Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

LBB Applications to CANDU Piping

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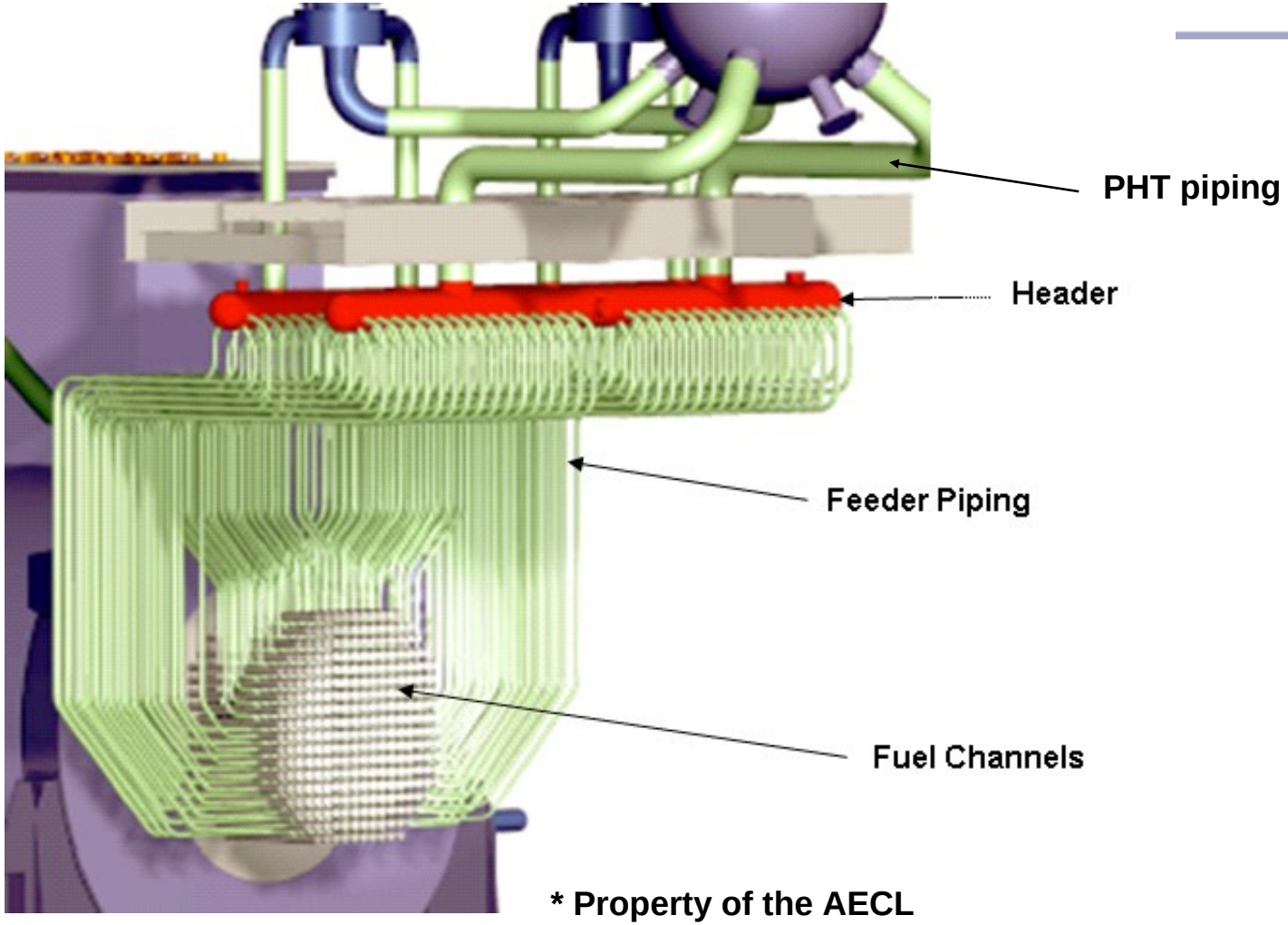
LBB Applications

- **To address dynamic effects of postulated pipe break (for new constructions or life extension)**
- **To support fitness for service assessment of degraded components (of operating plants)**

CANDU Piping System (Schematic)



