Structural Integrity Assessments of Class 1 CANDU Components

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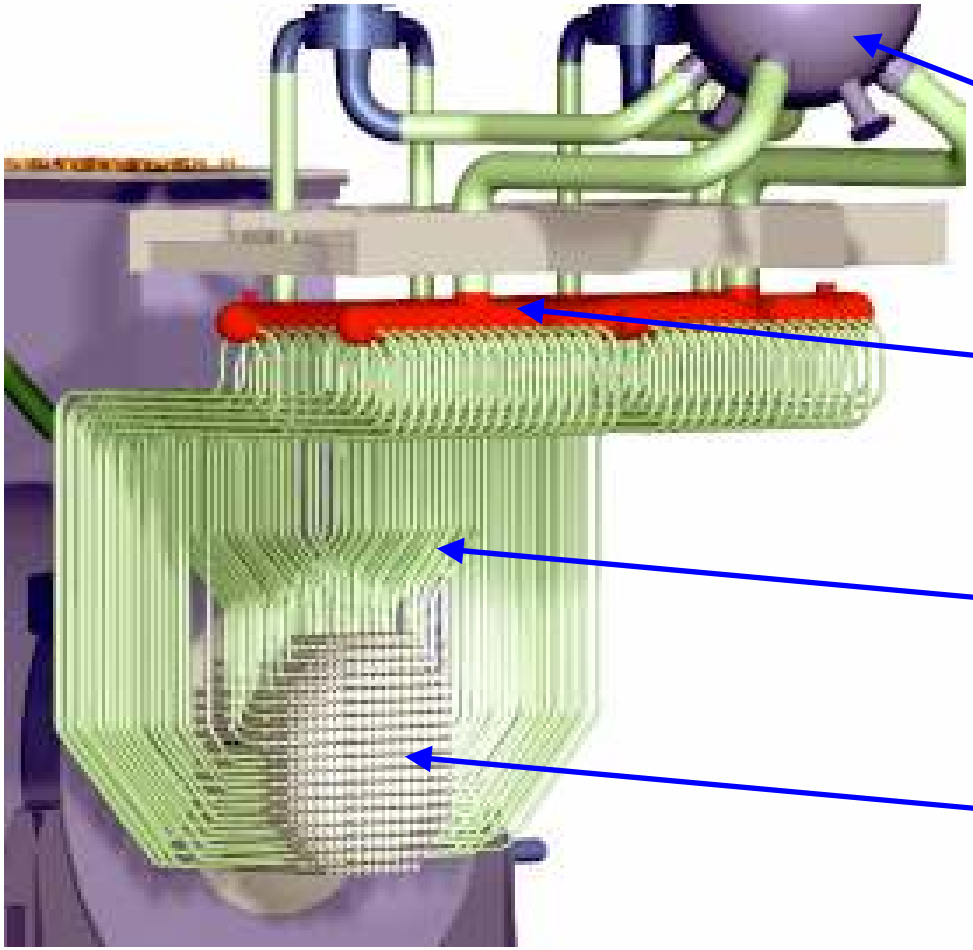
AECL EACL

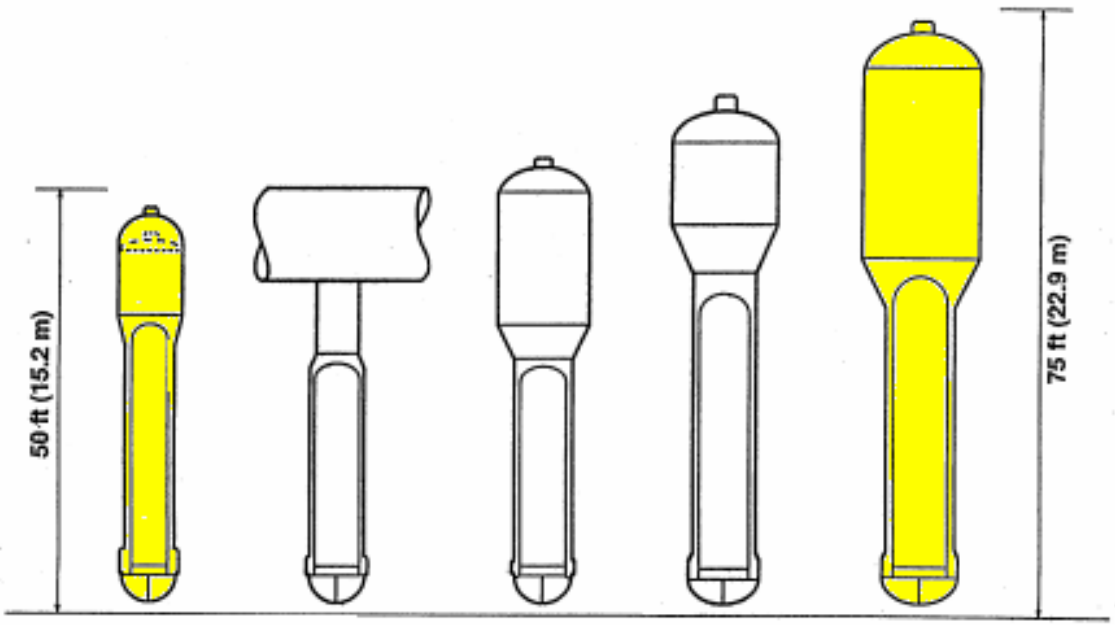
Outline

- Observed Degradations
  - Steam Generator Tubing
  - Feeder Piping
- Fitness-for-Service Guidelines
- Structural Integrity Assessments
  - Material Characterizations
  - Steam Generator Tube Testing Project (SGTTP)
  - Feeder Bend Testing Project (FBTP)
  - Advanced Finite Element Analysis
- Conclusions

