ASSESSMENT OF IFE STRUCTURAL AND ARMOUR MATERIALS

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INTRODUCTION

- **Structural Materials for MFE Applications**
  – Stainless steels (T< 425°C, <0.5 MW/m^2 heat flux)
  – Ferritic steels (250-550°C, < 1 MW/m^2 heat flux)
  – Vanadium alloys (400-700 °C, ≤2 MW/m^2 heat flux)
  – SiC composites (T<1100 °C, ≤ 1 MW/m^2 heat flux)
  – W-alloys (mainly divertor applications)

- **Armour Materials for MFE Applications**
  - Graphite and CfC composites
  - Be
  - SiC and SiC composites
  - W and W-alloys

CURRENT RESEARCH
Ferritic Steel (FS) Alloys

- Low activation
  - Fe-(7-9)Cr-2TaWV
  - Improve low T ductility (He-embrittlement effects??)
  - T_{max} ≈550°C due to poor thermal creep strength

- Oxide-dispersion-strengthened, Low Activation FS
  - Fe-(11-14)Cr-(2-3)W-(0.4-0.5)Ti-(0.2-0.7)Y_2O_3
  - Improve isotropy through improved fabrication

- References: ICFRM-9 overview papers

CURRENT RESEARCH
Vanadium Alloys (VA)

- **Full Characterization of V-4Cr-4Ti Alloy**
  - Thermal creep at T≤800°C
  - Ductility at 400-450 °C
  - Effects of He and neutron damage on properties
  - Effects of Si, O, C, N
  - Insulator coating development for VA/Li system

- **Optimization of Vanadium Alloys**
  - Lower Cr may give better low-T ductility
  - Higher Cr gives better high-T creep strength

CURRENT RESEARCH
Silicon Carbide Composites (SiC_f/SiC)

- **Improve Composition and Fabrication**
  - High-strength stoichiometric fibers
  - Stoichiometric, dense SiC matrix
  - Decrease excess C and porosity at interface
  - Optimize for high thermal conductivity, strength and dimensional stability in a neutron environment

- **Increase Operating Temperature and Lifetime**
  - T limited by swelling and compatibility
  - Lifetime limited by fiber creep, He effects, etc.

CURRENT RESEARCH
Tungsten Alloys

- **Challenges**
  - Fabricability and joining
  - Embrittlement in a neutron environment

- **Potential Solutions**
  - Tailor microstructure (small grain size)
  - Dispersion of fine TiC particles
  - Improved fabricability
  - Performance under irradiation: underway

Graphite and Carbon Fiber Composites (CFC) General Considerations

- Graphite/CFC's are an entire class of materials
  - Need to trade-off all properties in selecting a specific CFC
- Graphite/CFC's undergo significant changes in many properties with radiation
  - Radiation lifetime is limited
- Operating temperatures play an important role in property behavior
- Most irradiation data are for nuclear graphites
  - Limited data available for CFC
- This initial assessment addresses bulk properties