*** Property of the AECL**

I. LBB Application to address dynamic effects of postulated pipe break

- **LBB application for new construction**
  - **In 1980's, the LBB was accepted for large diameter piping (larger than 20 inches) of PHT piping at Darlington NGS to eliminate the requirement for pipe whip restraints**
  - **SA-106 Gr.B Pipes and SA-105 fittings**
  - **Consistence with NUREG 1061, Vol.3**
  - **Enhanced in-service inspection program**

- **Possibility of active degradation mechanisms such as FAC in the LBB applied piping is a concern.**

- **LBB Applications for Life Extension:**
  - **Requested to conform to modern safety standards and practices (Integrated Safety Review).**
  - **Proposed the application of LBB, in lieu of plant modifications, as a means of demonstrating the adequacy of piping systems of existing CANDU plants for postulated pipe rupture.**
  - **Condition assessment for assurance of no active degradation mechanisms, such as IGSCC and FAC, recently discovered in some CANDU piping.**

- **LBB Applications for New Plants**
  - **To smaller size piping up to 6 inches (ACR)**
  - **NUREG 1061, Vol.3, SRP 3.6.3**

II. LBB Applications to support fitness for service assessment of degraded components

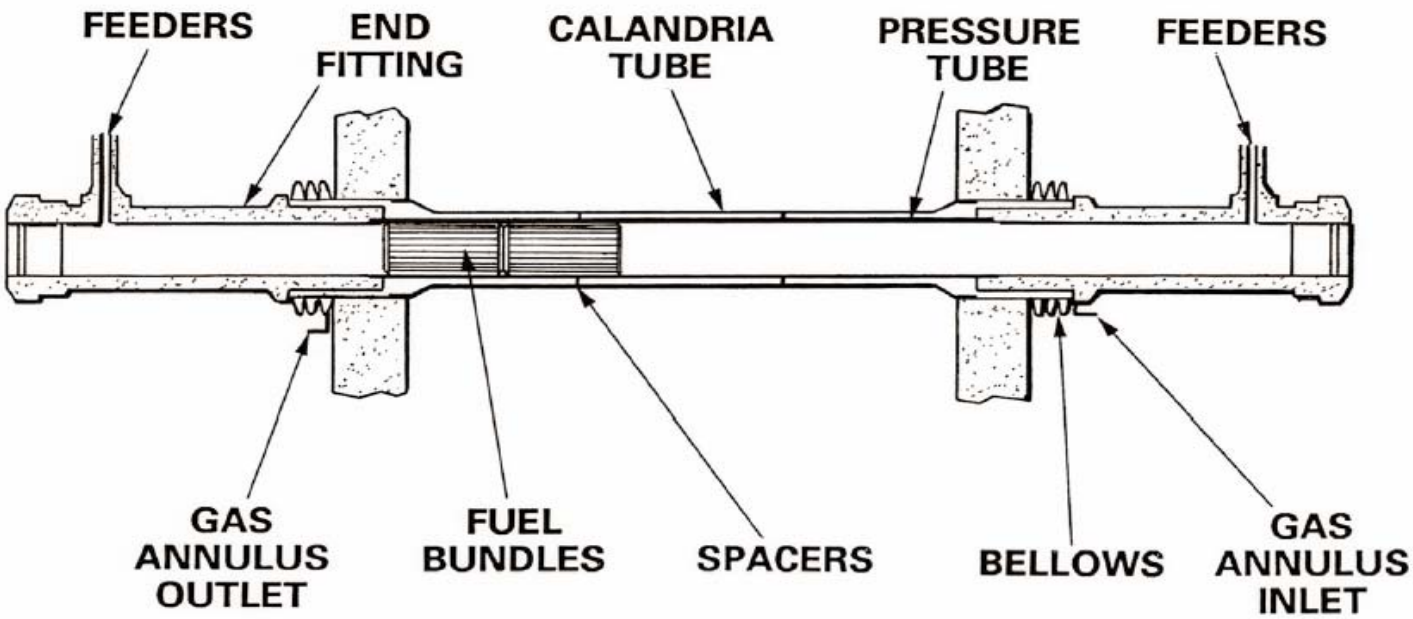
- The LBB assessment is applied for enhancing the defence-in-depth of continued service of components with potential flaws for a specified operating period by demonstrating pipe rupture is not a likely event.
  - Pressure tubes
  - Feeder pipes
  - S/G tubes

