

Irradiated Materials

(Non-proprietary Version)

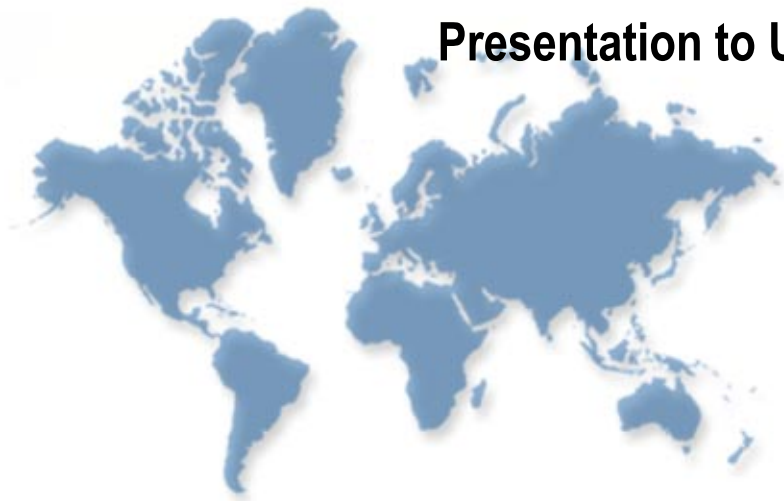
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Washington DC

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Outline

- **Components affected**
- **Response to irradiation**
- **Monitoring / Inspection**
- **Assumed failures / consequences**
- **Significance of failure**
- **Summary**

