BWROG Pressure-Temperature Curve Licensing Topical Report Revision

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NRC Pre-submittal Meeting
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Washington DC

Meeting Agenda

- Introductions
- Meeting Objectives
- P-T Curve Methods LTR (SIR-05-044, Rev. 1)
  - Purpose of LTR
  - Summary of Changes
  - Basis information
- Water Level Instrument Nozzle Evaluation LTR (0900876-401, Rev. 0)
  - Purpose of LTR
  - Basis information
  - Overview of Methodology
  - Summary of Results
- Open Dialogue

Meeting Objectives

The BWROG objectives for this meeting are:

- Introduce purpose of each Licensing Topical Report.
- Discuss general methodology and results.
- Provide an early opportunity to identify NRC questions on the LTRs to improve quality of BWROG submittal to NRC and efficiency of NRC review.

P-T Curve Methods LTR (SIR-05-044, Rev. 1)

LTR Purpose

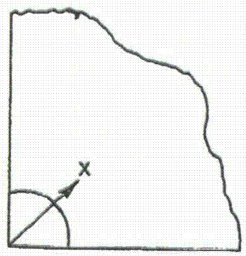
- Provide BWROG participants with a NRC approved methodology for preparing BWR P-T limit curves and test temperatures with solutions suitable for water level instrument (WLI) nozzles included in the LTR.
- Eliminate need for plant specific instrument nozzle submittal requiring review.

Summary of Changes

- Include water level instrument nozzle LEFM solutions consistent with those used in plant specific instrument nozzle evaluations previously submitted to the NRC and subsequently approved.

QUARTER-CIRCULAR CRACK IN INFINITE QUARTER-SPACE

$$K_I = \sqrt{\pi a}\left[0.723A_0 + 0.551A_1\left(\frac{2a}{\pi}\right) + 0.462A_2\left(\frac{a^2}{2}\right) + 0.408A_3\left(\frac{4a^3}{3\pi}\right)\right]$$



P-T Curve Methods LTR (SIR-05-044, Rev. 1)

Basis Information

- Adequacy of the nozzle solutions are thoroughly documented in the references identified below:
  - PVP2011-57015
  - PVP2011-57742
  - PVP2011-57014
  - ORNL/TM-2010/246
  - ASME Paper 78-PVP-91
  - EPRI Report NP-339
- NRC has previously seen these solutions applied for plant specific submittals and has approved use for treatment of the WLI nozzles for these plant specific cases.

Discussion

WLI Nozzle Evaluation (0900876-401, Rev. 0)

LTR Purpose

- Provide BWROG participants with a NRC approved, simplified, methodology for obtaining a conservative K_{IT} and K_{IP} for the WLI Nozzle
- Eliminate the need for a plant specific instrument nozzle FEA thereby reducing cost to utility.