Same philosophy, different application

- LBB to address postulated pipe break
  - Design life
  - Postulated crack (screening criteria)
  - Margins on crack sizes & leak rate
- LBB to support fitness for continued service
  - Operating period
  - Actual crack characteristics
  - Margins on the time from leaking to instability
  - Reliable CGR, leak rate, leak detection system and operating procedure are crucial elements

LBB application to Pressure Tubes

- Zr-2.5Nb, 4mm thk, 103mm ID,
- Internal Pressure = 10 MPa
- Temp. = 250 ^{o}C to 300 ^{o}C



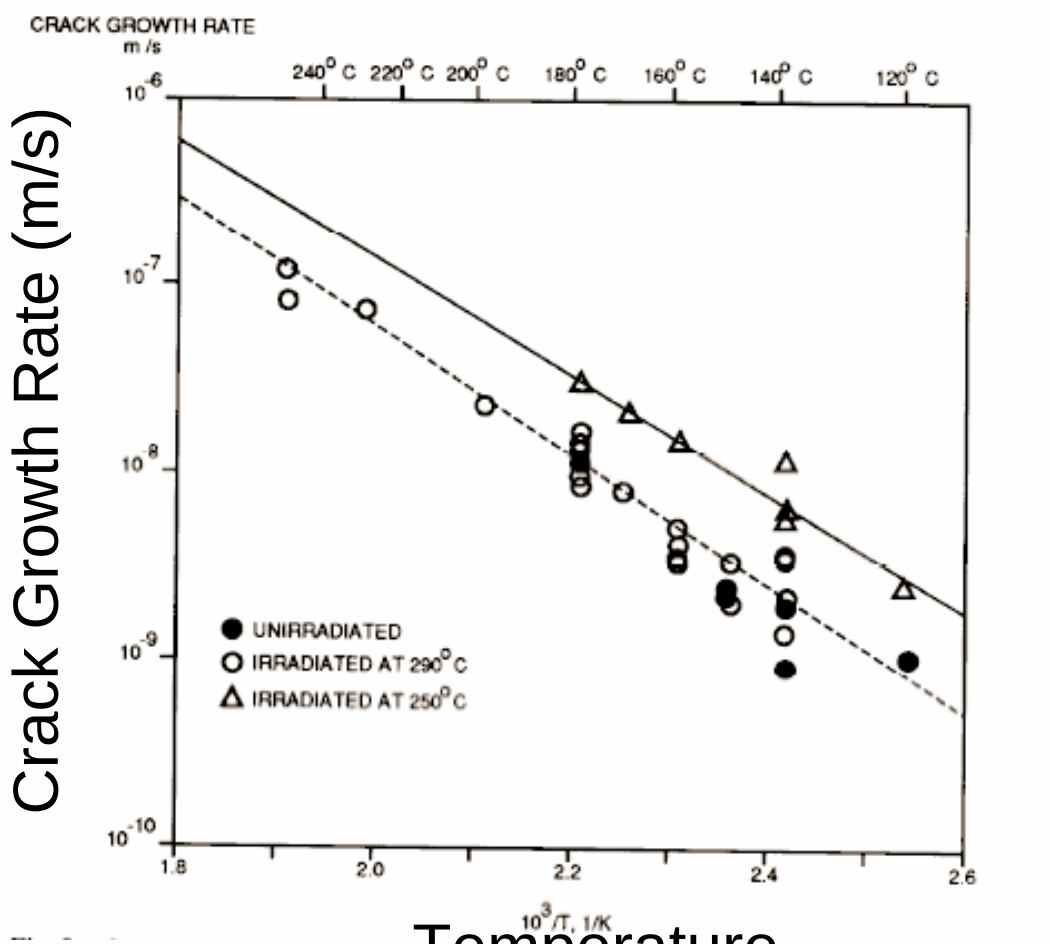
- Susceptible to Delayed Hydride Cracking (DHC)
  - Tensile residual stress produced during rolling process
  - Hydrides
- LBB applied as a defence-in-depth
  - it is required to demonstrate the DHC is not likely
  - even if the flaw is propagated by DHC, unstable rupture should be avoided by LBB