Piping in CANDU ® Reactor



Steam Generators in CANDU

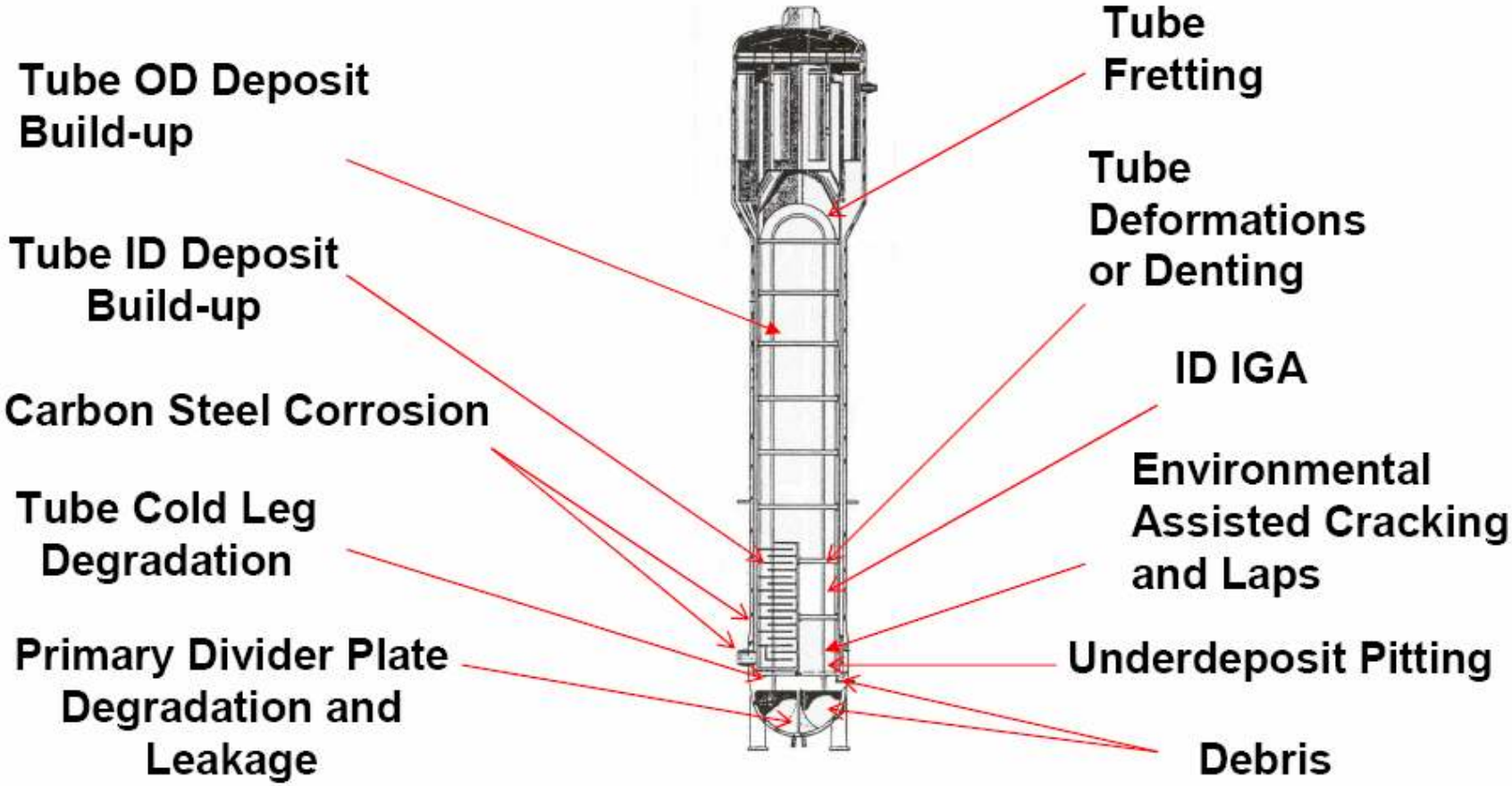


	PICKERING A &B	BRUCE A	BRUCE B	CANDU 6 (GENTILLY 2)	DARLINGTON
SG/UNIT	12	8	8	4	4
UNIT OUTPUT (MWe)	515	760	840	638	880

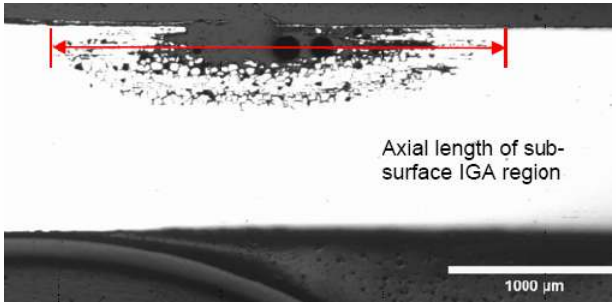
M400 I600 I600 I800 I800

0.5-inch 5/8-inch

Degradations in Pickering A S.G.