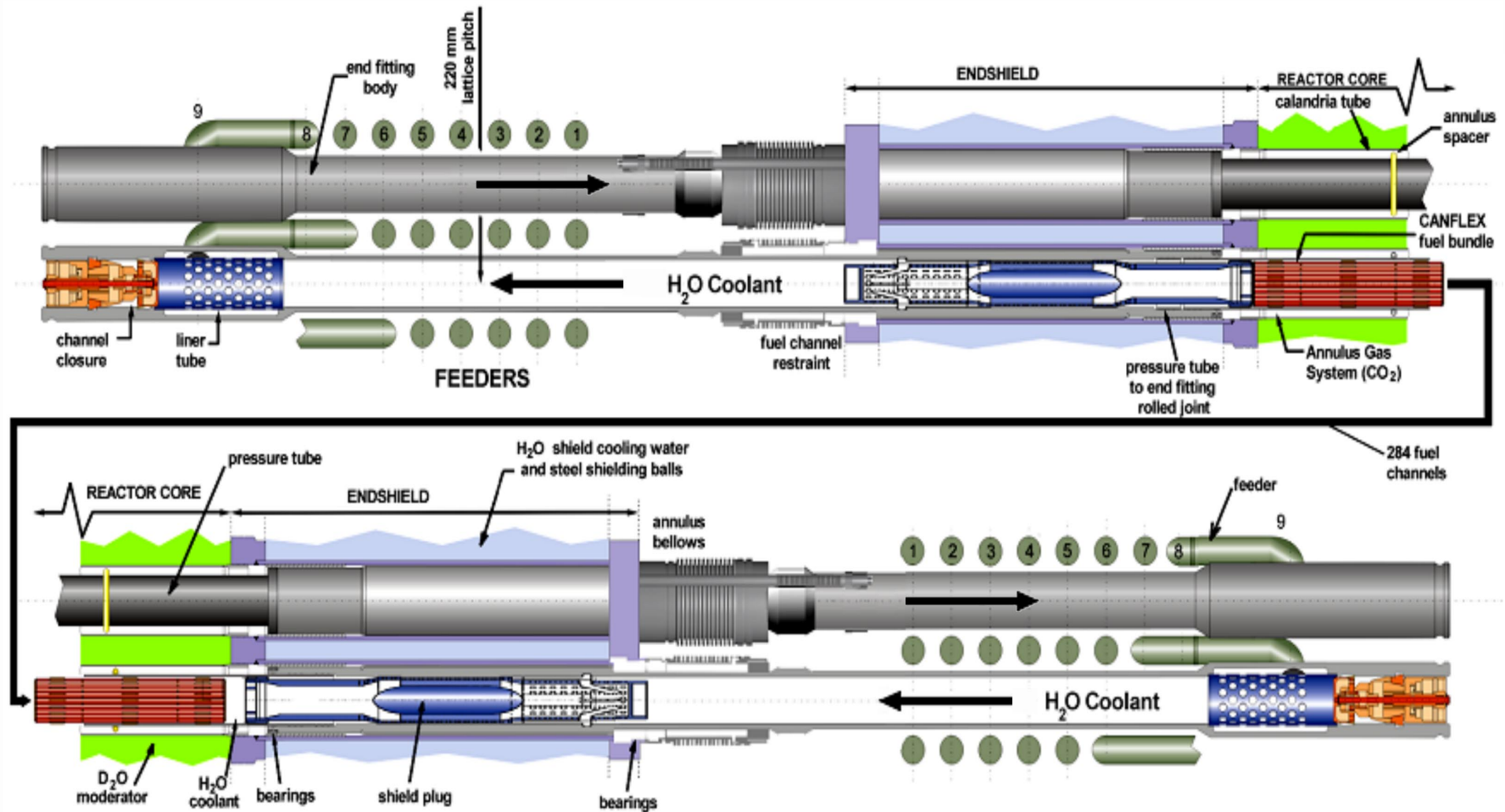


Components Affected

- **Class 1 pressure boundary components**
 - Pressure tube
 - Inboard end of end fitting
- **Other components not class one pressure boundary**
 - Calandria tubes, calandria vessel, end shields, control rod guide tubes, shut off rod guide tubes



ACR Fuel Channel





Pressure Tube

- **Irradiation–induced changes in microstructure**
 - Neutron bombardment produces vacancies and interstitials in lattice
 - Migration of these to other internal structures produces a variety of effects
 - Rapid formation of small dislocation loops aligned on specific planes
 - Precipitation of Nb within alpha Zr phase
 - Development of dislocation substructure
 - Local chemical changes
 - Fe moves from beta phase to alpha boundaries
- **Microstructural changes produce macroscopic property changes**

