Pressure Boundary Materials

(Non-proprietary Version)

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Outline

- Material Selection for Class 1 Boundary
  - Feeders
  - Steam generators
  - Fuel channel materials
- Compliance with regulatory guides where applicable
- Discussion of several issues of potential in-service degradation of components

Material Selection

- **Feeder material will be austenitic stainless steel SA 312 TP 316N**
  - **Additional specification to reduce carbon concentration**
- **Piping and pressure vessels will be ferritic carbon steel meeting Appendix I of Section III of ASME**
- **Fuel channel materials not specified in ASME code**
  - **Acceptance to be based on database of material property information and experience in existing CANDU**

Feeder Compliance with RG 1.36

- **To prevent external stress corrosion cracking (ESCC) any insulation material that will be in contact with the component is tested in accordance with ASTM C 692 and the chemical analysis of the insulation material meets the requirements of ASTM C 795.**
- **All austenitic stainless steel pipe in contact with insulation is painted with silicone-based Thurmalox 70 paint.**

Feeder Compliance with RG 1.44 and RG 1.37

- Austenitic stainless steel components are protected against contaminants that can cause stress corrosion cracking
- Raw austenitic stainless steels material is supplied in solution heat treated condition
- The ‘L’ grade variant with C < 0.03 wt% of the un-stabilized austenitic stainless steels is specified
- All RCPB austenitic stainless steels are screened in accordance with ASTM A 262 to ensure non-susceptibility to stress corrosion cracking

Feeder Compliance with RG 1.31, RG 1.34 and RG 1.71

- All austenitic stainless steel filler metal used for welding of RCPB components meet the requirements of NB-2340 of the ASME BPVC, Section III, Division I
- All welding is performed according to the requirements of Articles NB-2400 and NB-4300 of ASME, Section III, Division I, using low hydrogen filler material only
- Austenitic stainless steel welds and repair welds exposed to system fluid are solution annealed; when impractical, a low heat input welding process with restricted low interpass temperature is used.