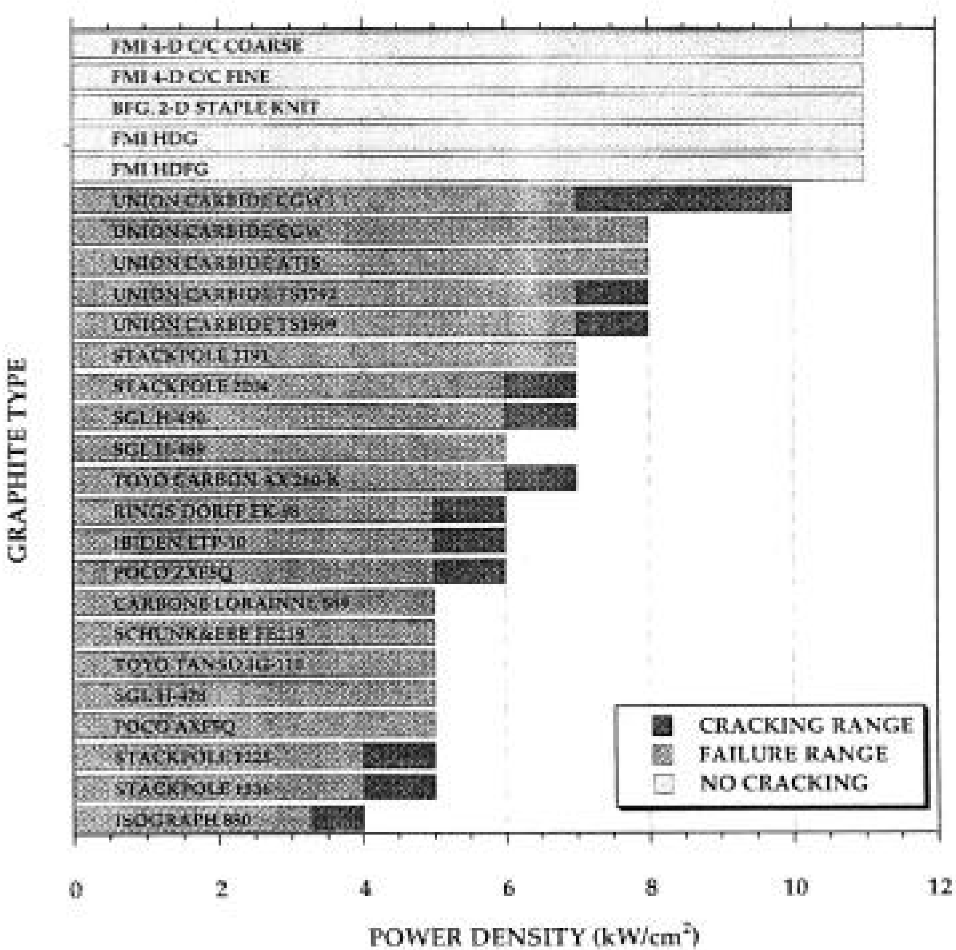
First Wall Issues

- Surface Erosion
- Tritium inventory - co-deposition
- Chamber clearing
- Thermophysical properties
  - Initial properties*
  - Irradiation effects*
- Mechanical properties
  - Initial properties*
  - Irradiation effects*
- Dimensional changes
  - Densification and Swelling*
  - Radiation creep

Magnetic Fusion Experience

- Major Function - plasma facing material
  - Non-structural applications only
- Reasons for using
  - Low-Z - not an issue for IFE
  - Thermal shock resistance - important for IFE
- Concerns
  - High tritium inventory - co-deposition
  - High erosion rates - important for reactors
  - Limited radiation lifetime - important for reactors

Graphite/CFC Thermal Shock

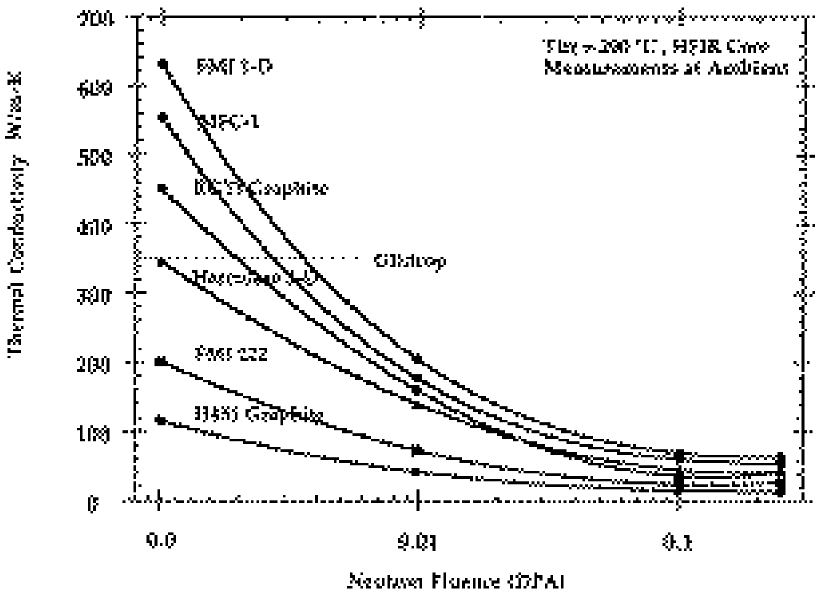


- Thermal shock behavior can vary by a factor of ~3 for various types of graphite/CFC.
- Thermal shock closely tied to value of thermal conductivity and CTE.