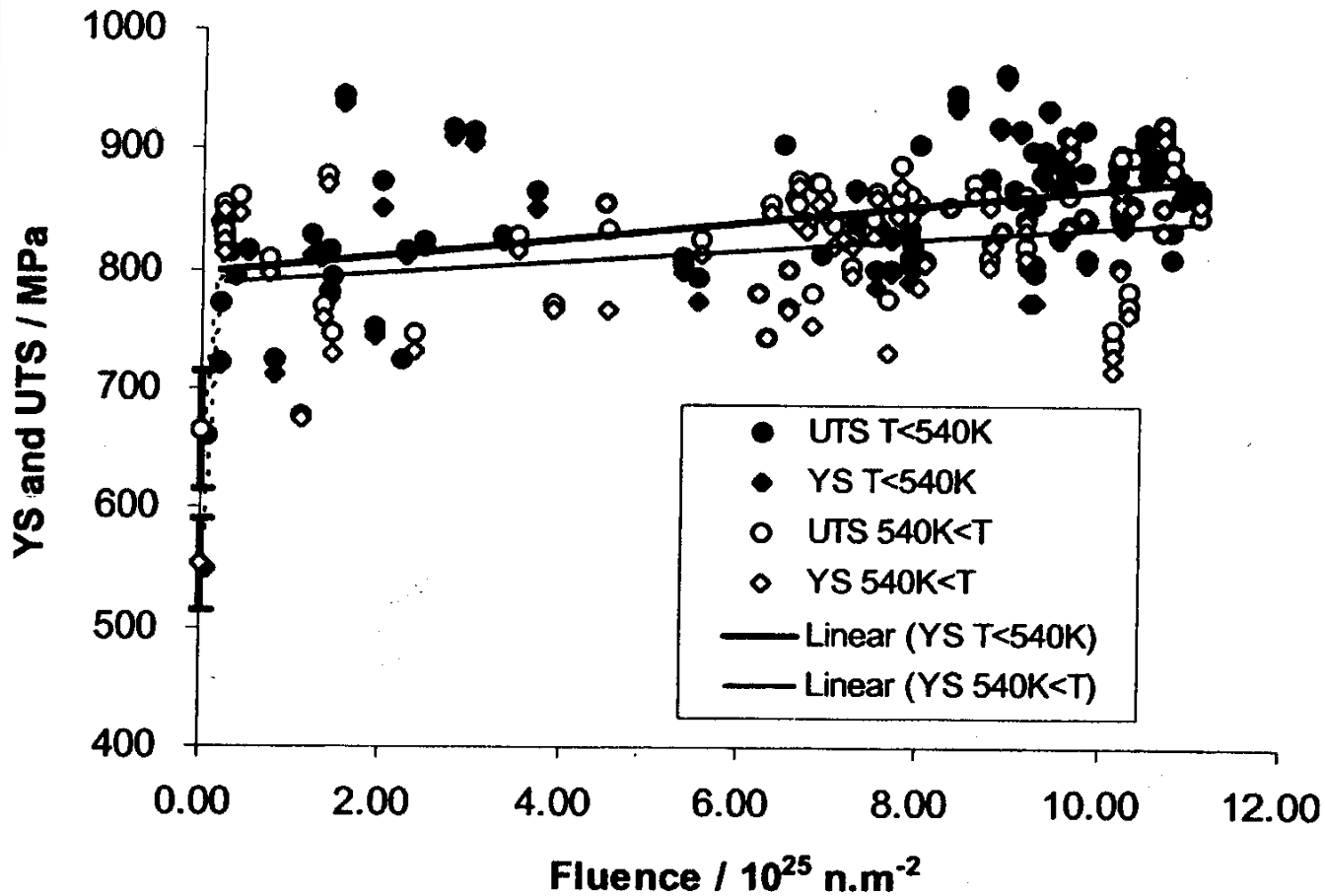


Pressure Tube

- **Effects**
 - **Strength increase**



Strength (250 °C) Increase



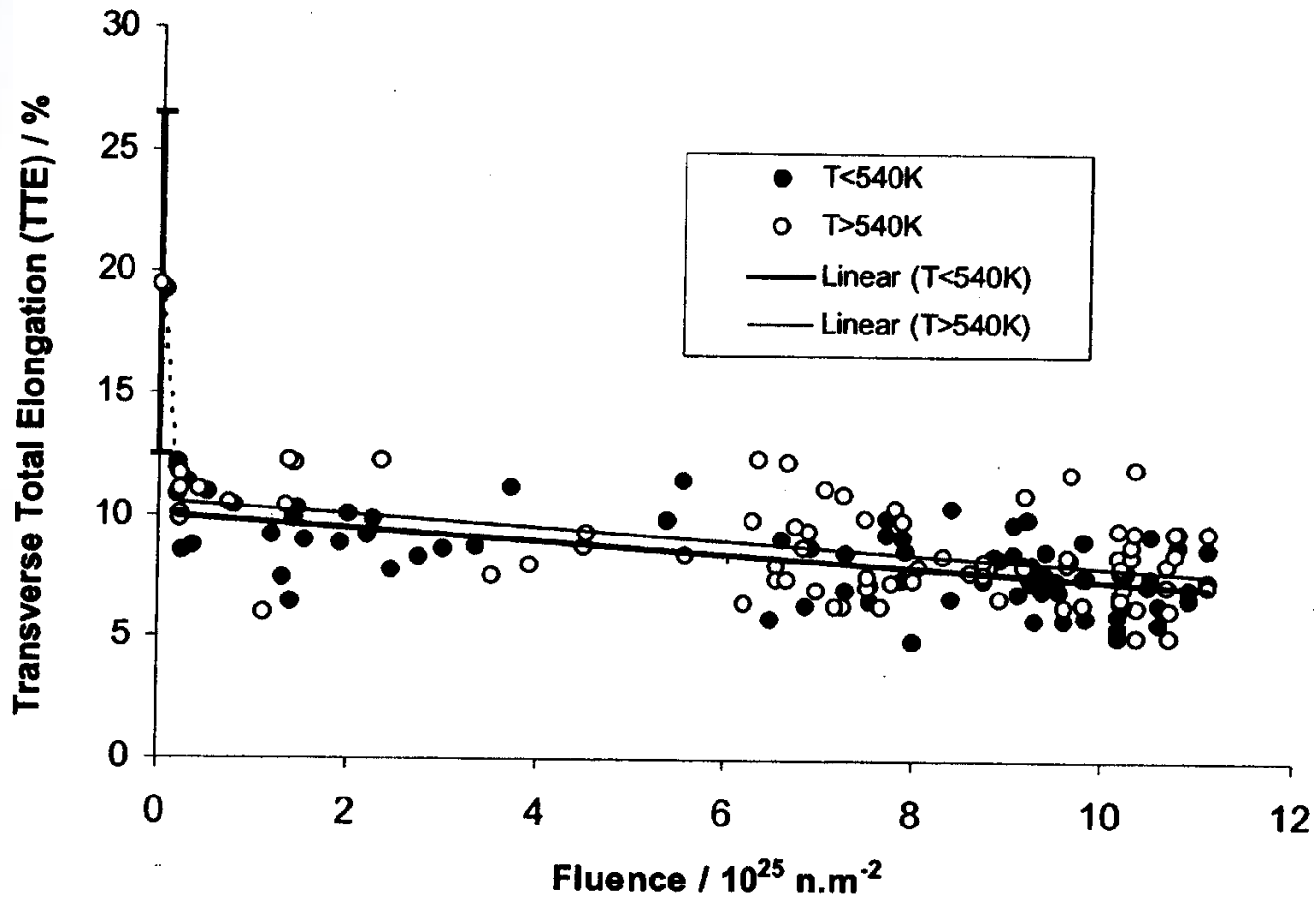


Pressure Tube

- **Effects**
 - Strength increase
 - **Ductility decrease**



Ductility Decrease





Pressure Tube

- **Effects**
 - Strength increase
 - Ductility decrease
 - **Fracture toughness decrease**



Fracture Toughness

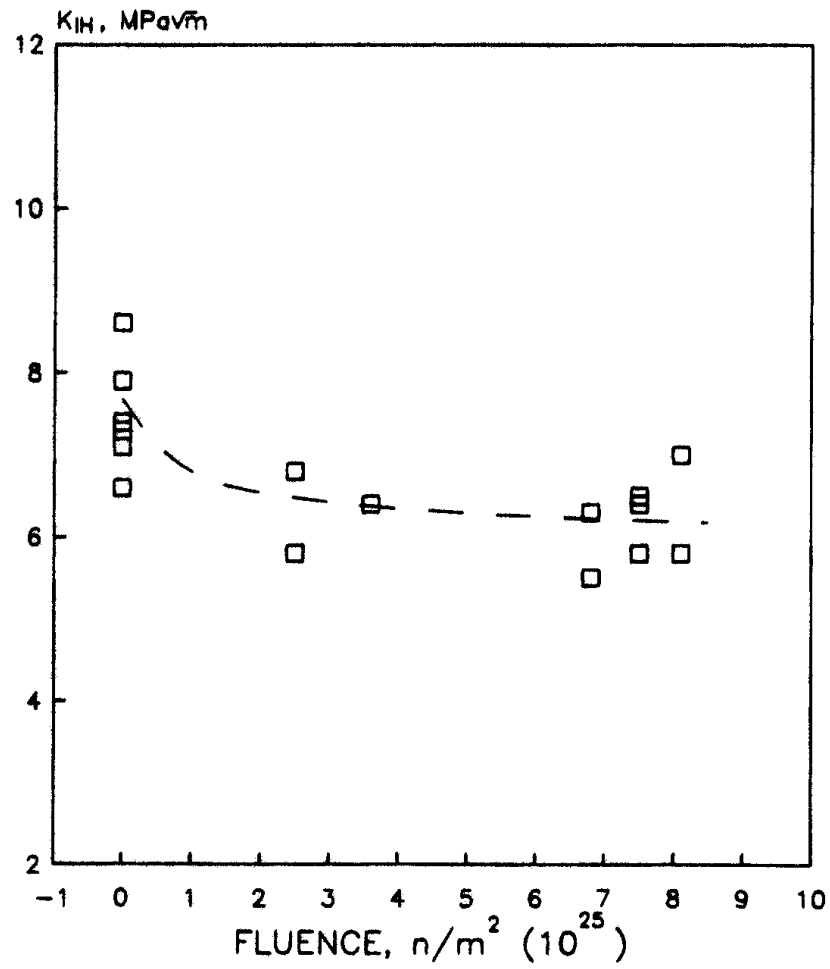


Pressure Tube

- **Effects of irradiation**
 - Strength increase
 - Ductility decrease
 - Fracture toughness decrease
 - **K_{1H} decrease**



K_{1H}





Pressure Tube

- **Effects of irradiation**
 - Strength increase
 - Ductility decrease
 - Fracture toughness decrease
 - K_{1H} decrease
 - **DHC crack growth rate**
 - **Increase under hydrogen saturated conditions**
 - **Decrease possible under some unsaturated conditions due to increased solubility of hydrogen in irradiated material**



DHC Growth Rate at 240°C



Pressure Tube

- **Effects of irradiation**
 - Strength increase
 - Ductility decrease
 - Fracture toughness decrease
 - K_{1H} decrease
 - DHC crack growth rate
 - Increase under hydrogen saturated conditions
 - Decrease possible under some unsaturated conditions due to increased solubility of hydrogen in irradiated material
 - **Dimensional change**
 - Length increase
 - Diameter increase
 - Wall thickness decrease
 - Sag