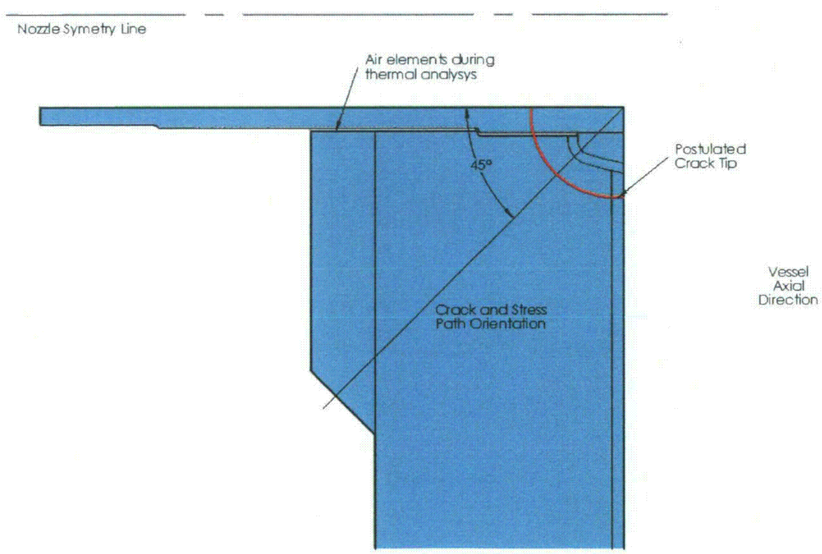
Basis Information

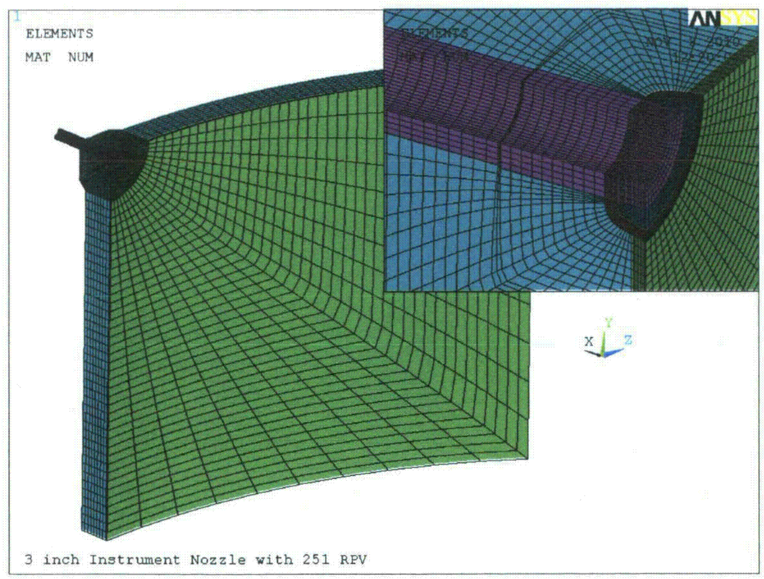
- 3 Plant specific calculations:
  - 251" RPV Evaluation, 0900876-301, Rev. 0.
  - 218" RPV Evaluation, 0900876-302, Rev. 0.
  - 238" RPV Evaluation, 0900876-303, Rev. 0.
- 1 Parametric Evaluation:
  - WLI Nozzle fracture mechanics solution, 0900876-304, Rev. 0.
- Adequacy of LEFM solution given by basis documents identified for SIR-05-044, Rev. 1.

WLI Nozzle Evaluation (0900876-401, Rev. 0)

Methodology

- Performed 3 plant specific calculations for RPV diameters, nozzle materials and sizes which are considered to span the population of plants with partial penetration style WLI Nozzles.
  - 3-D FEM of RPV, nozzle insert, attachment weld, vessel cladding.
  - Considered both internal pressure and cool-down transient.
  - Linear elastic FEA, ANSYS.

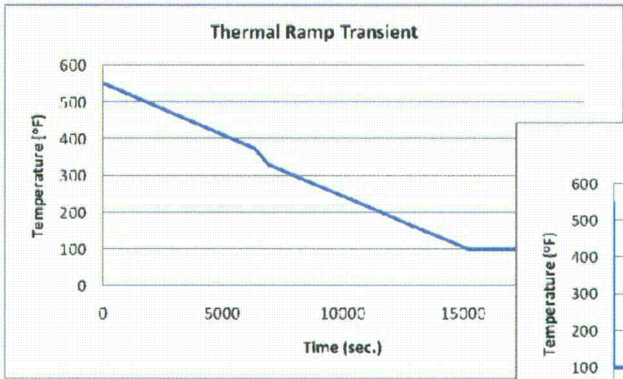


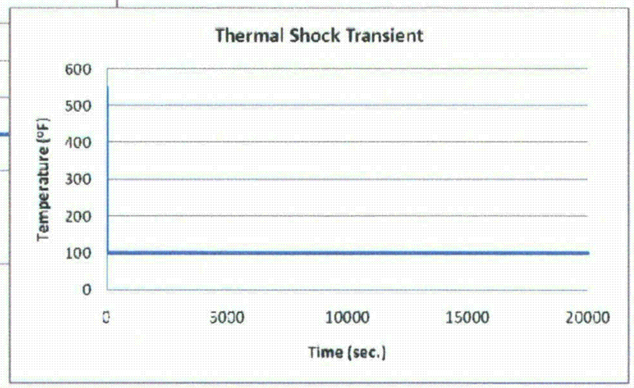


WLI Nozzle Evaluation (0900876-401, Rev. 0)