The performance of several grades of graphite and graphite composites subjected to thermal shock loading (with notch).

R.D. Watson, et al., High Heat Flux Testing of CIT First Wall Tiles, 1988

Graphite Thermal Conductivity

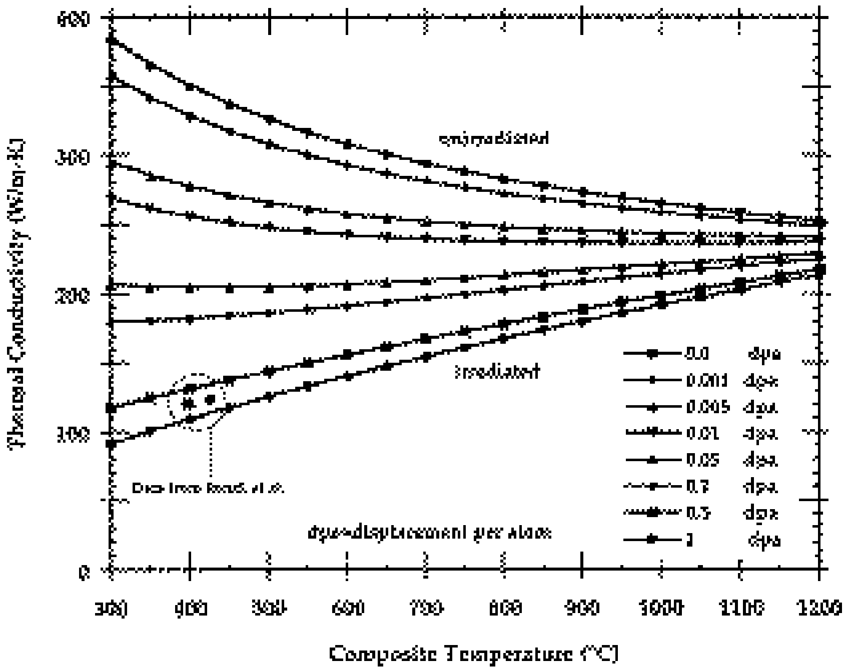


- At low T, initial value of thermal conductivity has limited effect on irradiated value.
- Changes saturate at ~1 dpa

Irradiation induced thermal conductivity degradation in selected graphite materials.

L.L. Snead, Fusion Energy Applications, Carbon Materials for Advanced Technologies, Pergamon Press, (1999)

Model Predictions for CFC

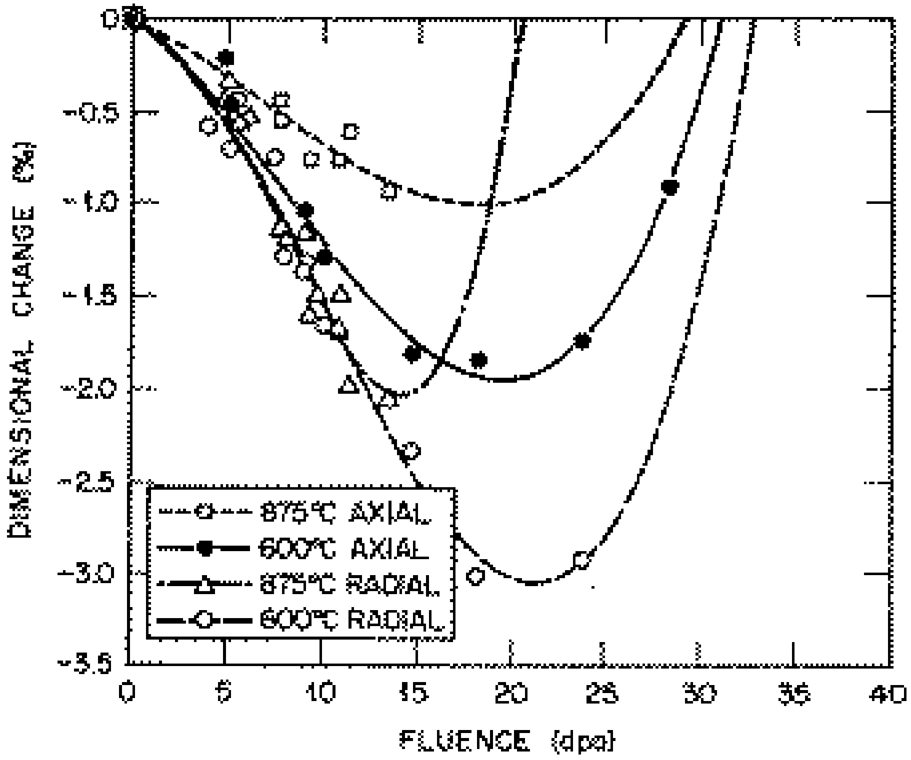


- Thermal conductivity approaches 200 W/m-K at high T
- Greatest effect is at low T