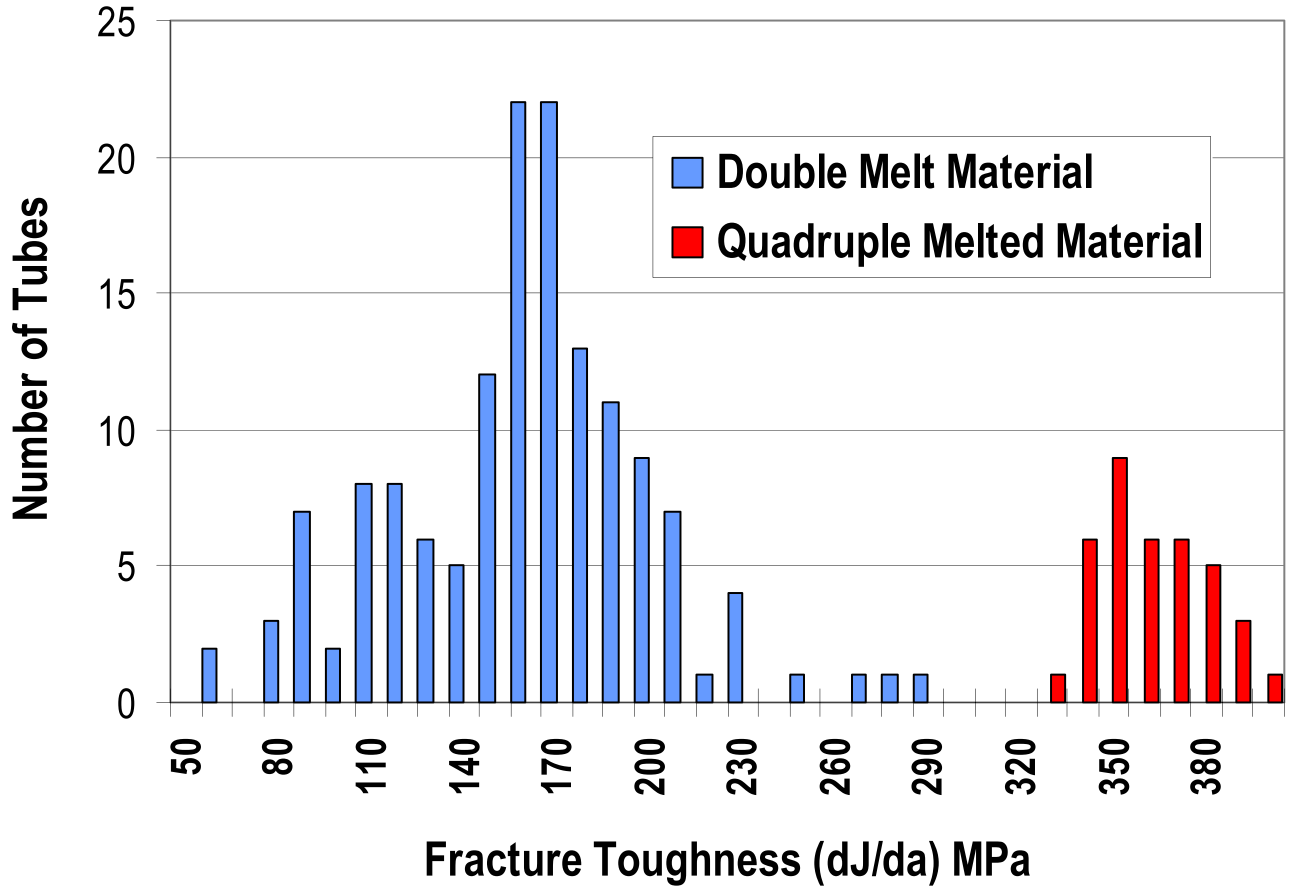
Steam Generators

- No exceptions to ASME requirements
- Steam generator construction practice and materials will be consistent with the best practices and information available
  - CANDU 6 reactors have ferritic stainless steel support structure and Incoloy 800 tubing
  - Very few problems experienced
- AECL has expertise in SG design, thermal hydraulic analysis, materials and chemistry requirements for long life
- Reference tubing material is Incoloy 800 with Inconel 690 judged acceptable also

Fuel Channels

- **Pressure tube**
  - Pressure tubes are designed to ASME Section III NB3200
  - Tubes meet CAN/CSA Standard N285.6 and additional AECL Technical Specifications for material
  - Zr-2.5%Nb is an ASTM Standard B353 (UNS R60901) material
  - ASME – type criteria apply for allowable design stress levels
  - Tubes are a consistent, high quality product
  - Current production tubes have improved properties compared to earlier production achieved by improved material specifications and production methods – especially with respect to fracture toughness properties after irradiation – a result of R&D programs in fracture area

Double Melt vs. Quadruple Melted Material



Materials Degradation Issues

- Rolled joint integrity and corrosion
- Garter spring material
- Annulus gas system performance

Rolled Joint Integrity and Corrosion

- **Leakage experience – of the joint – not the pressure tube**
  - **Leakage rates usually exceptionally low and are not abnormal pressure boundary leaks**

Annulus Gas Performance

Annulus Gas Performance

- **With added oxygen get hydrogen isotope reaction to produce additional water through this reaction:**

$$CO_2 + H_2 \Leftrightarrow CO + H_2O$$

- **Additional reactions a result of radiation**

Annulus Gas Performance

Annulus Gas Performance

- **Dewpoint rate of rise without any abnormal system leaks corresponds to water ingress from all joints combined at the rate of the order of 0.1 g/hr (grams per hour)**
  - **Much of the moisture may come from hydrogen isotope permeation through the end fitting material**

Rolled Joint Integrity and Corrosion

- Leakage experience – of the joint – not the pressure tube
  - Extremely rare experience of abnormal leakage
  - In approximately 400 years of reactor experience there has been one joint removed due to excessive leakage
    - Leak rate increased over a period of months to 4 g/hr
    - Channel located within an annulus gas “string”
    - Channel inspection found individual leaking channel
    - Examination after removal showed that leak was caused by a scratch on the outside surface of the pressure tube that was likely formed during assembly but oxidized over time and finally led to leak
- Such small leakage cannot result in any component damage and none was observed