Methodology

- Performed 1 parametric study in which 38 FEMs built to separately evaluate (using same modeling approach as plant specific evaluations).
  - Geometry considered:
    - 4 RPV diameters (205", 218", 238", 251")
    - 2 WLI diameters (2", 3")
    - 3 WLI insert thicknesses (0.23-0.28", 0.53-0.54", 0.70")
    - 3 WLI materials (Alloy 600, 304 SS, CS)
    - 2 J-groove weld configurations (Short, Long)
  - Load Cases considered:
    - Internal pressure
    - 100 ˚F/hr thermal ramp
    - Thermal shock

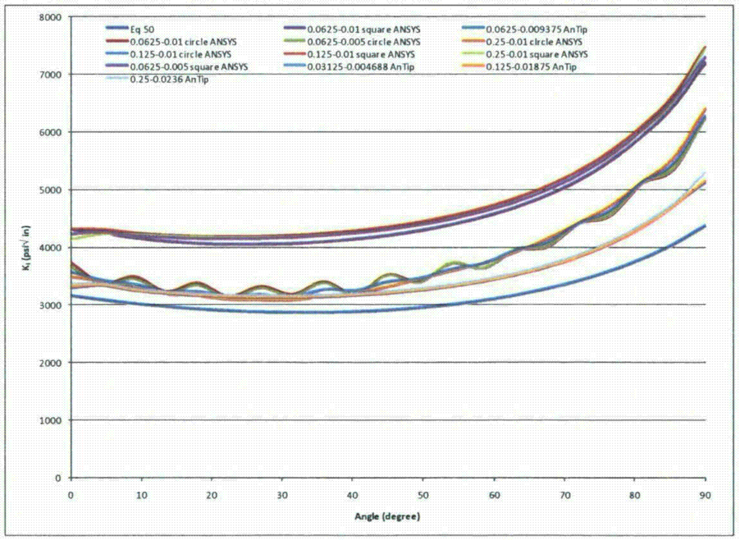


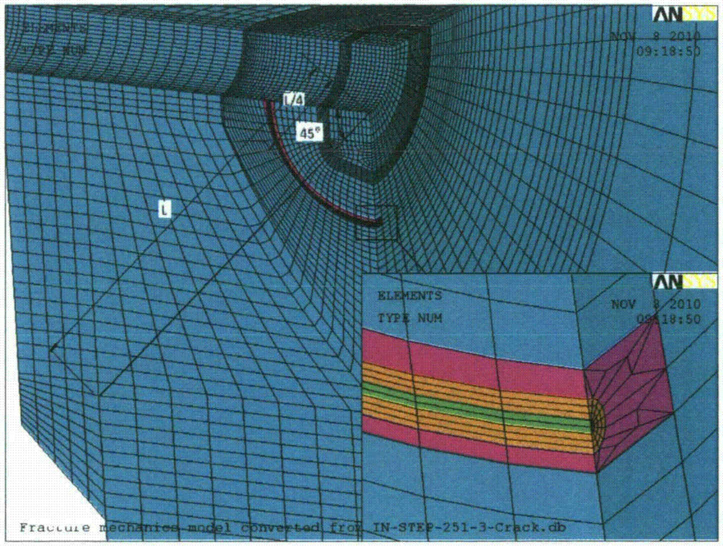


WLI Nozzle Evaluation (0900876-401, Rev. 0)

Methodology, cont.

- Mesh Density studies performed to ensure mesh independent results obtained from FEA
- Benchmark of FE LEFM mesh and fracture parameter calculation algorithms against Raju and Newman results for corner cracked hole
  - Common method of meshing crack front using quadratic elements with mid-side node on crack face moved to ¼ point location





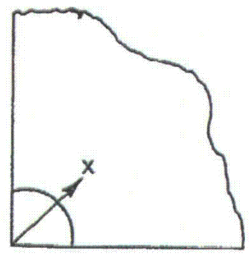
WLI Nozzle Evaluation (0900876-401, Rev. 0)

Methodology, cont.