Calculated thermal conductivity of neutron irradiated MKC-1PH CFC

L.L. Snead, T.D. Burchell, Carbon Extended Abstracts, 774-775 (1995)

Graphite Swelling Lifetime

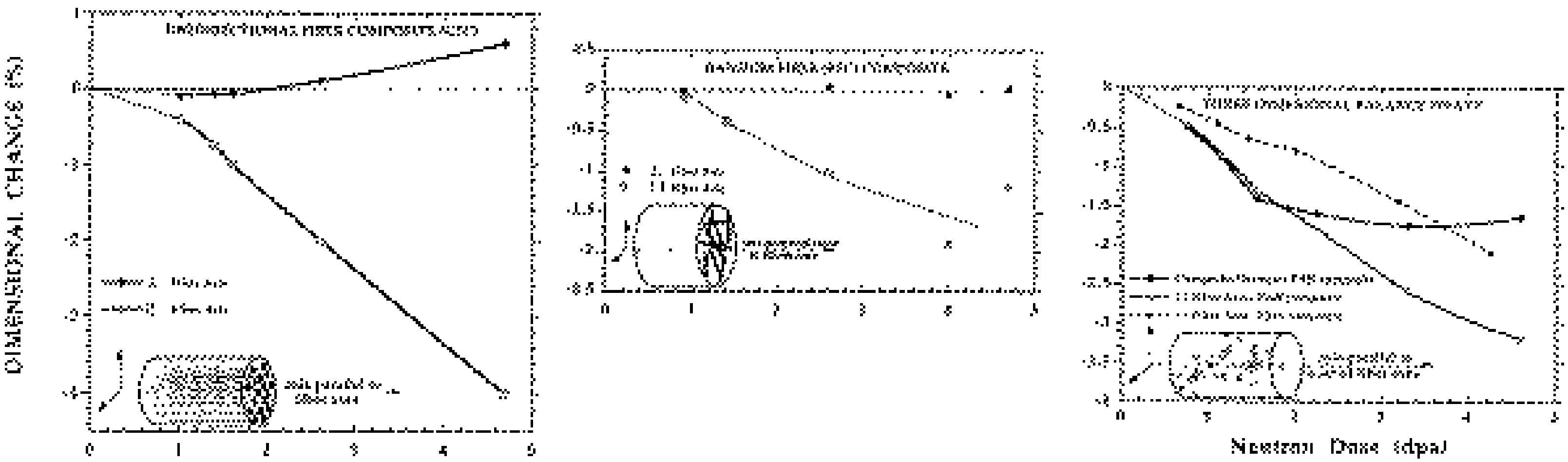


- Lifetime from ~20-35DPA
- Densification rate ~0.1%/dpa

Neutron irradiation induced dimensional changes for Graphnol N3M. Note, radial dimensional changes exceed axial changes due to textural effects.

T.D. Burchell, W.P. Eatherly, The effects of radiation damage on the properties of Graphnol N3M, J. Nucl. Mater., 179-181, 205-208 (1991)

