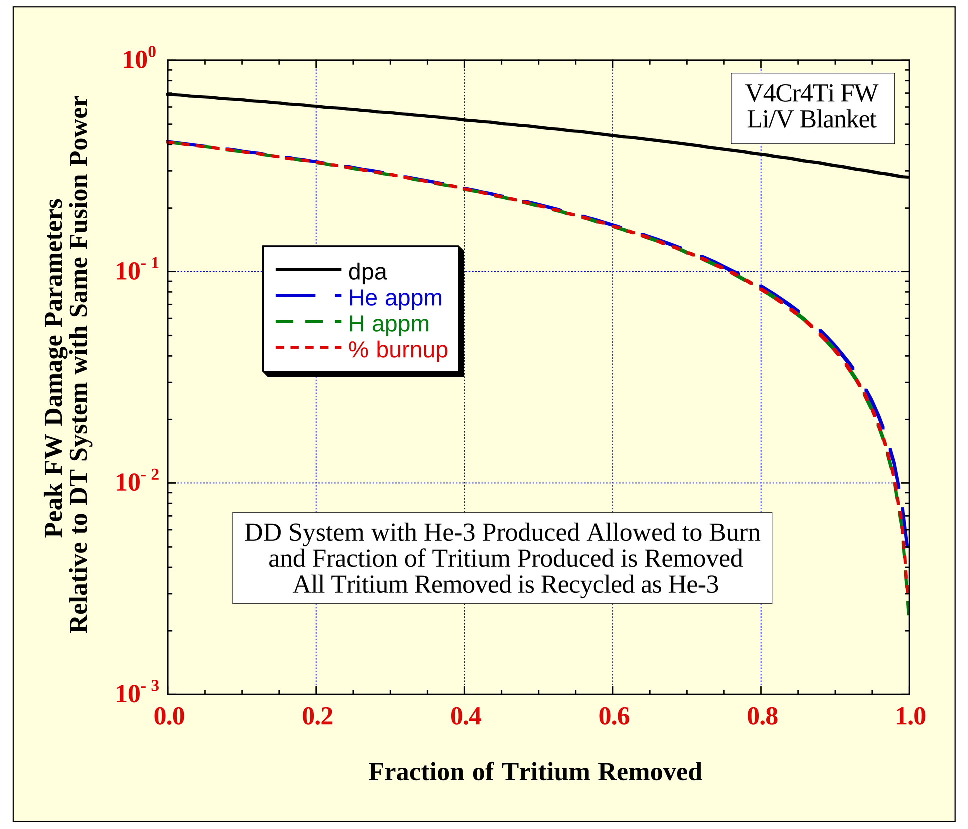
Neutron Production in D-D System

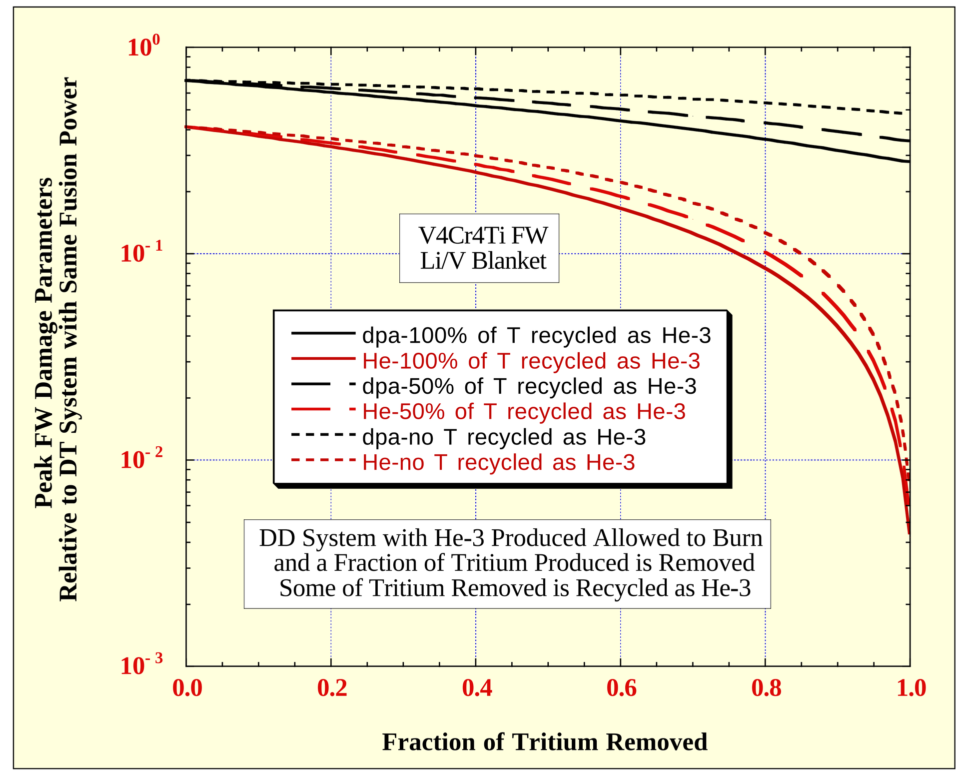


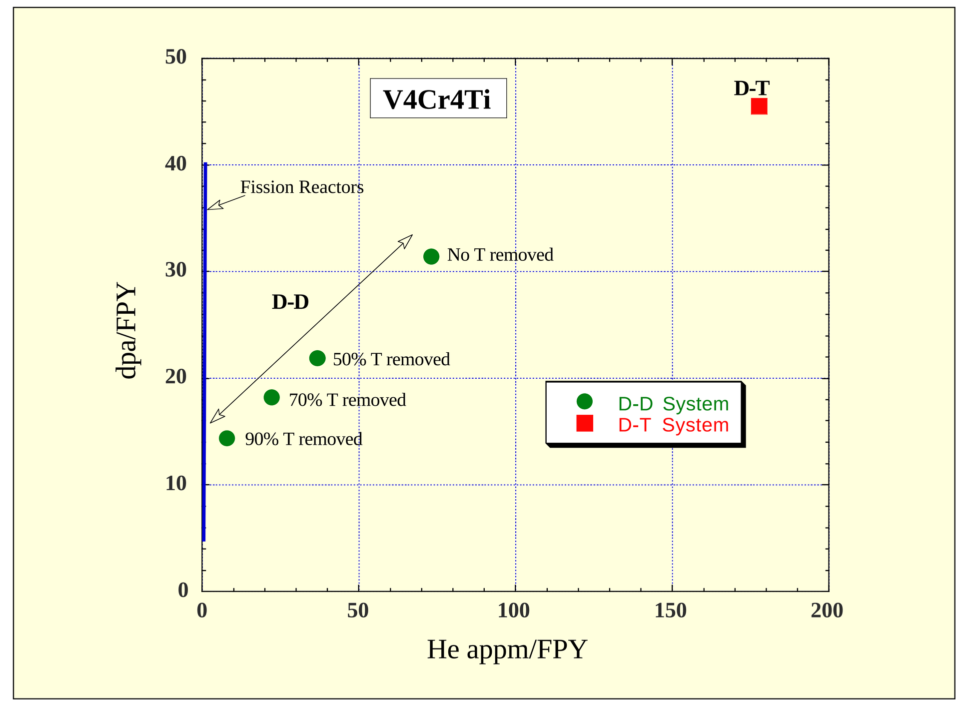


- Significant reduction in fraction of energy carried by neutrons and spectrum softening achieved with a large amount of tritium being removed
- Recycling He-3 obtained from decay of removed tritium also results in additional moderate reduction of fraction of fusion energy carried by neutrons