- Boundary Integral Equation / Influence Function (BIE/IF) LEFM solution selected from those being considered by ASME Code for inclusion in ASME XI, Appendix G:

QUARTER-CIRCULAR CRACK IN INFINITE QUARTER-SPACE

$$K_I = \sqrt{\pi a}\left[0.723A_0 + 0.551A_1\left(\frac{2a}{\pi}\right) + 0.462A_2\left(\frac{a^2}{2}\right) + 0.408A_3\left(\frac{4a^3}{3\pi}\right)\right]$$

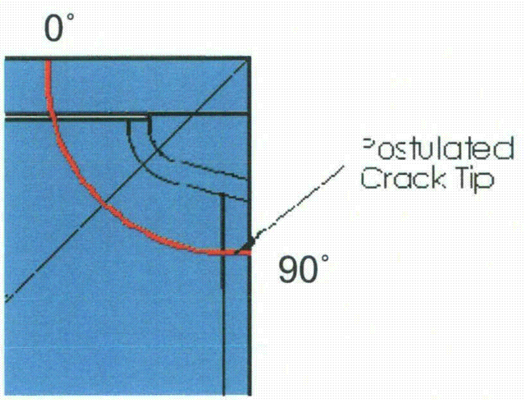


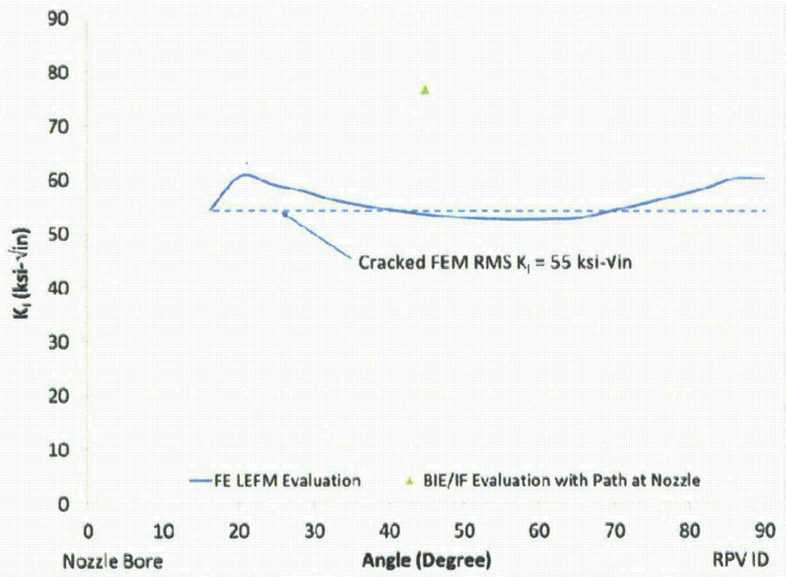
- Adequacy of BIE/IF solution assessed by comparing:
  - LEFM results for K_{IT} and K_{IP} obtained from a polynomial curve fit to a nozzle corner path stress distribution obtained from a linear elastic FEA for each load case.
  - Root Mean Square (RMS) K_I obtained from a FE LEFM evaluation of equivalent geometry and load case.
- General WLI nozzle K_{IP} and K_{IT} solutions obtained from a least squares linear curve fit to parametric results obtained using BIE/IF solution.
- Adequacy of general WLI nozzle solution assessed by benchmark against 3 plant specific evaluations, performed separately, using BIE/IF solution.

WLI Nozzle Evaluation (0900876-401, Rev. 0)

Results Summary

- Pressure Load Case - BIE/IF LEFM solution is shown to be conservative compared to FE LEFM results of comparable case:
  - **BIE/IF solution** provides K_{IP} which **bounds K_I calculated along crack front**.
  - **BIE/IF solution** provides K_{IP} which is **~40% conservative** for the case considered