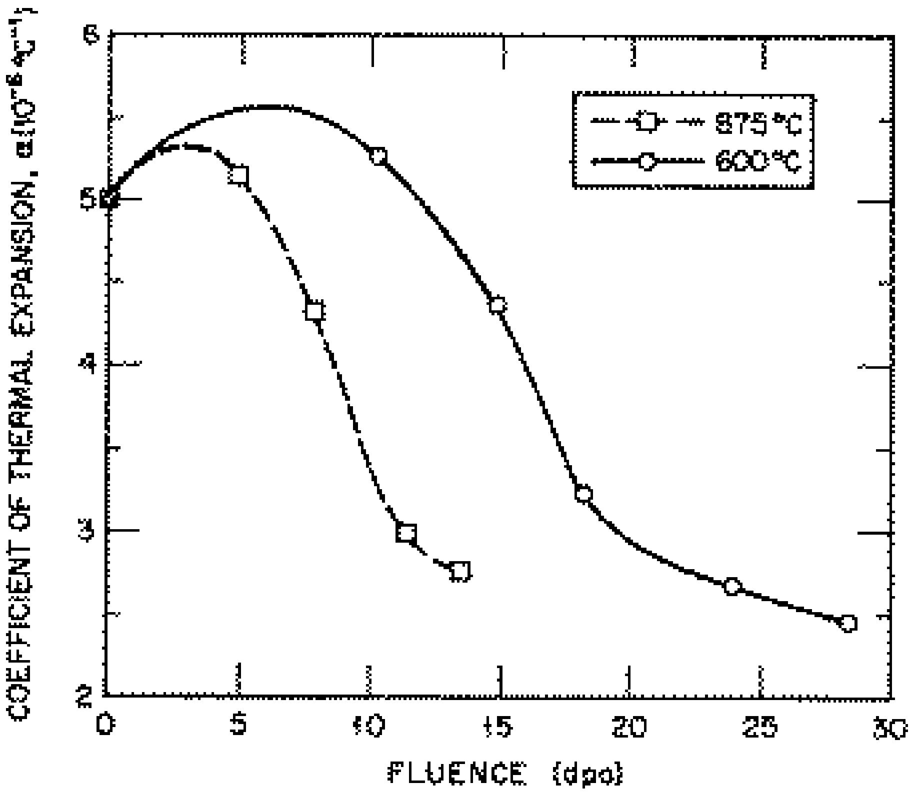
Densification in CFC's



- Behavior depends on weave
  - Anisotropy effects are significant
- Densification rate ~1%/dpa

T.D. Burchell, Radiation Damage in Carbon Materials, In Physical Processes of the Interaction of Fusion Plasmas with Solids, Academic Press, 341 382 (1996)

Graphite Thermal Expansion

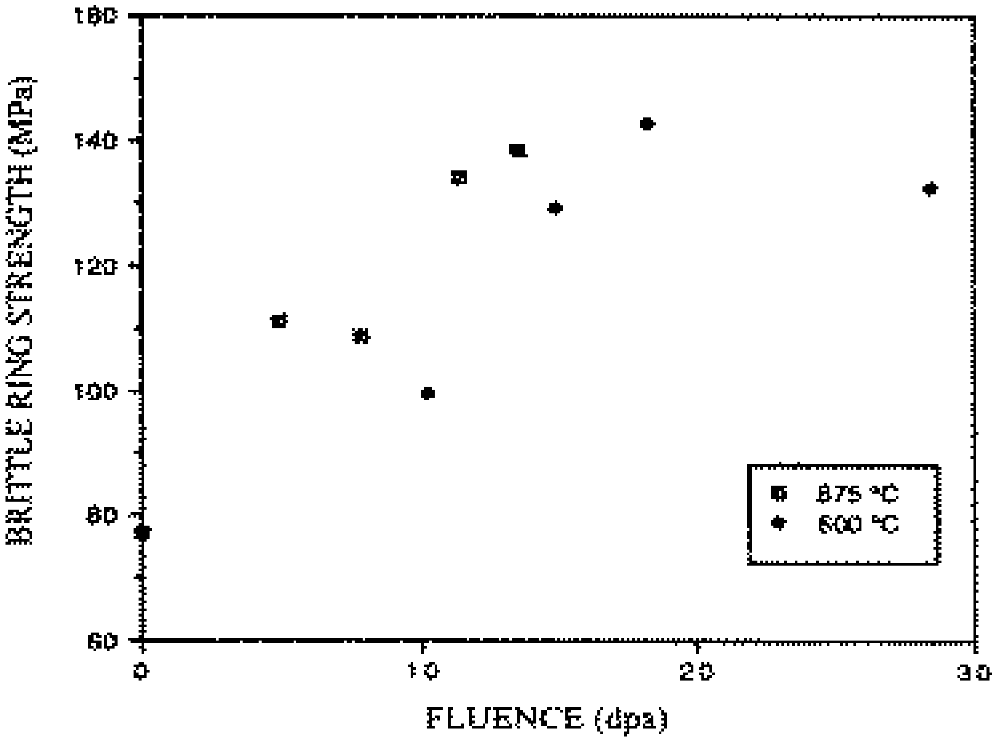


- Initial increase in CTE followed by reduction by a factor of ~2

Neutron irradiation induced changes in the coeficient of thermal expansion of GraphNOL N3M.