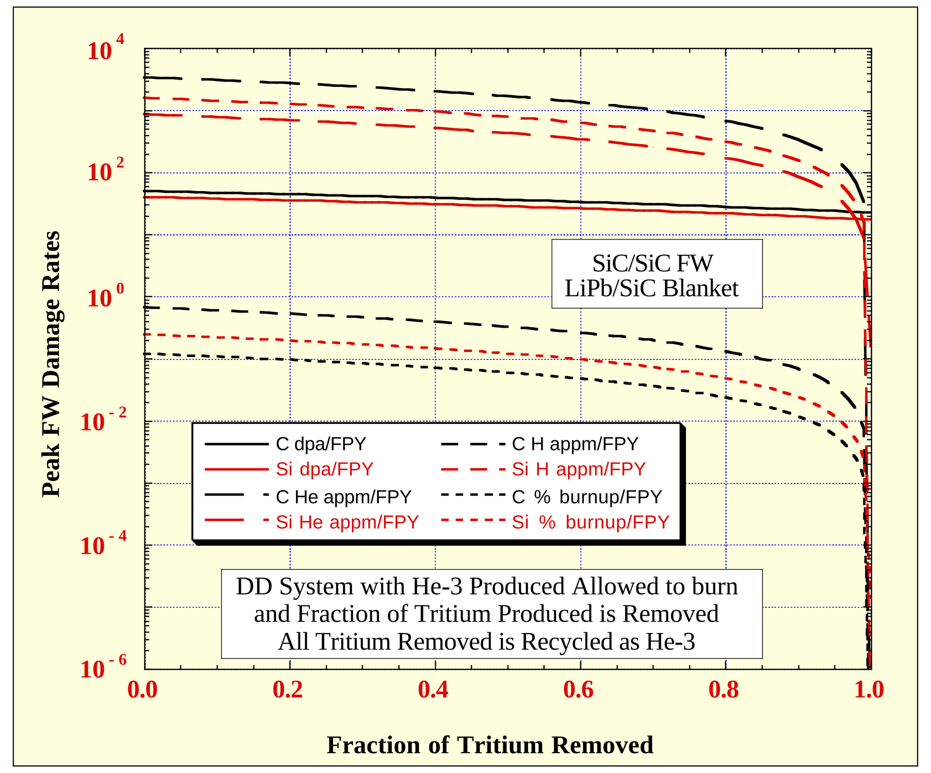
V4Cr4Ti

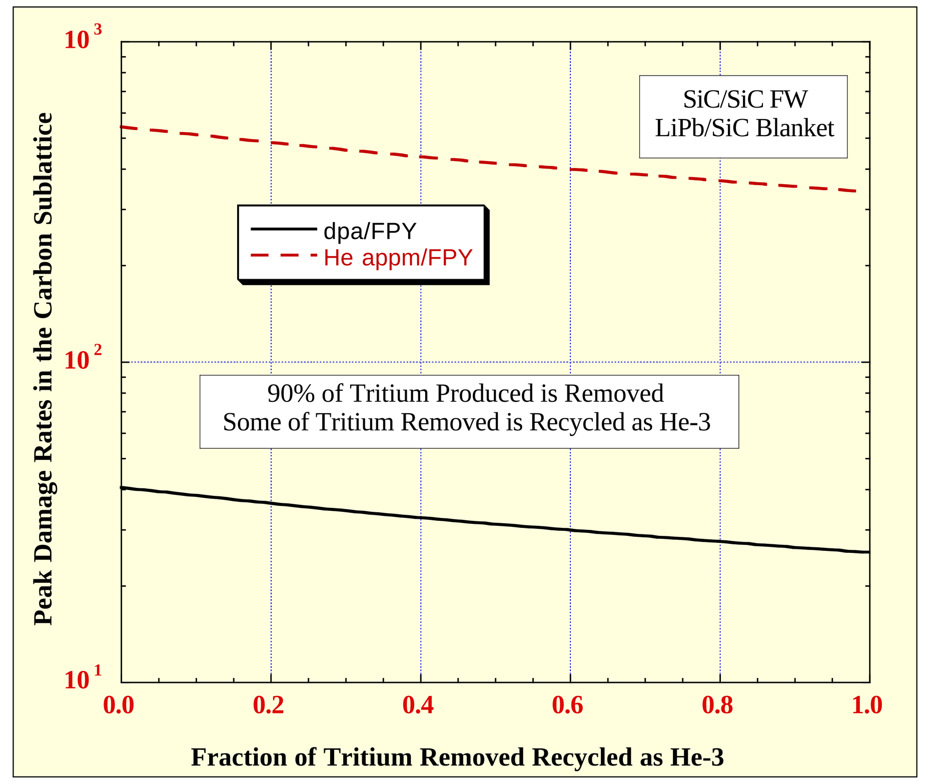


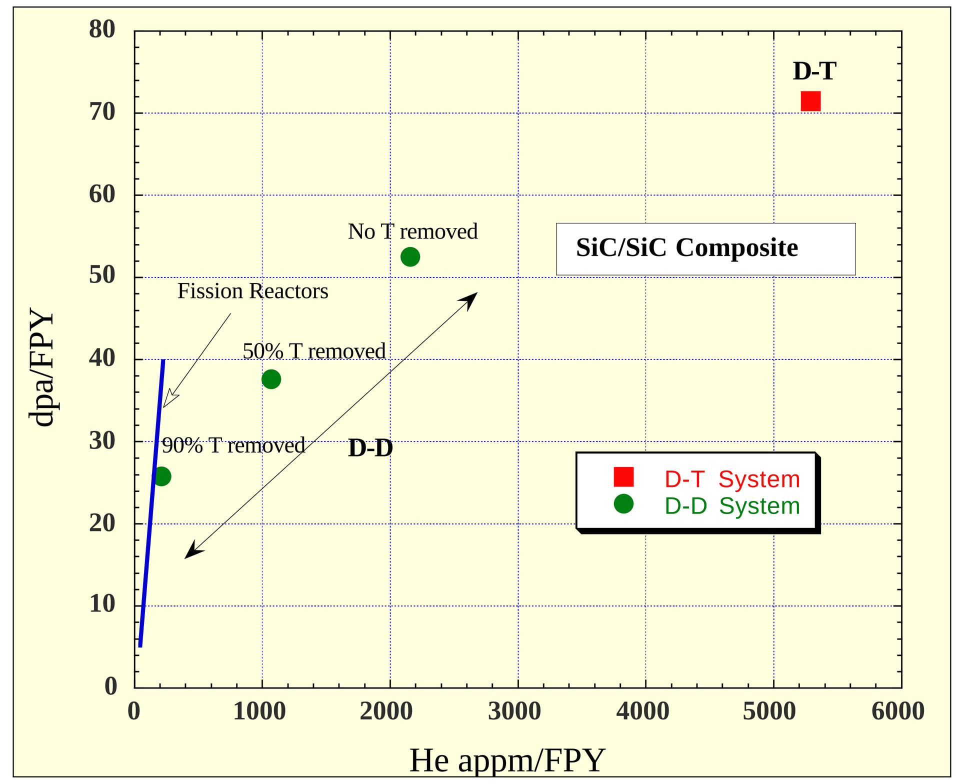




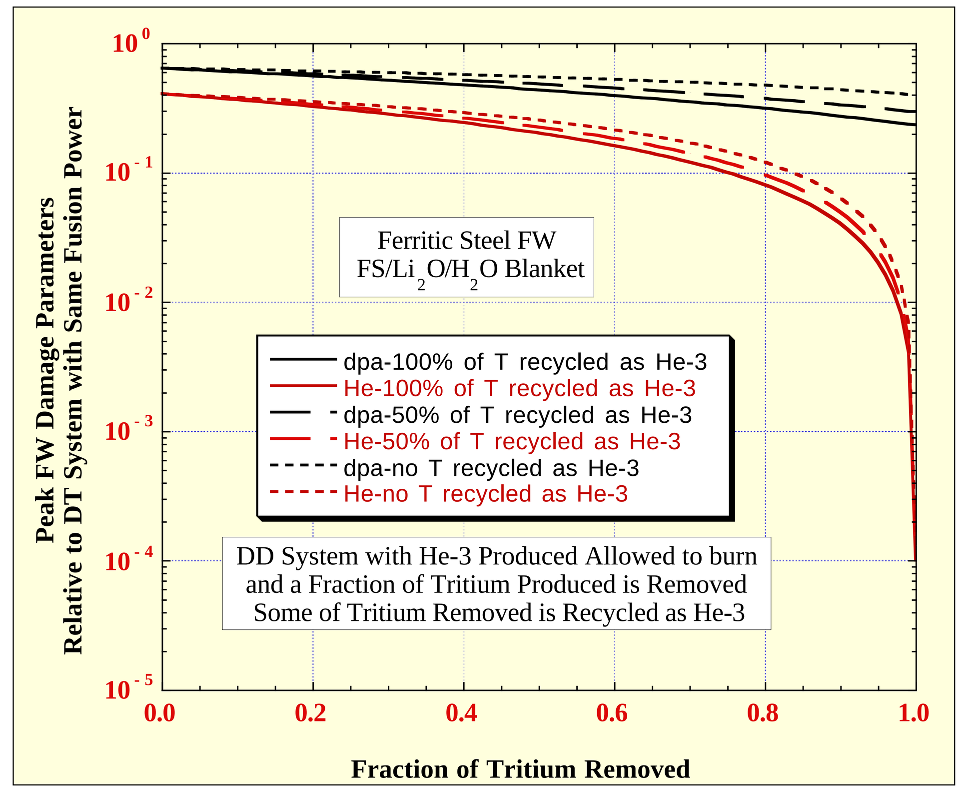
SiC/SiC Composite

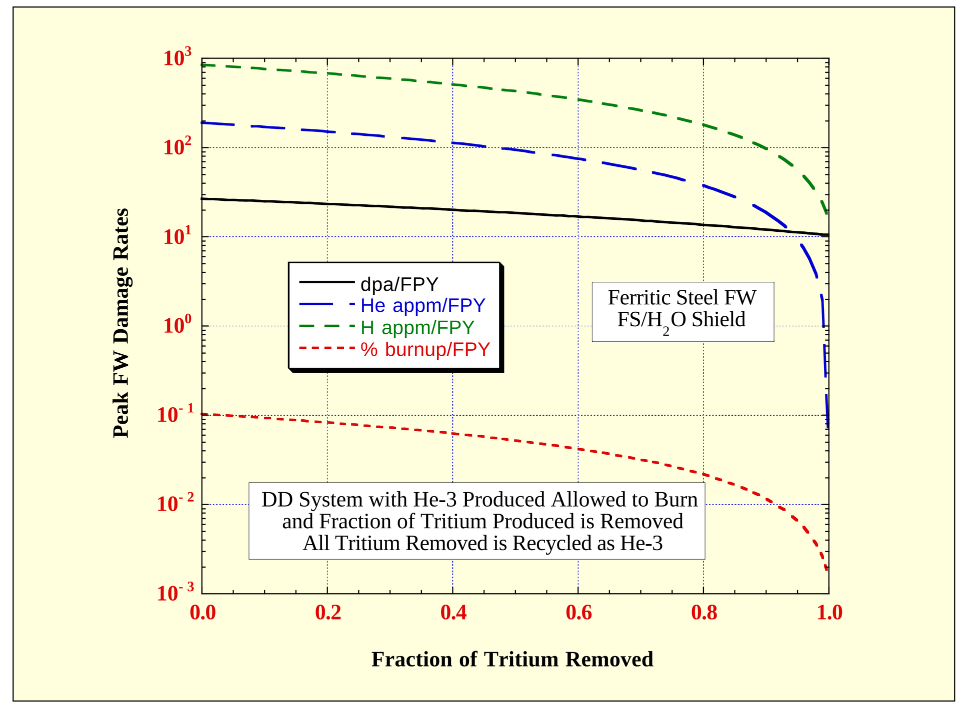


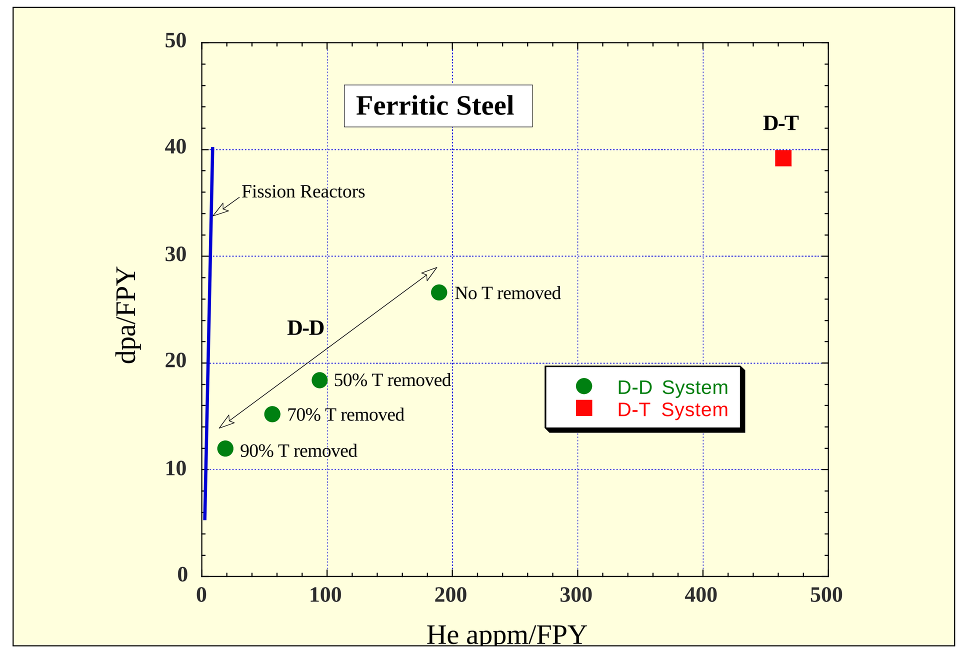




Ferritic Steel







Observations and Conclusions

- Removing tritium produced by D-D fusion and recycling part of it after it decays to He-3 significantly reduces fraction of fusion energy carried by neutrons and softens the neutron energy spectrum
- Relative effects on damage parameters are similar for the different structural materials
- For a catalyzed D-D system (no tritium removal), peak dpa rate in candidate structural materials is 25-35% lower than that in an equivalent D-T system and gas production and transmutation rates are ~60% lower
- As tritium is removed gas production and transmutations decrease by more than two orders of magnitude and the dpa rate decreases by a factor of 2.3-2.8
- An additional reduction of a factor of 1.6-1.7 in damage parameters is achieved by recycling the removed tritium as He-3
- He/dpa ratio drops below one when more than 75% of tritium is removed
- Removing the produced tritium from the D-D system results in dpa and He production rates that approach values in fission reactors
- Information from tests in fission reactor spectra will be useful in determining lifetime of structural material
- In addition to enhancing structural material lifetime, safety and environmental characteristics will improve