ACR Fuel Channel Fitness for Service

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Overall Objectives

The design process for CANDU fuel channels includes ensuring their pressure tubes will remain fit-for-service throughout their design life. This primarily involves ensuring:

- the maximum deformation of the pressure tube (elongation, diameter increase, wall thickness reduction and sag) that could occur at the end of its design life can be accommodated and
- there is adequate protection from failure due to overloading, crack initiation and unstable fracture.

Design

- Deformation is accommodated primarily by providing adequate allowances for it. To achieve this, it is necessary to have appropriate predictions for a pressure tube for the maximum deformation that can occur at the end of the design life.
- Protection from overloading is demonstrated by showing the maximum stress that could exist in a pressure tube has an adequate margin (different depending on service level) with respect to the lower bound tensile properties for pressure tubes. This defines the minimum allowable pressure tube wall thickness.

Design

- Protection from fatigue crack initiation is demonstrated using the standard type of fatigue crack initiation/propagation data. This is not a limiting condition for pressure tubes.
- Protection from unstable fracture is demonstrated by showing that a postulated, conservatively large flaw is stable for all design conditions, including startups/shutdowns, using an adequate margin (different depending on service level) on the lower bound critical crack length, which is determined by the fracture toughness of pressure tubes. This defines a pressure/temperature safe operating envelope for PHTS operation.

Design

In the design of Pressure Tubes (PTs), protection against Delayed Hydride Cracking (DHC) initiation and consequent rupture is ensured by:

- **Having no reportable flaws from manufacturing**
- **Initial (dry) fuel loading does not scratch the surface of PTs**
- **Limiting the sum of tensile stress (from internal pressurization and initial residual) to 67% of tensile stress to initiate DHC as determined in the laboratory on unnotched specimens**
- **No hydrides in PTs when at operating temperature**
- **Leak-Before-Break (LBB)**
  - **Annulus Gas System able to detect leaks from through-wall crack**
  - **Procedure in place to shut down reactor prior to through-wall crack reaching its critical length**

Operation (to Design Life)

Ensure fitness for service through periodic inspection of a pre-selected set of PTs. If reportable flaws are found, these are evaluated based on Fitness for Service Guidelines (FFSG). (An updated version of this exists as a draft CSA N285.8 Standard.)

The FFSG consists of:

- Material Property Data and Derived Values
- Acceptance Criteria and Evaluation Procedures to determine whether :
  - reportable flaws are acceptable for continued service
  - PTs in contact with their CTs are acceptable for continued service
  - generic changes to fracture properties of all PTs in core are acceptable for continued service

Operation (to Design Life)

- **Reportable flaws are evaluated against:**
  - Unstable fracture initiation
  - Plastic collapse
  - Fatigue crack initiation
  - DHC initiation

Summary

- To design pressure tubes and perform fitness for service evaluations, it is necessary to have data describing various material properties and how these are affected by reactor operation. The required data include:
  – Deformation rates
  – Tensile strength
  – Fatigue crack initiation/propagation
  – Critical stress intensity factor at unstable fracture initiation, K_i
  – Fracture toughness and critical crack length
  – Hydrogen/deuterium ingress rate
  – Terminal solid solubility for hydrogen/deuterium
  – Threshold stress intensity factor for DHC initiation from cracks (planar flaws), K_{IH}
  – Threshold stress for DHC initiation at a blunt (volumetric) flaw
  – DHC velocity

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