Measured & Predicted Elongation in CANDU 6 Units



Effect on Corrosion



Effect on Corrosion

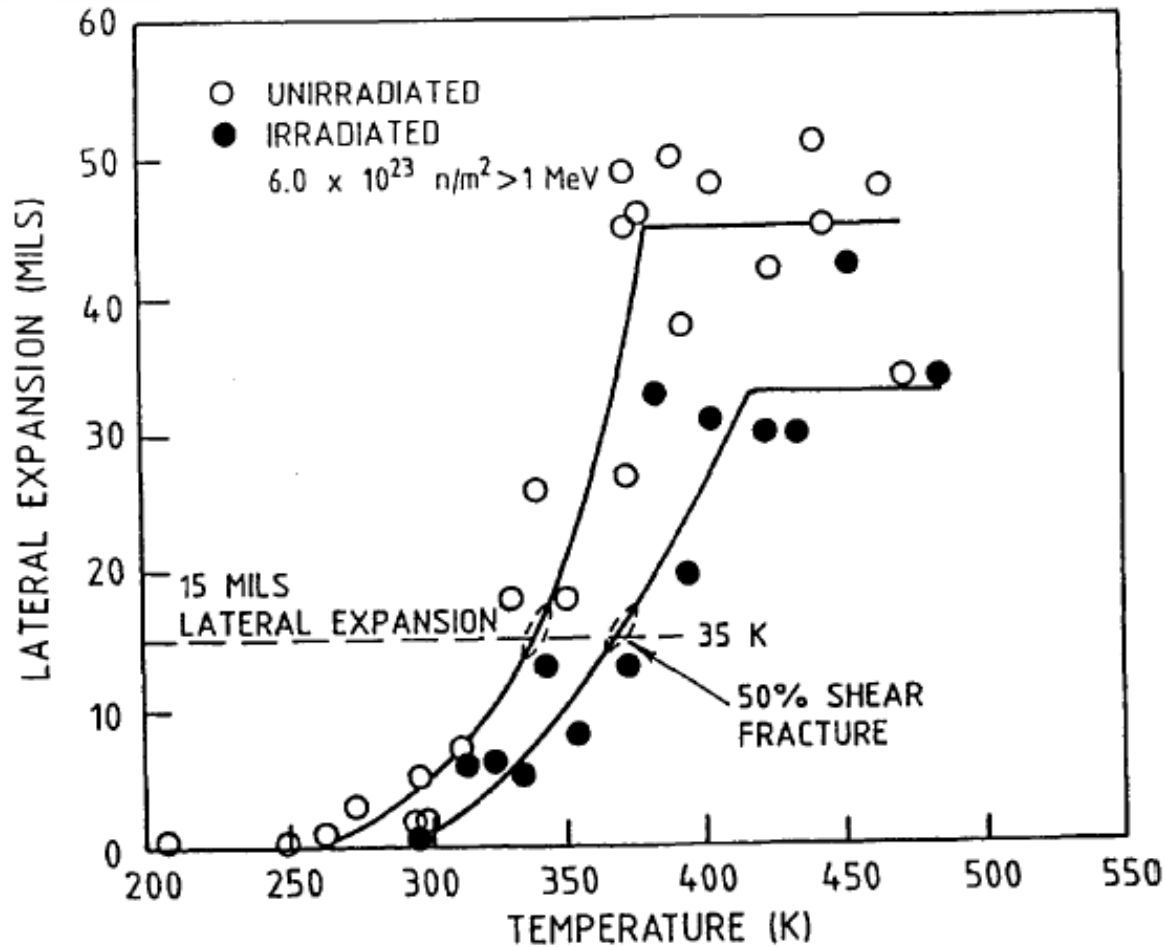


End Fitting

- **Effect of irradiation**
 - Increase in fracture toughness transition temperature



Effect of Irradiation on End Fitting Fracture





Monitoring and Inspection

- **ISI Program**
 - Including surveillance removal of pressure tubes
 - Generic effects
- **Annulus gas leak detection system**
 - Defense-in-depth in case DHC occurs from an unknown flaw during operation



Assumed Failures and Consequences

- Complete list to be provided
- Includes:
 - Pressure tube rupture
 - Rolled Joint failure



Significance of the Failure

- **Assessed in safety analysis**
- **Additional information to be provided**



Summary

- **Irradiation effects in CANDU are well characterized**
- **Materials maintain adequate properties to ensure channel integrity throughout the design life**
- **Need to extend data base to higher temperature conditions**



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