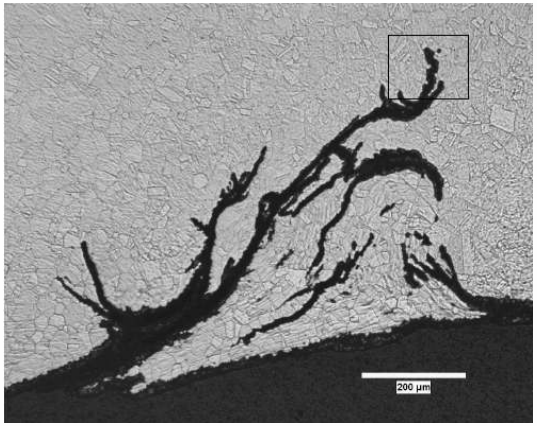


Degradations of Monel 400 SG Tubes

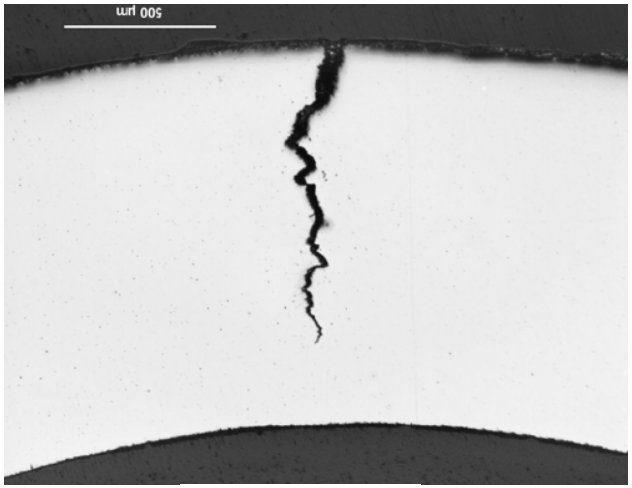


Inter Granular Attack

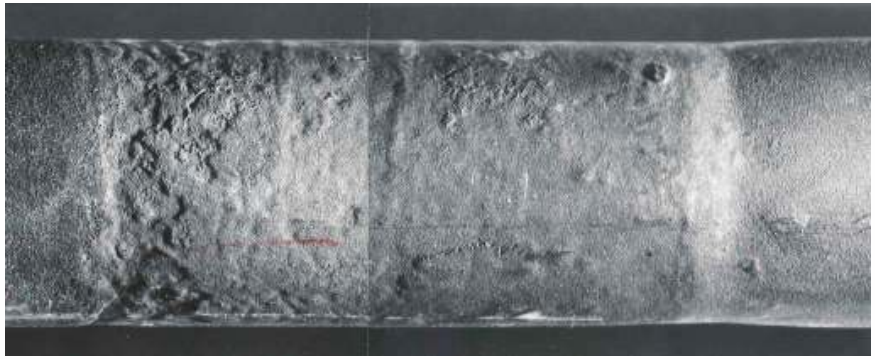
Pitting



Inner Diameter Lap

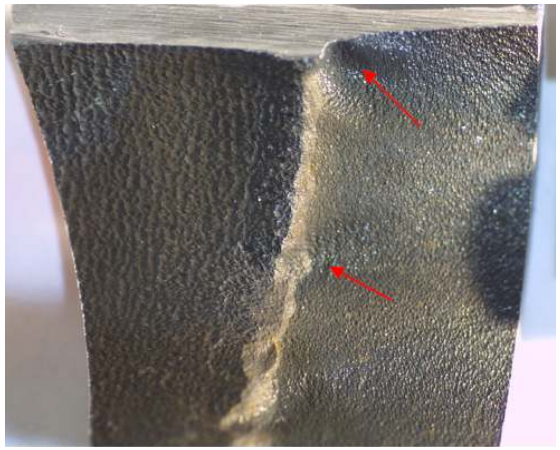


Cracking

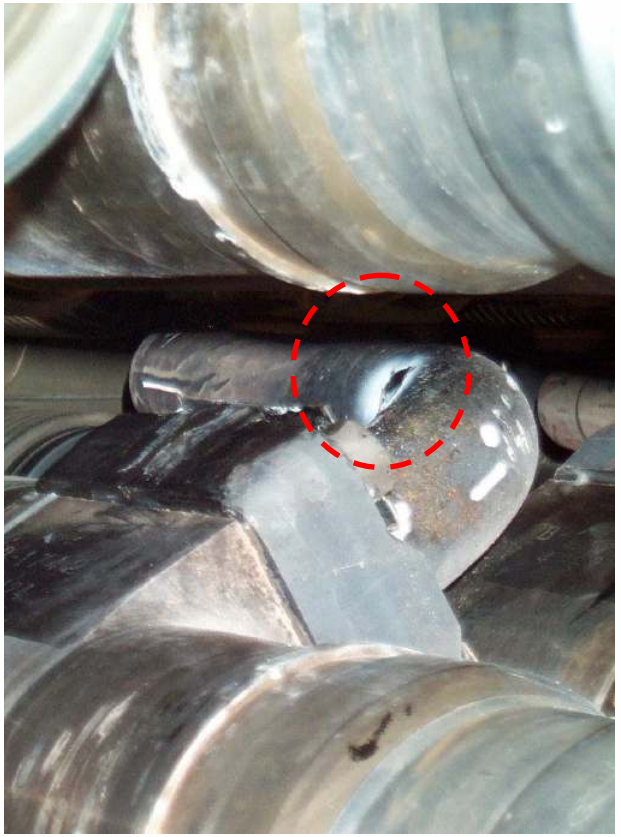


Wall Thinning

Degradations in Feeder Piping



Local Wall Thinning



Cracking

Fitness-for-Service Guidelines for Steam Generator and Feeder

- Inspection
- Condition Monitoring Assessment
  - Current and backward looking
- Operational Assessment
  - Forward looking
- Assessment of inspected and uninspected components
- Leak-Before-Break
  - Must be demonstrated whenever through-wall penetration is credible
  - operational leakage
  - consequential leakage