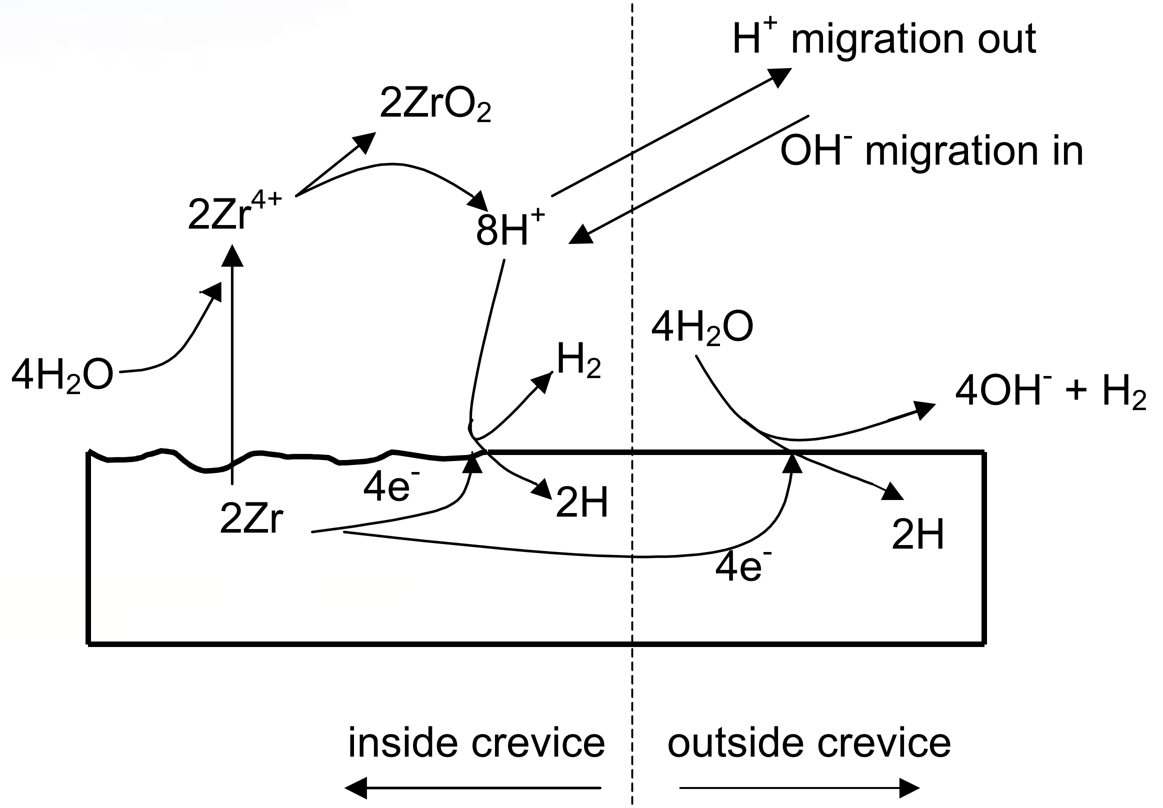
Rolled Joint Integrity and Corrosion

- **ACR rolled joints must be shown by qualification testing to have similar very low, normal leakage**
  - **Virtually leak tight**
- **Developmental program is currently underway**

Rolled Joint Integrity and Corrosion

- Galvanic corrosion effects in rolled joint lead to hydrogen ingress but total amount of corrosion is small
- Rolled joint corrosion not considered to be an integrity issue

Rolled Joint Integrity and Corrosion



Note: Amount of corrosion-freed hydrogen entering metal is not to scale.

