Extremely Low Probability of Rupture (xLPR) Project

V2 Stress Requirement Document

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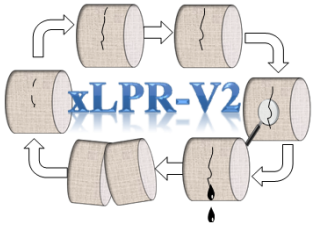
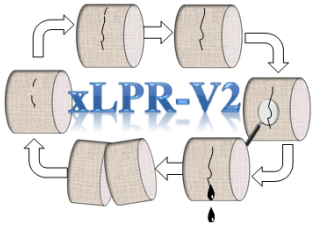
xLPR External Review Board Meeting
February 20, 2013

Normal Operating Stress



- **Stress considered include:**
  - **Pressure**
  - **Deadweight (DW) - axial membrane and global bending**
  - **Sustained normal thermal stress (NTE), may include stratification -axial membrane and global bending**
  - **Weld residual stress (WRS) - axial and hoop through thickness stress**
- **Superposition of stresses is assumed in all cases**
- **User choice – Stress or force/moment**
- **Crack face pressure included as needed**
- **Maximum bending stress calculated based on R_o using equivalent moment**
- **Global bending stress is scaled based on azimuthal location**

Normal Operating Stress



- **Weld Residual Stress**
  - **Defined by up to 26 points through thickness**

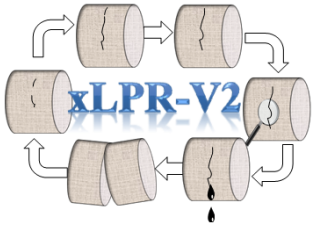
$$\begin{bmatrix} \sigma_{WRSa(1)} & \xi_{(1)} & 1 \\ \vdots & \vdots & \vdots \\ \sigma_{WRSa(n_{max})} & \xi_{(n_{max})} & n_{max} \end{bmatrix} \begin{bmatrix} \sigma_{WRSh(1)} & \xi_{(1)} & 1 \\ \vdots & \vdots & \vdots \\ \sigma_{WRSh(n_{max})} & \xi_{(n_{max})} & n_{max} \end{bmatrix}$$

  - **Hoop WRS is averaged for through-wall crack growth (discussed later)**

$$\sigma_{WRSh(avg)} = \int_0^1 \sigma_{WRSh} d\xi$$

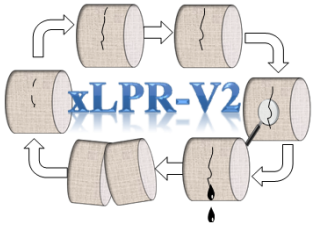
- **Additional surface stress included to account for very shallow surface stress due to grinding, etc.**

Transient Stresses

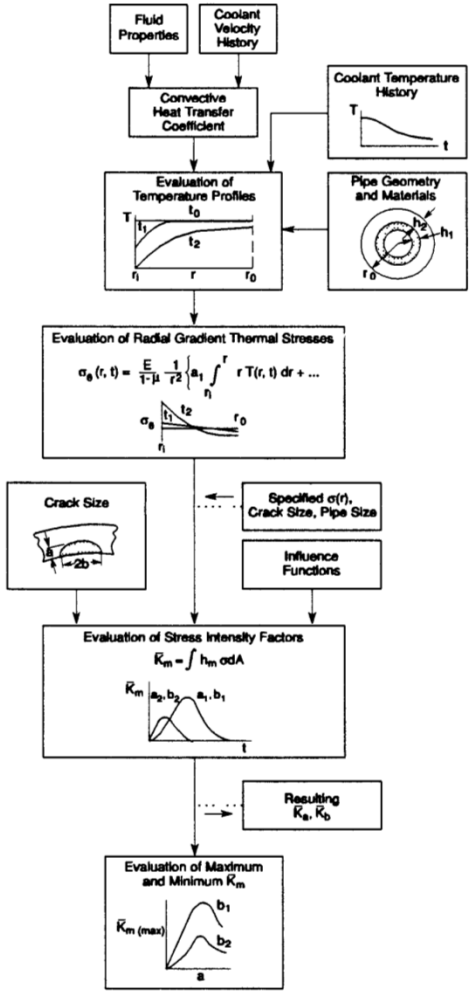


- **Anticipated and accident loads from design basis**
  - **Impacts fatigue crack growth, fatigue initiation, and crack stability**
- **Radial gradient self-equilibrating thermal stress as a function of transient time**
  - **Input or calculated by Tiffany**
- **Transient pressure as a function of transient time**
- **Thermal expansion stress as a function of transient time**
  - **May be calculated by Tiffany**
- **Number of cycles per year**