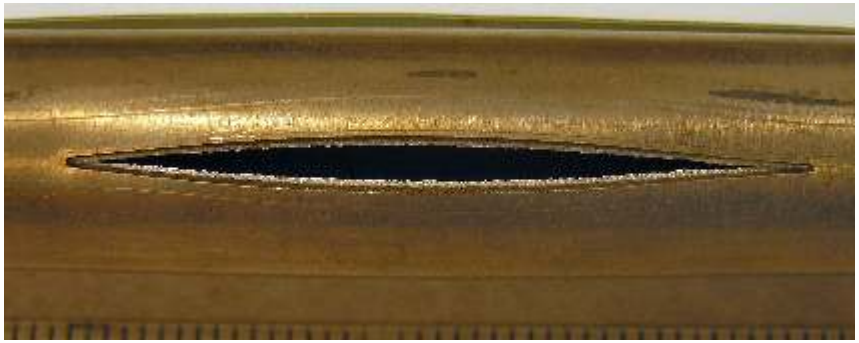
Steam Generator Tube Testing Project (SGTTP)

- Initiated in 1999 by OPG
- Three Materials
  - Monel 400
  - Inconel 600
  - Incoloy 800
- Four Types of Tests
  - Burst-Pressure Test
  - Pressurized-Bending Test
  - Leak-Rate Test
  - Materials Characterization

Some SGTTP Testing Results

Fret Scar

360° Uniform Thinning (Wastage)



EDM Axial Slot (Crack-Like Flaw)

Defect-Free Ex-Service Tube

Feeder Bend Testing Project (FBTP)

- Initiated in 2002 by CANDU Owners Group (COG)
- SA-106 Gr. B carbon steel
- Phase 1 (2003-2005)

  Through-wall axial crack at the *intrados/cheek* of feeder bend
- Phase 2 (2005-2007)

  Through-wall axial crack at the *extrados* of feeder bend
- Phase 3 (2007-2009)

  Local wall thinning downstream of welds
- Utilities sponsored tests of ex-service components