Rolled Joint Integrity and Corrosion

End Fitting

Pressure Tube

Inlet Rolled Joint After ~ 100,000 hrs of operation

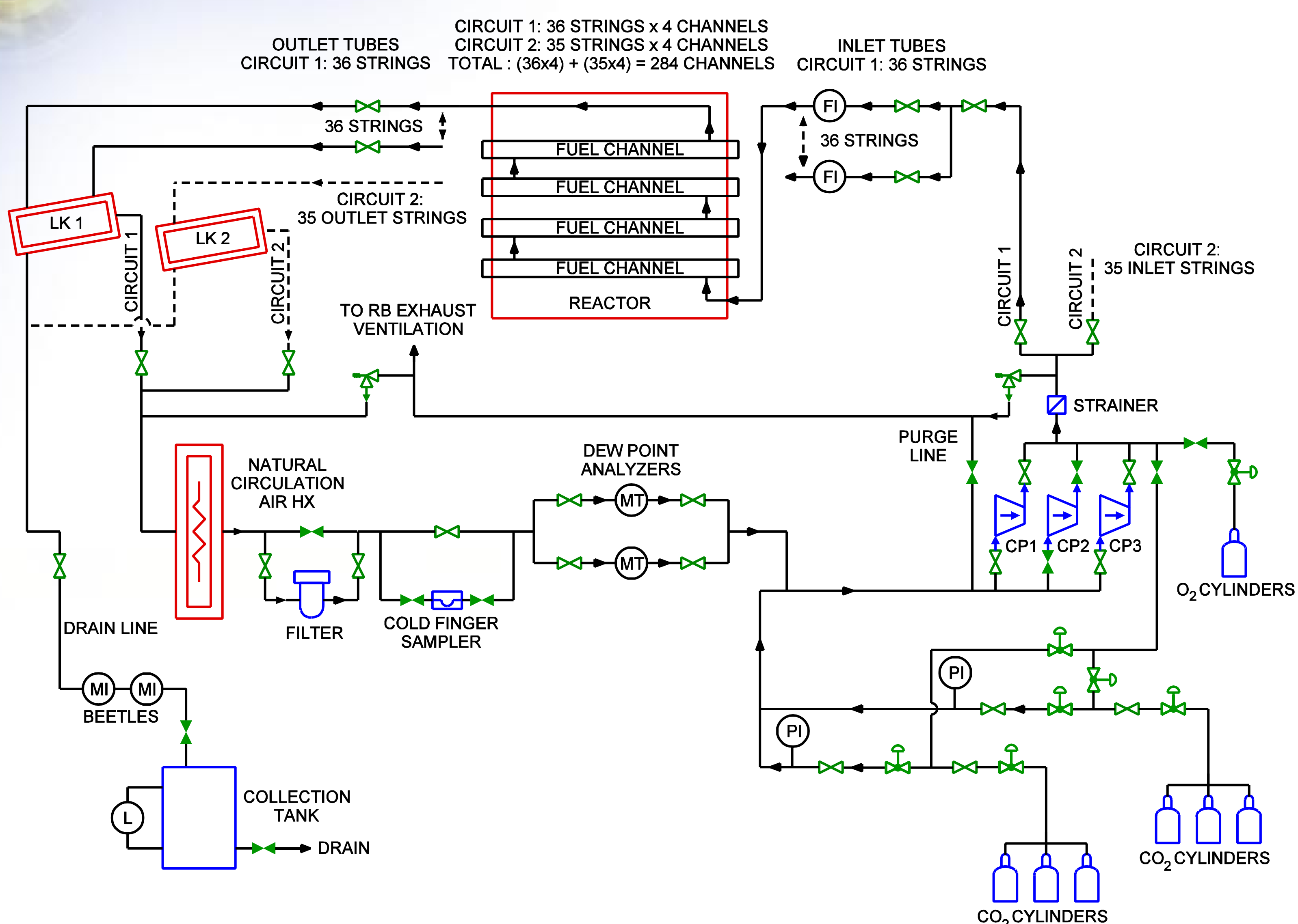
Degradation of Components in Annulus System due to Moisture

- Annulus gas system is maintained dry during operation
- No opportunity for SCC under normal circumstances
  - No electrolyte can be present unless annulus becomes wet

Annulus Gas Pigtails

- Plugging of pigtails occurred in only a few units
- Some units operating without oxygen addition do not observe any annulus flow blockages
- Plants that had blockages and added oxygen no longer experience blockages
- Blockages detected by checks of flow rotameters
- Consequence of blocked pigtail is longer detection time for leaks into the system. For a pressure tube leak, blockage would be cleared by increasing pressure as coolant enters the system.

Annulus Gas Flowsheet



Predictions from Scattered Data

- In component design, for issues likely to affect the plant life, predictions of performance are based upon bounding (95%) rates – sometimes with additional margin
- Some coupled effects
  – E.g. wall thinning must account for irradiation deformation and corrosion
    - Upper bounds used for each separately
    - Strength used based on S_m in calculations

Data Outside Correlations

- **Data that falls outside correlations would generally only be removed if it could be demonstrated, with some confidence, to be not valid.**

Environmental Effects Testing

- No evidence from pressure tube inspection or examination of surveillance pressure tubes that environmental effects are significant - except insofar as the environment causes hydrogen ingress
- Creep and growth tests have been carried out in water at high temperature in NRU - no effect of the environment on creep rates noted
- Very little pressure tube fatigue testing has been carried out in the coolant environment
- Tests of irradiated materials removed from surveillance tubes have been exposed to the environment but are not generally tested in the environment

Differences between Light and Heavy Water

- Light and heavy water are chemically very similar
- Kinetics of reactions may be slightly different
- Corrosion behavior of pressure tube material and hydrogen isotope uptake during corrosion are very similar in two media
- Solubilities of hydrogen isotopes in pressure tube material are similar
- Diffusion kinetics and DHC velocities should differ by a factor of 1.4, but this small factor is difficult to determine in such tests

Pressure Tube Temperature at the Garter Spring Contact

- Temperature will be calculated by conservative analysis – not yet done for ACR
  - Factor in gamma heating of components
- Temperature gradient at the garter spring should not be large enough to cause accumulation of hydride at the contact point at operating conditions even at the end-of-life
- Garter spring contact point changes continuously with time of operation due to pressure tube elongation

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