*Methodology**

- Demonstrating that the time available to detect a leak and take actions is much greater than the time required to detect the crack
- LBB Parameters
  - Max. crack length at penetration (Lp)
  - DHC Velocity (V)
  - K_{DHC}
  - Critical Crack Length (CCL)
  - Leak rate
  - Leak detection by AGS

*** Ref. [1] G. D. Moan, et. al, 1990, Leak Before Break in the Pressure Tube of CANDU Reactors", Int. J. Pressure Vessels & Piping, 43, 1-21**

Crack Growth Rate



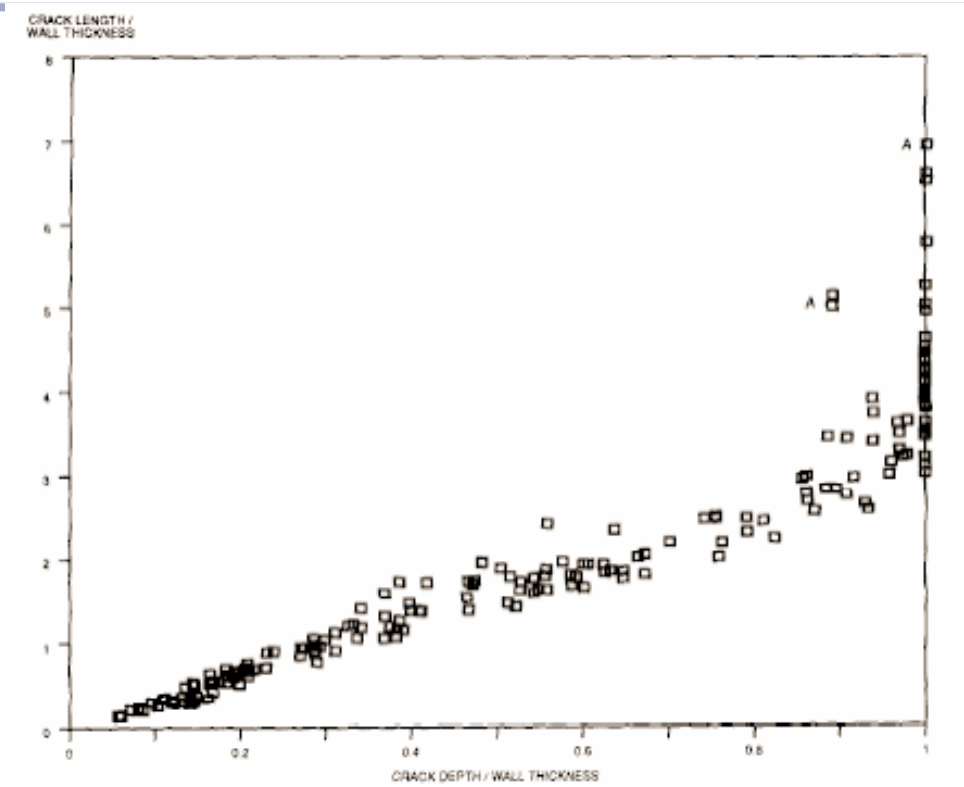
Crack Growth Rate (m/s)

Temperature

*** Fig. 5 of Ref.[1]**

Aspect Ratio

Crack length/wall thickness



Crack depth/wall thickness

Fig. 7 of Ref.[1]