  Feeder bend with surface cracks

  Feeder elbow with local wall thinning

Material Characterizations

- Tensile Properties

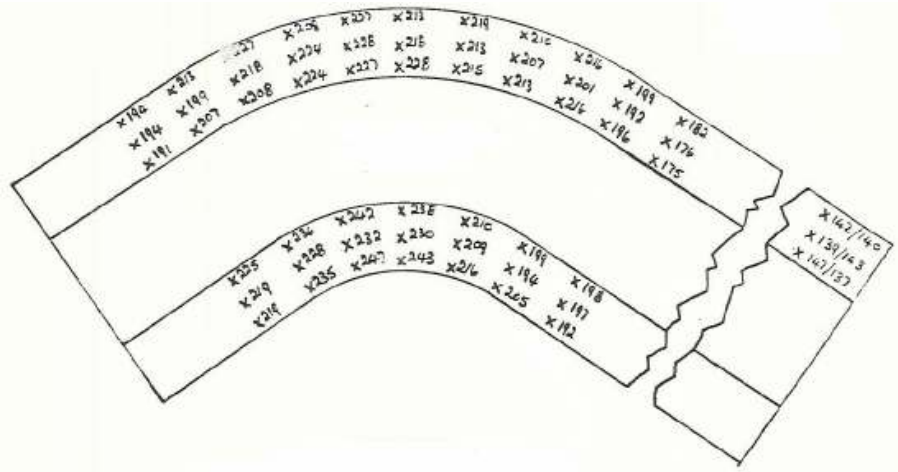
  Temperature: -196°C - 400 °C

  Strain rate: 0.0001s^{-1} - 10 s^{-1}

- Fracture Toughness

  -196°C to 310°C

- Micro Hardness

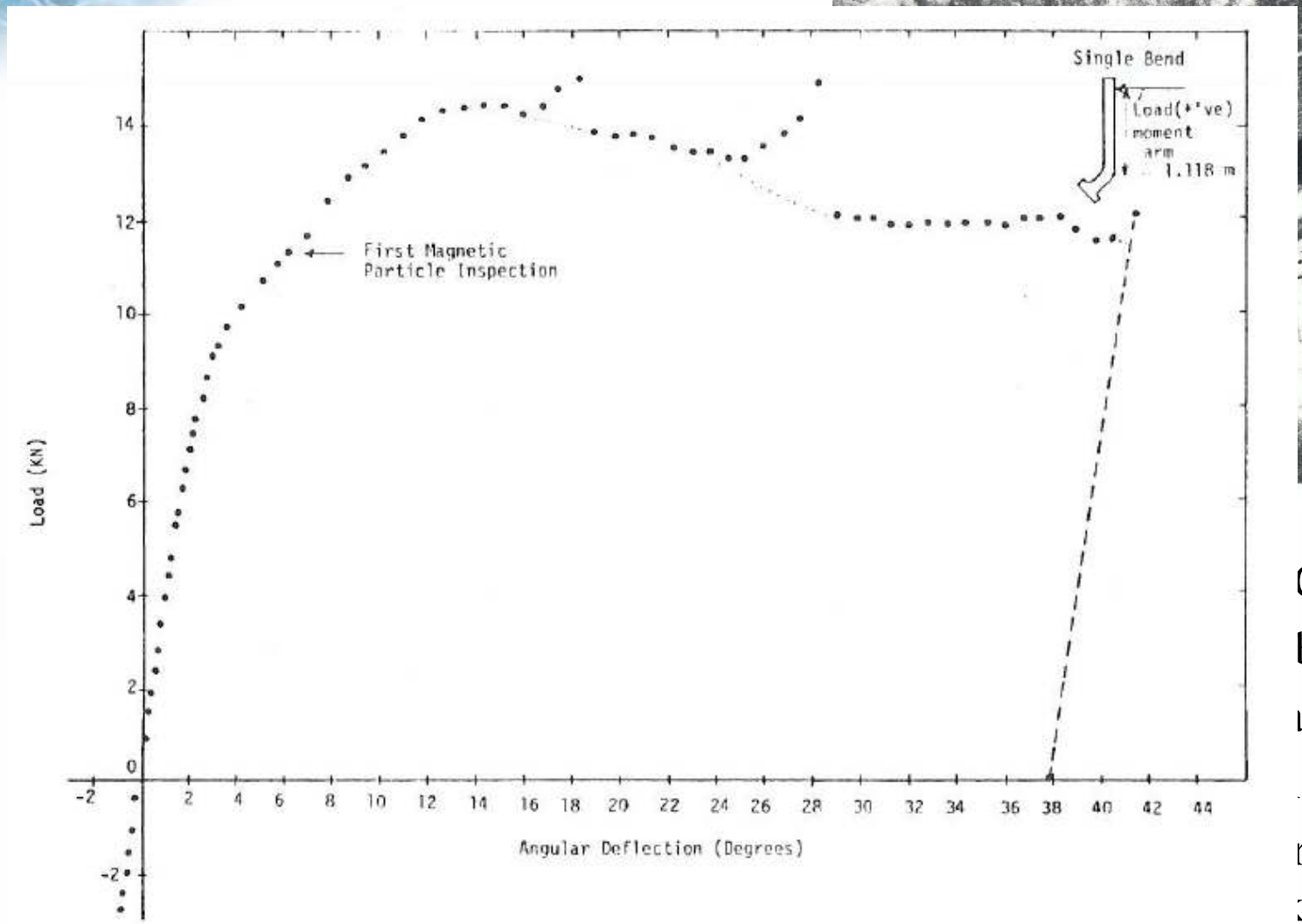


Large database since 1970s

Locations: Straight pipe, Extrados, Cheeks

Materials: Archive, **Ex-service**