T.D. Burchell, W.P. Eatherly, The effects of radiation damage on the properties of Graphnol N3M, J. Nucl. Mater., 179-181, 205-208 (1991)

Graphite Irradiation Strength

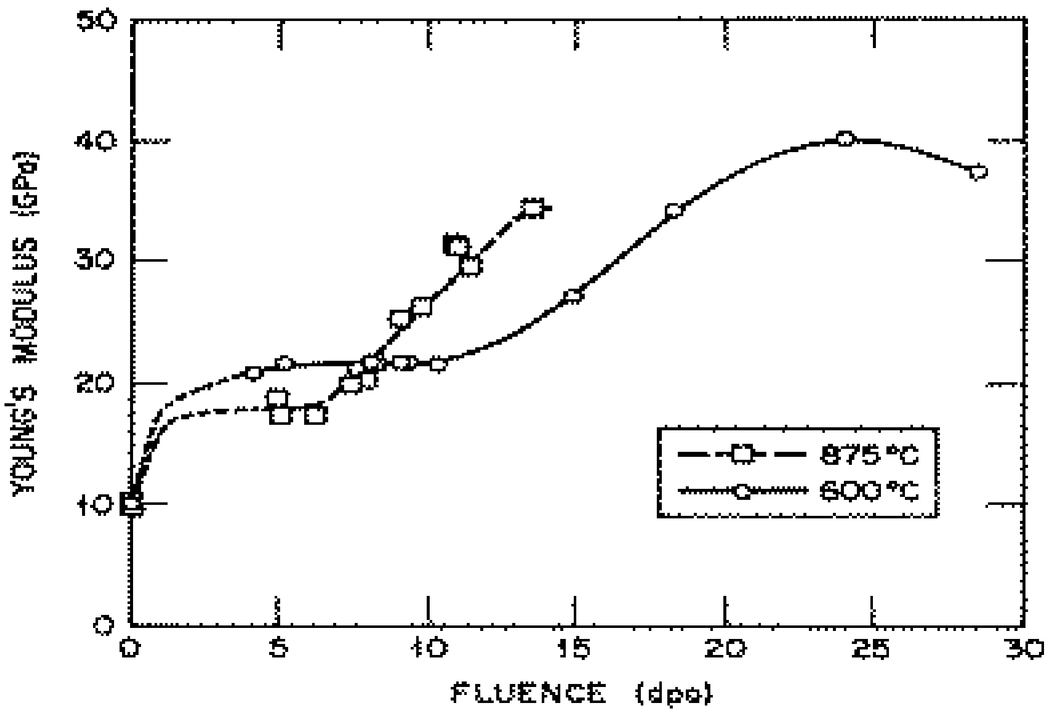


- Strength increases with fluence
- Probable peak at point of greatest densification

Neutron irradiation induced strength changes in Graphnol N3M.

T.D. Burchell, W.P. Eatherly, The effects of radiation damage on the properties of Graphnol N3M, J. Nucl. Mater., 179-181, 205-208 (1991)