The time available to detect the leak and take action, Ta

Ta = (CCL-Lp)/2V

= 18 hours for

CCL = 50mm

V = 2.7×10^{-7} m/s

Lp = 4W

The time required to detect the leak

❑ Leak rate from actual cracks >> 1 kg/h

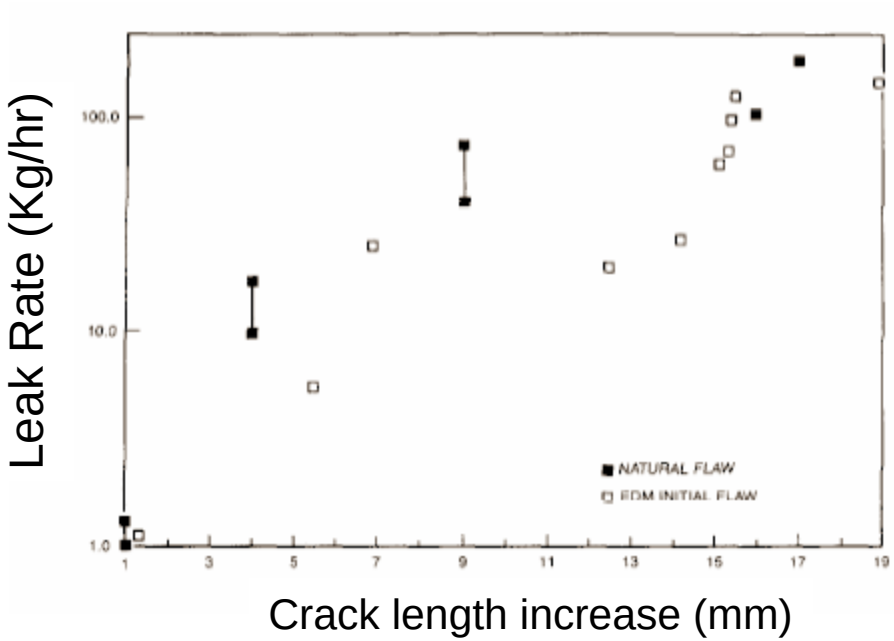


Fig. 12 of Ref.[1]

Effect of crack length increase on the water leak rate measured from cracks in pressure tubes in laboratory tests after tubes were removed from the reactor

The time required to detect the leak (con't)

❑ Leak detection by the AGS

- **Rate of change of dewpoint alarm**
  - **less than 1 hour for the addition of D_2O at a rate of 10 g/hr**
- **Beetle alarm for the presence of liquid**
  - **less than 1 hour for the addition of D_2O at 2.3 Kg/hr**

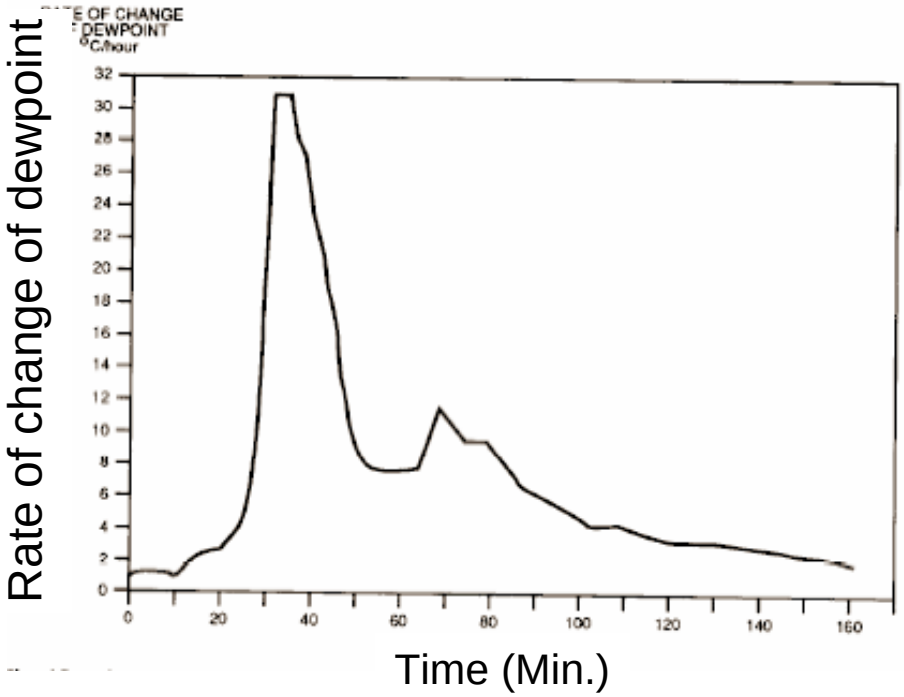


Fig. 15 of Ref.[1]