Tests in 1980s



After Test

C

bined loading

ıbricated bend

.aw

rupted to check

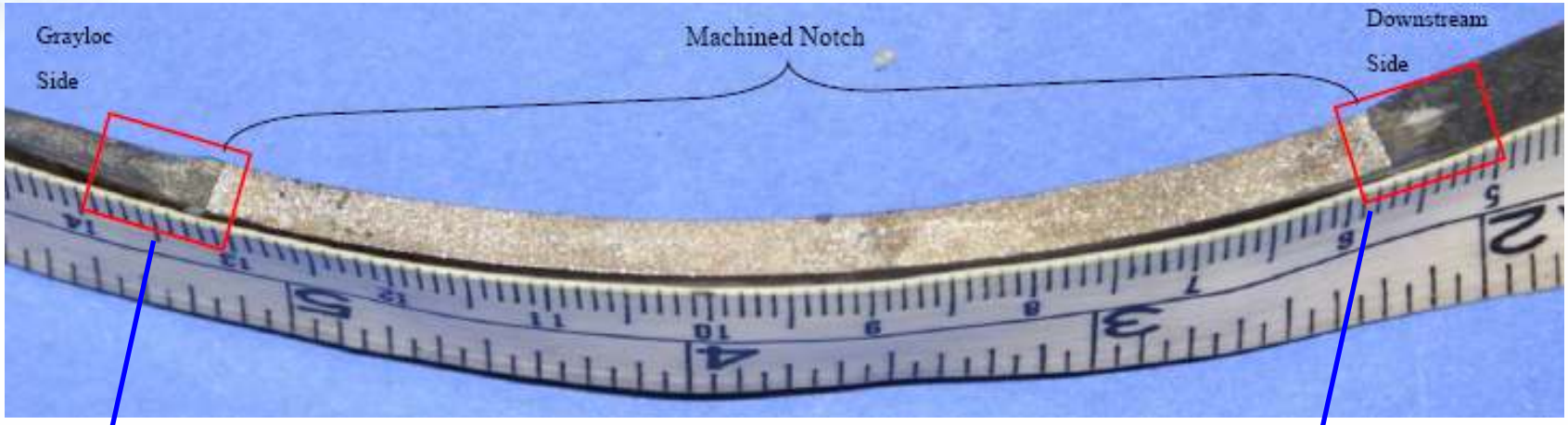
: initiation

Before Test

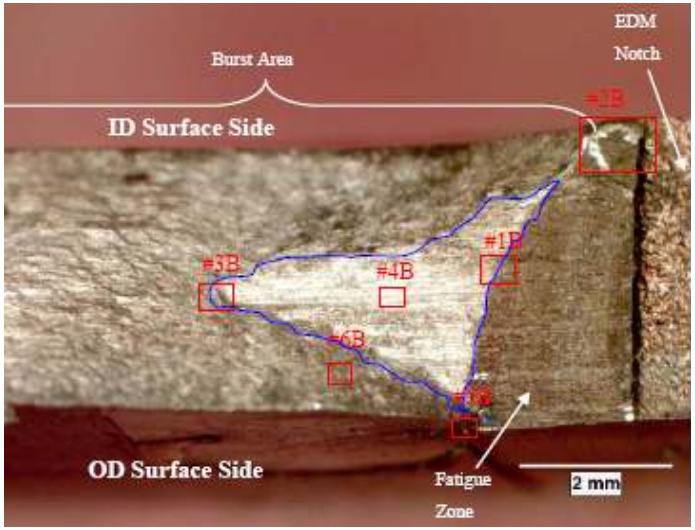
FBTP – Phase 2 Extrados Crack

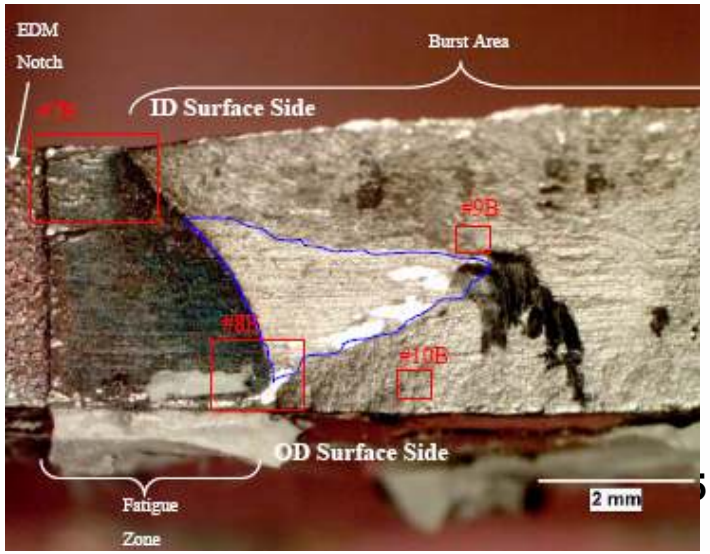
- 265°C
- Through-Wall Axial Crack
- High Temperature Liner
- Thinned Bend
- Quasi-Static Loading
- Pressure & Bending Moment
- Ductile Shear Failure