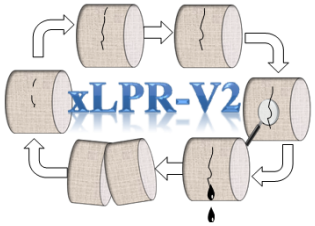
Tiffany (Thermal Stress Intensity Factors For ANY Coolant History)



- A module for evaluation of cyclic stresses and stress intensity factors (as functions of crack size) is being developed for use in fatigue crack initiation and growth analysis in xLPR.
- Accompanying diagram shows steps in TIFFANY analysis
  - calculation of temperature in pipe wall using coolant temperature/flow history [$T(r,t)$],
  - calculation of resulting thermal stresses [$\sigma(r,t)$],
  - calculation of stress intensity factors
    - [$K(a/h,a/b,t)$, surface and depth]
    - sorting to obtain max and min K
    - [$K_{max}(a/h,a/b)$, $K_{min}(a/h,a/b)$]
    - axial, circumferential, part-through, through-wall cracks considered
    - Transient rise time
  - cyclic stresses at ID also evaluated for fatigue crack initiation.
- Uncertainty in stresses treated by a random multiplier on output.

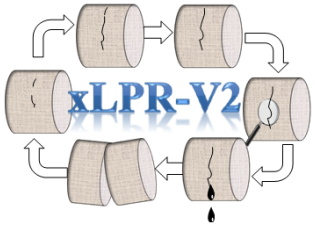


Earthquake Loads



- **Unexpected Events**
  - **Influences crack stability only**
- **Maximum membrane stress**
- **Maximum seismic anchor motion stress**
  - **Displacement controlled**
- **Maximum seismic inertial stress**
- **Probability of occurrence**

Crack Initiation

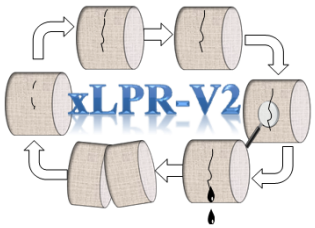


- All primary and secondary stresses are considered

- PWSCC
  - Axial (membrane and bending(ϕ)) stress – Pressure, DW, NTE, WRS at ID, additional surface stress
  - Hoop - Pressure, WRS at ID, additional surface stress

- Fatigue
  - Minimum and maximum ID stress for each transient – Hoop and axial
  - Normal operating DW, WRS at ID, additional surface stress

SCC Growth



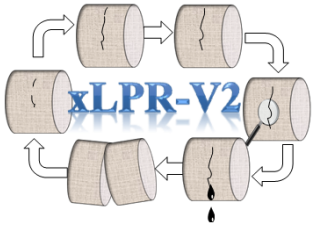
Circumferential

- **Surface crack**
  - Membrane and bending(ϕ)
  - Pressure, DW, NTE, axial WRS
- **Through-wall crack**
  - Membrane and bending(ϕ)
  - Pressure, DW, NTE
  - Displacement controlled stresses can be reduced – user input
  - WRS is ignored

Axial

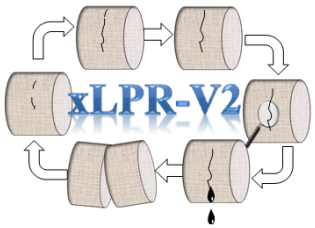
- **Surface crack**
  - Pressure and hoop WRS
- **Through-wall crack**
  - Membrane and bending(ϕ)
  - Pressure, DW, NTE
  - Average axial WRS

Fatigue Crack Growth



- Output of Tiffany is K matrices based on crack size, one for each transient
- Framework interpolates K matrices for crack size to get max and min K
- xLPR K-module calculates K for WRS and other loads
- Framework combines transient K and K for WRS / other loads
- Details in process

Crack Stability



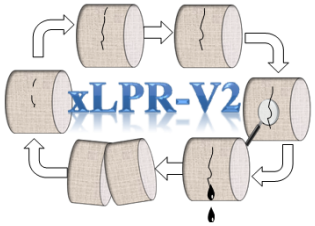
Circumferential

- Surface crack
  - Membrane and bending(ϕ)
  - Pressure, DW, NTE, earthquake/transient loads when applicable
- Through-wall crack
  - Membrane and bending(ϕ)
  - Pressure, DW, NTE, earthquake/transient loads when applicable
  - Displacement controlled stresses can be reduced – user input

Axial

- Surface crack
  - Pressure
- Through-wall crack
  - Pressure

Crack Opening Displacement



Circumferential

- Membrane and bending(ϕ)
- Pressure, DW, NTE
  - Displacement controlled stresses can be reduced – user input
- WRS is ignored

Axial

- Membrane and bending(ϕ)
- Pressure
- Average axial WRS