CCL to Crack growth

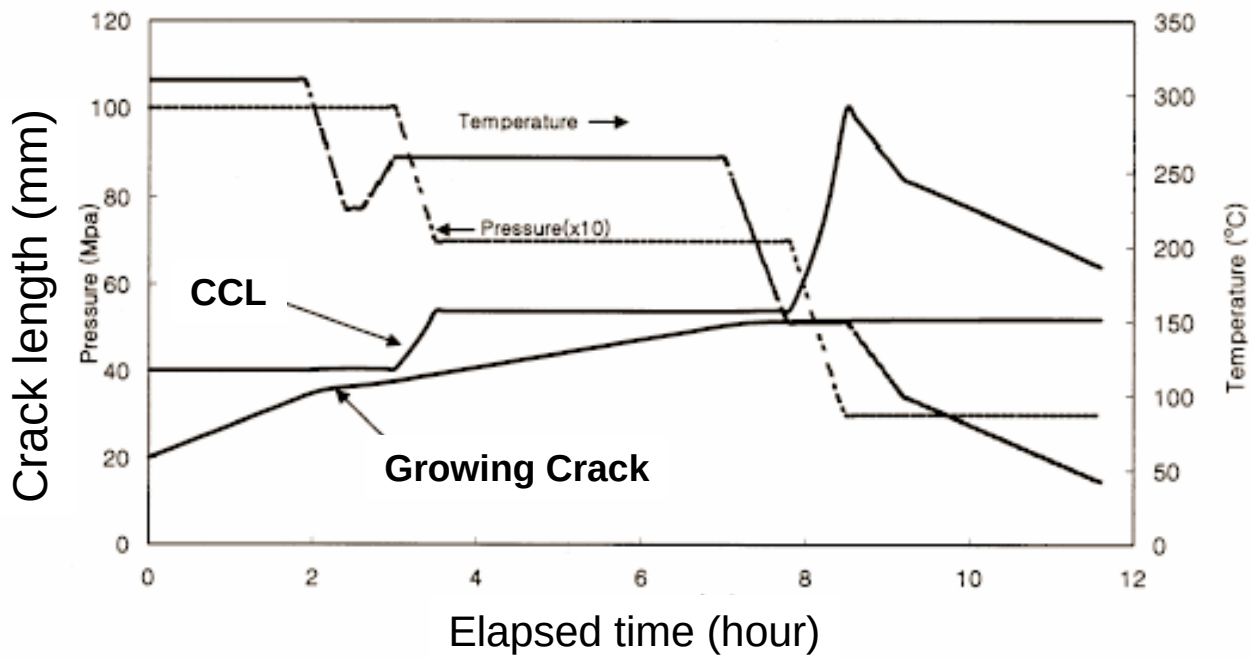


Fig. 9. Results of LBB assessment based on the modified operating procedure.

*** Ref. [2] Y. W. Park and Y. K .Chung, 1999, Leak-Before-Break Assessment of CANDU Pressure Tube Considering Leak Detection Capability", Nuclear Engineering and Design, 191, 205-216**

Issues

- Possibility of longer crack
  - due to through wall thermal gradients preventing crack growth in the radial direction while axial crack growth continues
- Degradation of margins
  - deterioration in fracture toughness due to hydrogen/deuterium pickup
- Stability of part-through wall crack

Feeder pipes

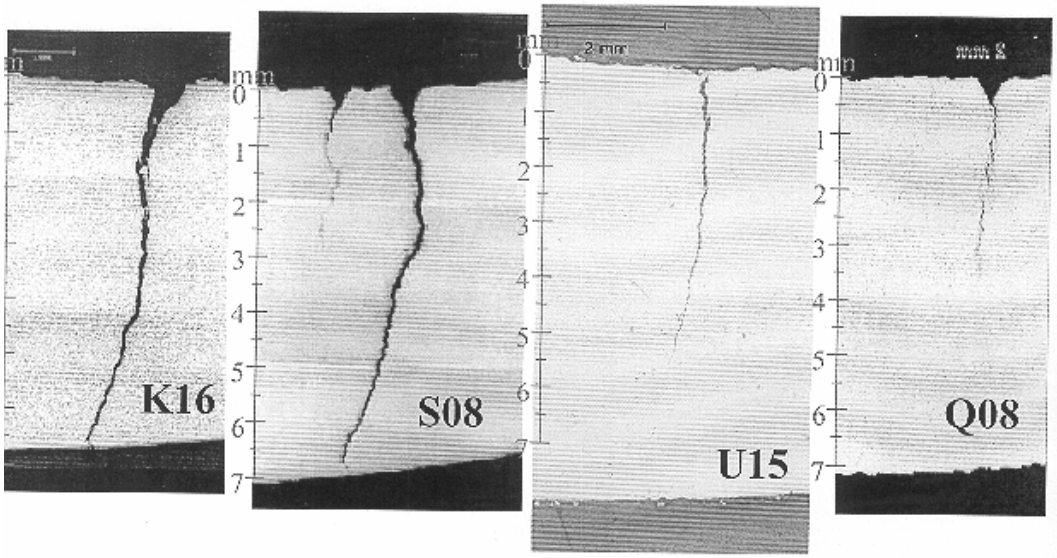
- 380~480 inlets/outlets
- 1.5 ~ 3.5” NPS 80
- Carbon Steel, SA-106, Gr.B
- Bend or Fitting
- Pressure: 1,475 - 1,550 Psig
- Temperature: 515 - 585 ^{o}F