Mode of Failure

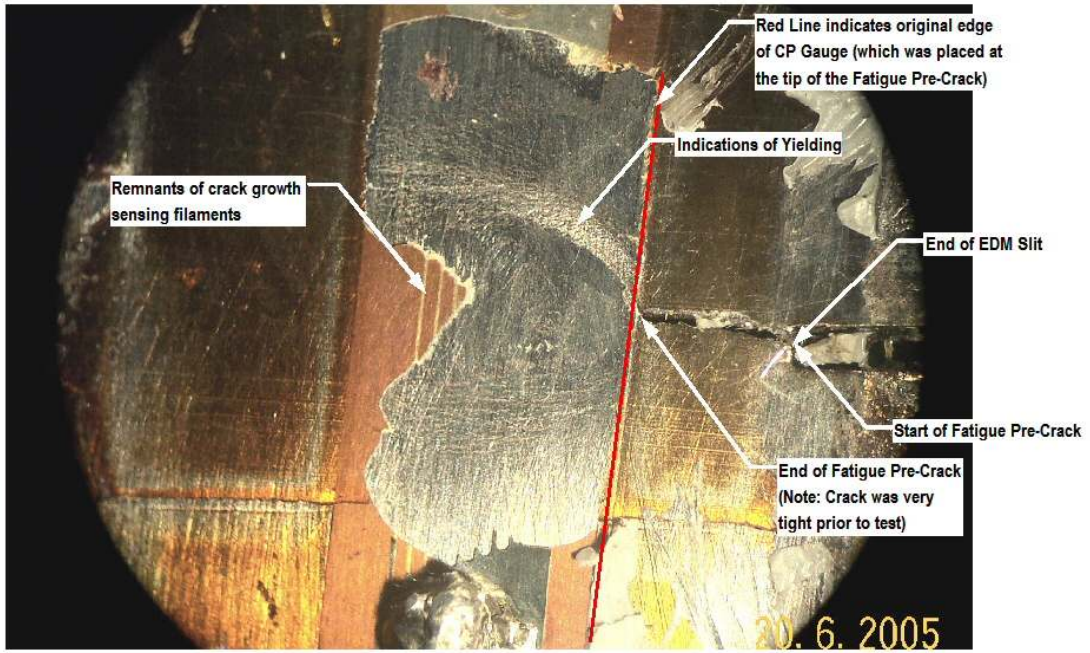


Full ductile mode of failure





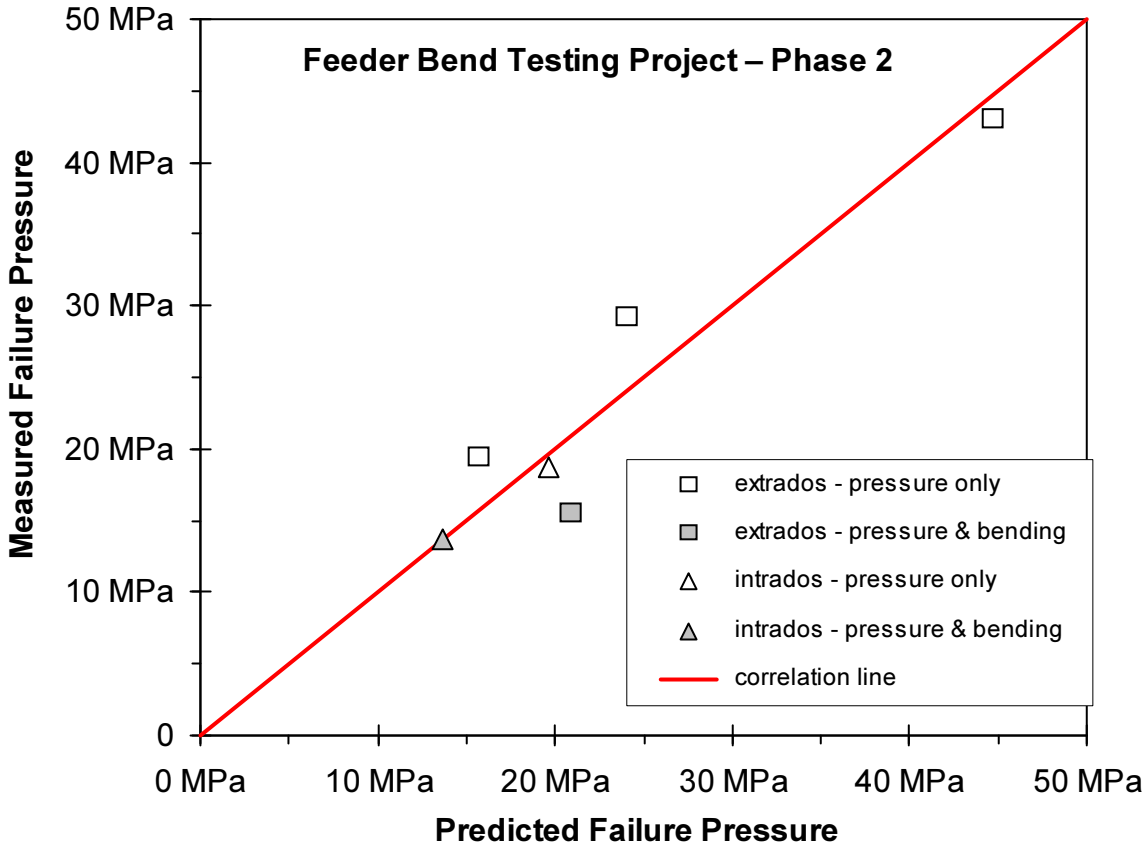
Unique Feature of Thin Wall Piping



View Through Optical Microscope of Crack-Propagation Gauge at "Fixed" or "Weld" End of Phase 2 Hot Commissioning Specimen - Post Test

Substantial plastic deformation ahead of crack tip

Predictions versus Measurements



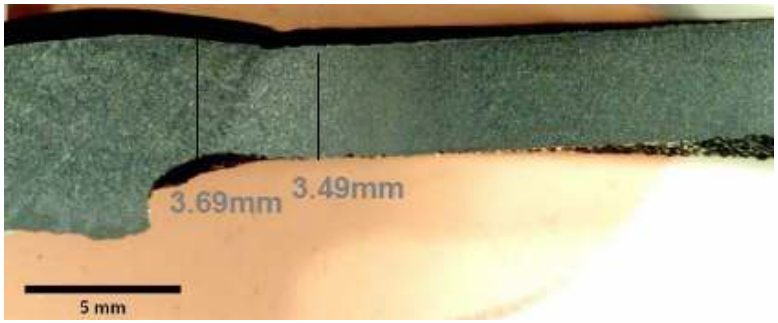
Simple Folias model gives good predictions.

