Fitness for Service Assessment of Pressure Tube Flaws

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Introduction to Pressure Tube Flaws
CANDU Pressure Tubes
Pressure Tube Flaw Types

Flaw Sources
- Debris fretting flaws
- Bearing pad fretting flaws
- Crevice corrosion flaws
- Manufacturing flaws
- Mechanical damage flaws
- Dummy fuel bundle pad fretting flaws
Pressure Tube Flaw Types

Typical debris fretting flaw
Pressure Tube Flaw Types

Typical bearing pad fretting flaws (Burnish Mark)
Pressure Tube Flaw Types

Typical crevice corrosion flaws
Pressure Tube Flaw Types

Manufacturing flaw (Linear Indication)
Pressure Tube Flaw Types

Mechanical damage flaw
Pressure Tube Flaw Types

Dummy bundle pad fretting flaw
# Flaw Evaluation Procedures Overview

<table>
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<tr>
<th>Flaw Type</th>
<th>Planar Evaluation</th>
<th>Volumetric Evaluation</th>
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<tr>
<td>Debris fretting flaw</td>
<td><img src="image1" alt="Planar Evaluation" /></td>
<td><img src="image2" alt="Volumetric Evaluation" /></td>
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<td></td>
<td><img src="image3" alt="Planar Evaluation" /></td>
<td><img src="image4" alt="Volumetric Evaluation" /></td>
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<tr>
<td>Bearing pad fretting flaw</td>
<td><img src="image5" alt="Planar Evaluation" /></td>
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<td><img src="image7" alt="Planar Evaluation" /></td>
<td><img src="image8" alt="Volumetric Evaluation" /></td>
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- **Debris fretting flaw**:
  - Axial direction

- **Bearing pad fretting flaw**:
  - Axial direction
Flaw Evaluation Procedures Overview

Deterministic methodology given by CSA Standard N285.8-05

Planar evaluation:
- Postulated growth due to fatigue and Delayed Hydride Cracking (DHC)
- Safety Factors vs. fracture and plastic collapse

Volumetric evaluation:
- DHC initiation, crack initiation due to fatigue, crack initiation due to hydride overload
- Safety Factors vs. plastic collapse

Flaws depths cannot be more than 0.5 x wall thickness
Flaw Assessments in Practice
Flaw Inspection-Assessment Cycle

Channel selection

Re-assess flaws for outage scope-of-work

Inspection Outage

Flaw disposition

Assess newly detected flaws

(Assess replicated flaws)

(Replication)

Re-assess previously detected flaws

(Replication)
Pressure Tube Flaw Assessment Program

- Computer program implementing deterministic flaw assessment procedures of CSA N285.8
- Allows evaluation of hundreds of flaws in a typical flaw assessment
- Development by D. Mok started in mid 1990’s
- Qualified to CSA N286.7
Input data consists only of what is different between inspections:

- Pressure tubes inspected
- Flaws
- Evaluation period
- Operating history (i.e. cooldowns)
All other necessary data is drawn from built-in program databases:

- Fuel channel dimensions
- Reactor configuration
- Rates of elongation, thinning, diametral expansion
- Operating conditions and transients
- Hydrogen uptake models
- Material properties

The databases are regularly updated to reflect current conditions.
For channels that have been previously inspected before

Perform re-assessment of flaws in those channels to determine whether the channels should be re-inspected
Flaw Assessment Applications
– Inspection Outages

- All flaws detected during inspection outage must be assessed as acceptable **prior to unit restart**
- All flaws detected in previous outages are also re-assessed
- The assessments are submitted as part of the component disposition package
For limiting flaws, additional inspection information is often required, e.g.:

- Local wall thickness, tube diameter measurements
- Flaw depth profiles
- Replication – to obtain detailed flaw geometry
Flaw Replication

Obtain detailed geometry allowing less conservative analyses
Replica quality examinations performed in real time
Flaw Assessment Examples
Example #1

Likely caused by fuelling machine ram components lost in the channel

All assessed as planar

IND4, IND6 used orientation

IND6 0.60mm deep

IND5 0.48mm deep

IND4 0.55mm deep
Example #2

Assessed as planar in two parts

Credit for predominantly angular orientation
Example #3

0.35mm deep

0.053mm root radius
Example #4

Debris flaw within a dummy bundle fret
Flaw is mostly outboard of burnish mark
Detailed depth profiles used to build 3D finite element model
Example #6

Incomplete on 4 replication attempts
Assessed as planar using inferred replica depth
Example #7

Debris flaw with secondary feature
Summary

- Pressure tube flaws formed in-service due to interaction of fuel bundles with the PTs

- Flaws assessed as either planar or volumetric

- Assessments to support maintenance planning and assure Fitness-for-Service

- Detailed inspection information enables execution of advanced analyses
Thank you