Graphite Young’s Modulus

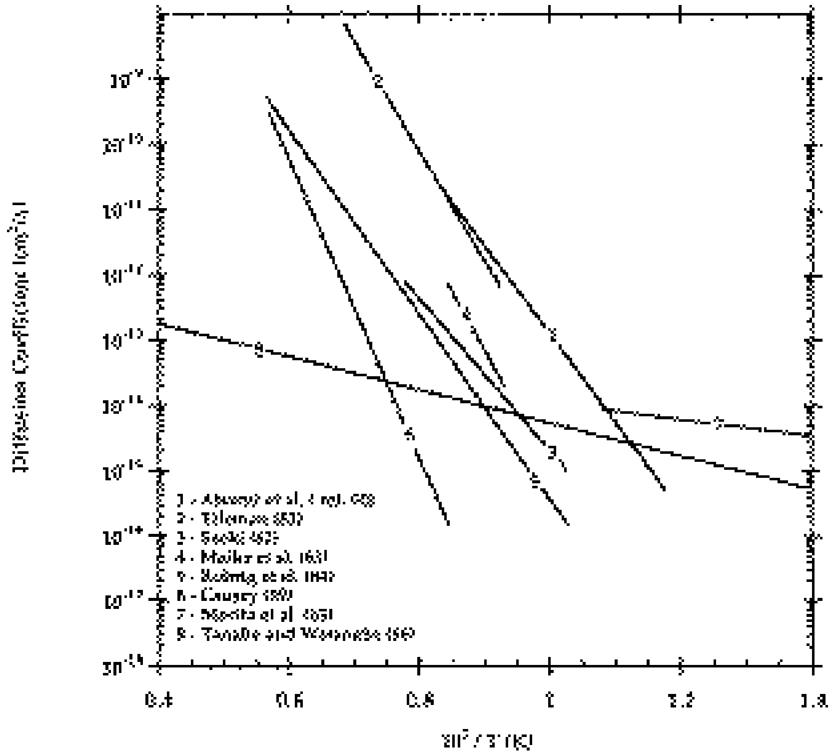


- Young’s modulus shows large increases with fluence
- Probable peak at point of greatest densification

Neutron irradiation induced Young’s modulus changes in Graphnol N3M at irradiation temperatures of 600 and 875 C.

T.D. Burchell, W.P. Eatherly, The effects of radiation damage on the properties of Graphnol N3M, J. Nucl. Mater., 179-181, 205-208 (1991)

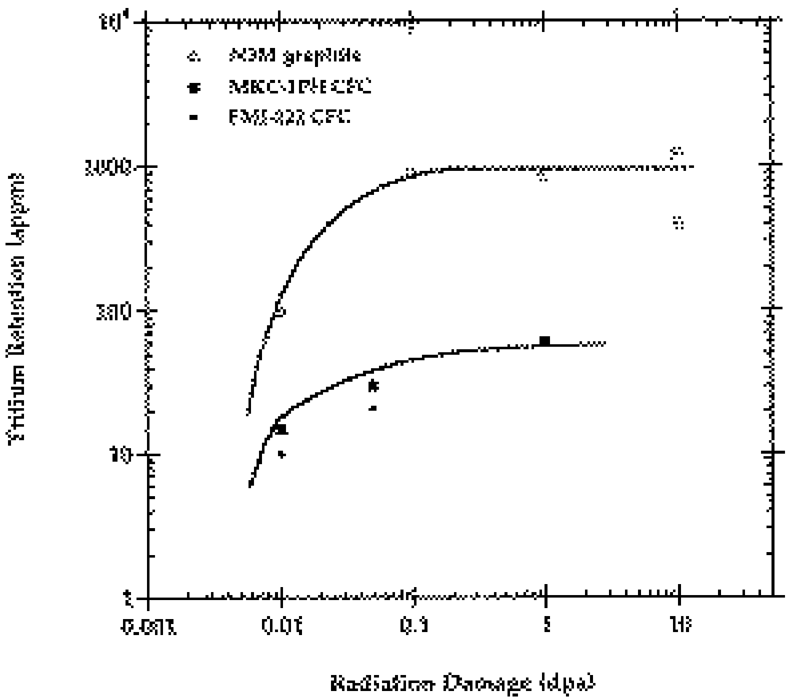
H Diffusion in Graphite



- H diffusion rates vary of several orders of magnitude for different graphites

L.L. Snead, Fusion Energy Applications, Carbon Materials for Advanced Technologies, Pergamon Press, (1999)

Tritium Retention



- Irradiation increases tritium retention
- CFC's show lower retention by a factor of ~20
- Effect saturates at ~1 dpa

Tritium retention as a function of neutron damage in graphite and graphite composite.

R.A. Causey, et al., Physica Scripta, T64, 32-35 (1996)

Graphite and CFC Summary

- Graphites and CFC’s are unique in the numerous changes in properties that occur with neutron radiation
- For IFE, a specific CFC needs to be identified, and all properties should be evaluated self-consistently
- Other options should be considered, e.g. graphite tiles on metal structure
- Surface properties need be addressed in the future