Test of Ex-Service Feeder

73%tw

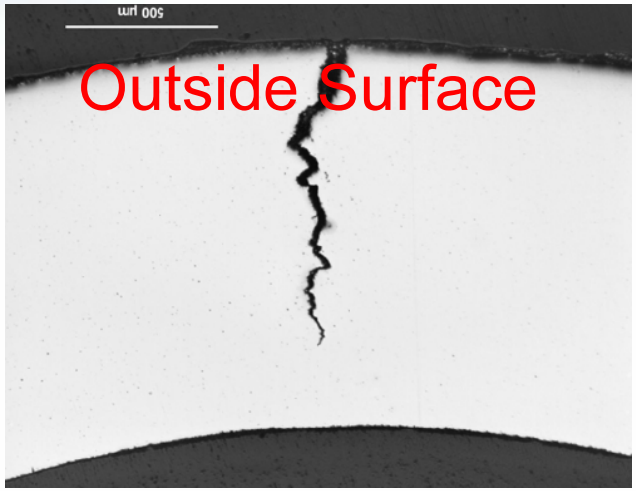
90°C

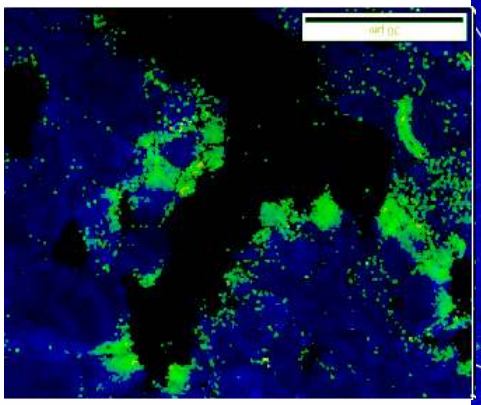
Tests of Ex-Service Feeder with Blunt Flaw

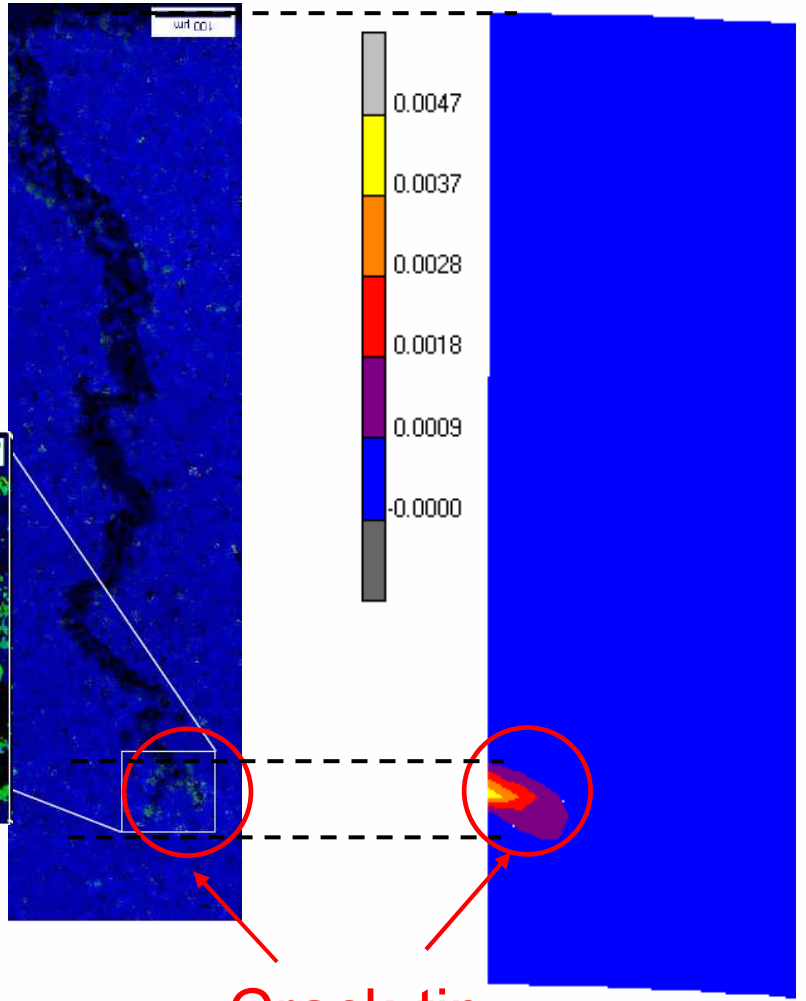


- Minimum wall thickness 3.0 mm
- Full ductile mode of failure
- 90°C

Heterogeneous Finite Element Model







Safety Factor:

1.3 ← FFSG

3.0 ← HFEM

Conclusions

- Tests of ex-service components provide strong support for the safe operation of ageing reactors.
- Both SGTTP and FBTP test results indicate that the fracture mechanics is not appropriate for the thin wall small diameter components.
- Advanced finite element model has been developed and proved to be useful for the failure analysis.

Acknowledgements

- CANDU Owners Group (COG)
  - Feeder Integrity Joint Project (FIJP)
  - Chemistry Materials & Components (CM&C)
- Ontario Power Generation
- New Brunswick Power Nuclear

Recent Publications

- Xinjian Duan, Michael J. Kozluk, Tracy Gendron, John Slade, *"Alternative Methodology for Assessing Part-Through-Wall Cracks in Carbon Steel Bends Removed from Point Lepreau Generating Station"*, SMiRT19, Paper Number 1318, August 12-17, 2007, Toronto, Canada.
- Xinjian Duan, Mukesh Jain, Don R. Metzger and David S. Wilkinson, *"A unified finite element model for the prediction of failure behaviour for sheet material"*, Journal of Pressure Vessel Technology, 2007 November.
- Xinjian Duan, Arnaud Weck, D. S. Wilkinson and D. R. Metzger, *"Plastic Limit Analysis of Perforated Material under Finite Deformation"*, Journal of Pressure Vessel Technology, 2008 May.
- Xinjian Duan, Michael J. Kozluk, Sandra Pagan, Brian Mills, *"Structural Integrity Assessment of steam generator tube by the use of* heterogeneous *finite element method"*, Journal of Pressure Vessel Technology, 2008 November.

Questions?