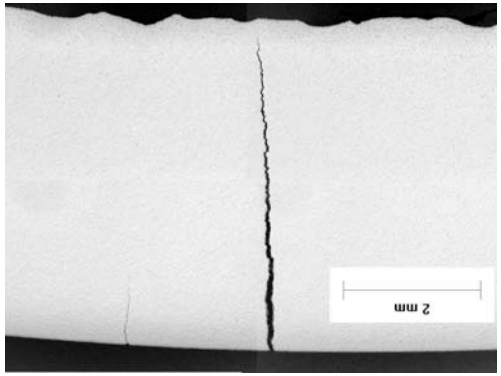
- Degradation Mechanisms
  - IGSCC/LTCC
  - FAC Wall Thinning

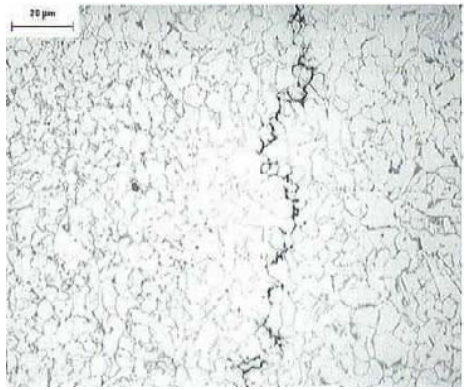
Cracking history

- **Bend Cracking**
  - **13 confirmed cases of feeder cracking in bends at the PLGS**
  - **Of these, 2 cracks went through-wall resulting in leaks in 1996 and 2001**
    - **Reactor was shutdown before the cracks reached critical sizes.**
- **Weld Cracking**
  - **1 leaking crack at a feeder repaired field weld at Gentilly-2 station**

Metallographic Images of Feeder Cracks







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Cracking mechanism

- **IG stress corrosion cracking caused by exposure to mildly oxidizing hot coolant (Inside surface cracking)**
- **Low temperature creep cracking exacerbated by hydrogen (inside and outside surface cracking)**
- **One of Possible Causes: *Residual stress produced during bending process***

Leak rate history

- Bend cracking
  - 20~37 days from when the crack first penetrate the all until the leak rate increases to 12kg/hr
  - 5~20 days for the leak rate increase from 2kg/hr to 20kg/hr
- Repaired weld cracking
  - < 3kg/hr
- Shutdown leakage limit: 20kg/hr

Bases of continued operation

- ❑ **Prevention of leakage no matter how small the leak may be**
- ❑ **Flaws to be detected by ISI and detected flaws to be repaired/replaced**
- ❑ **Full scope inspection upon discovery of cracks**
- ❑ **Assessment of risk increment (del CDF) associated with feeder degradation**

➢ **Issue: Capability of ISI**

LBB application

- Licensee claimed the applicability of the LBB, at least as a contributor to defense in depth, for the demonstration of the fitness for service of feeder pipes
- Issues:
  - Long surface crack
  - Uncertain crack growth rate
  - Axial crack in carbon steel pipe bends
  - Tight crack morphology
  - Material issues (cyclic load effect, dynamic strain ageing, toughness degradation)
  - Sensitivity and diversity of leak detection system
  - Plant operating procedures based on LBB assessment

Regulatory Position (under consideration)

- Detected service induced cracks shall be repaired.
- Inspection scope shall be expanded upon discovery of the cracks.
- Limitations in ISI capability and mechanistic understanding of the cracking shall be addressed:
  - It shall be demonstrated that a pipe break is an unlikely event even if undetected crack could grow through wall during the operating period :
    - Actual crack characteristics
    - Margins on the time from leaking to instability
    - Reliable CGR, leak rate, leak detection system and operating procedure are crucial elements