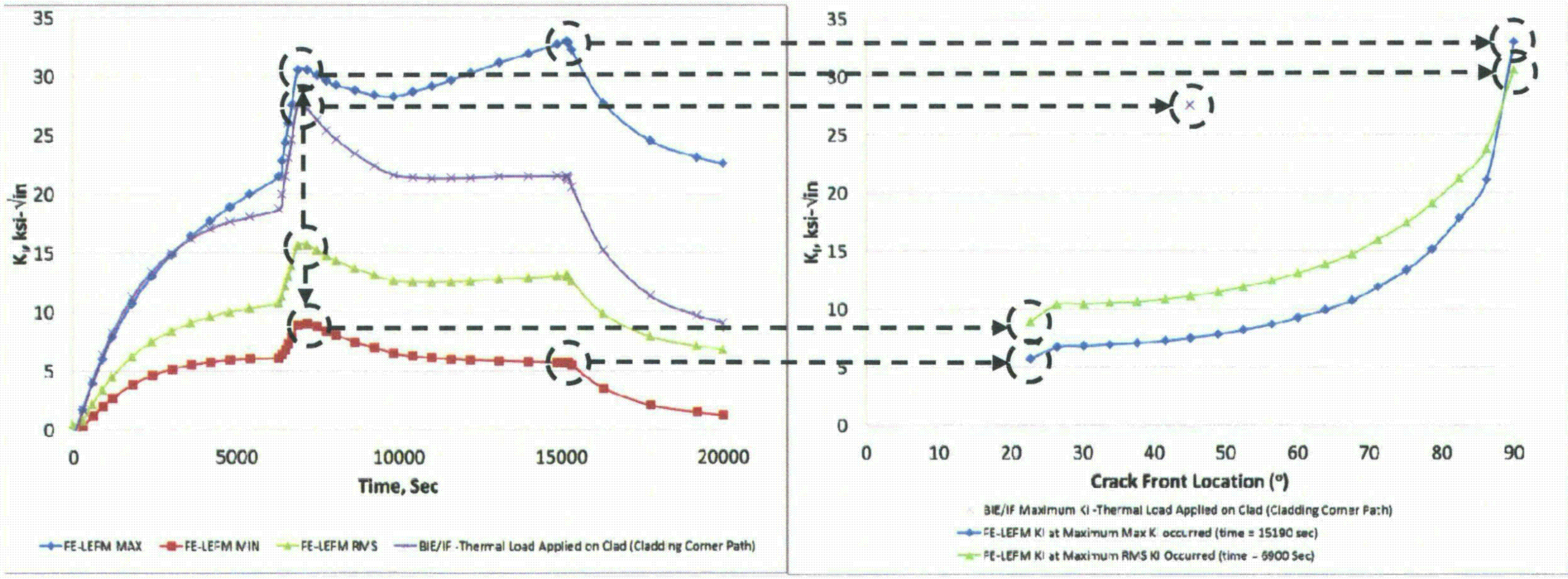


Note: K_I not calculated for WLI insert since this component is either non-ferritic or always is less than 2" thick and is thus exempt from the fracture toughness requirements

WLI Nozzle Evaluation (0900876-401, Rev. 0)

Results Summary

- Thermal Ramp Load Case – BIE/IF LEFM solution is shown to be conservative compared to FE LEFM results of comparable case:
  - **BIE/IF solution** provides K_{IT} which bounds **RMS K_I calculated along crack front** at time of max K_{IT}.
  - **BIE/IF solution** provides K_{IT} which is **~45% conservative** for the case considered



WLI Nozzle Evaluation (0900876-401, Rev. 0)

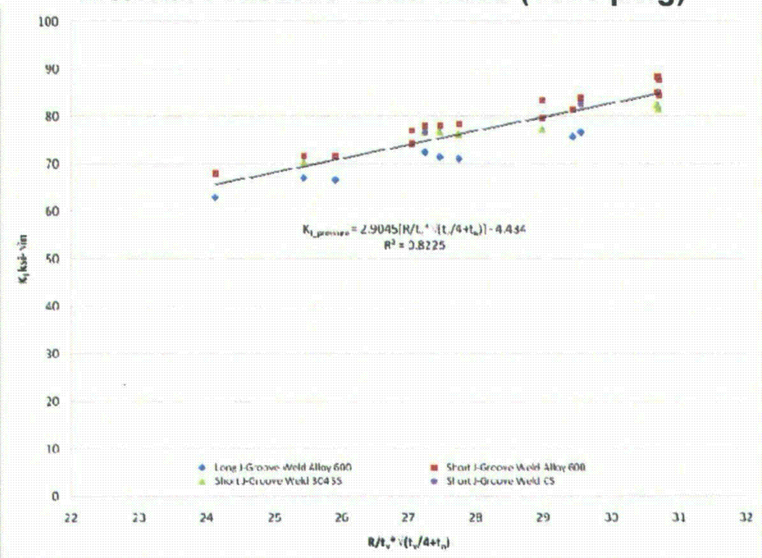
Results Summary

- General WLI nozzle equations for K_{IT} and K_{IP} are provided which eliminate need for additional expense for plant specific analysis:

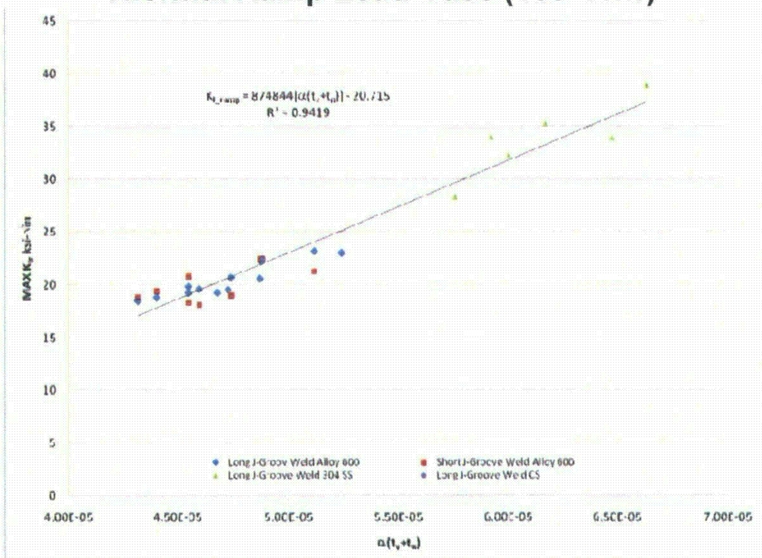
Pressure Load	Thermal Ramp Load
$K_{I\_Pressure} = 2.9045*[R/t_v\sqrt{(t_v/4+t_n)}] - 4.434$	$K_{I\_ramp} = 874844*[\alpha(t_v+t_n)] - 20.715$

1. Equations taken from 0900876-401, Rev. 0, Table 19.
2. Where R is the vessel radius (in), t_v is the vessel thickness (in), t_n is the nozzle thickness (in), and α is nozzle material thermal expansion coefficient (in/in/°F).

Internal Pressure Load Case (1000 psig)



Thermal Ramp Load Case (100 °F/hr)



WLI Nozzle Evaluation (0900876-401, Rev. 0)

Results Summary

- General WLI nozzle equations benchmark well against plant specific data:

Dimensions	Vessel Nominal Diameter (in)	251	218	238
	Vessel Thickness (in.)	6.102	5.375	6.000
	Nozzle Thickness (in.)	0.532	0.277	0.715
Material	Nozzle Material	Alloy 600	Alloy 600	304 SS
	Nozzle Thermal Expansion Coefficient (in/in/°F)	7.70e-6	7.70e-6	9.75e-6
Pressure	K_I per General Solution (ksi-√in)	81.24	70.53	81.29
	KI per Reference (ksi-√in)	72.88	71.26	69.40
	Relative Error (%)	**11.47%**	**-1.02%**	**17.13%**
Thermal Ramp	K_I per General Solution (ksi-√in)	23.97	17.35	36.56
	K_I per Reference (ksi-√in)	24.5	17.87	38.6
	Relative Error (%)	**-2.16%**	**-2.89%**	**-5.29%**

Taken from 0900876-401, Rev. 0, Table 18.

- Upper bound solutions not developed since **BIE/IF LEFM solution** used to obtain parametric data points is shown to be **~40-50% conservative** when compared to more accurate FE LEFM analysis of identical cases; thus, **best estimate fit to parametric results considered appropriate**.
- Plant specific evaluation for K_{IP}, using FE LEFM, may be performed to reduce conservatism, as necessary

Discussion

Summary

- BWROG to submit two (2) P-T curve LTRs for NRC review in Fall 2011

Submittal	Supporting Documentation
P-T Curve LTR - SIR-05-044, Rev. 1	PVP2011-57015 PVP2011-57742 PVP2011-57014 ORNL/TM-2010/246 ASME Paper 78-PVP-91 EPRI Report NP-339
0900876-401, Rev. 0	0900876-301, Rev. 0 0900876-302, Rev. 0 0900876-303, Rev. 0 0900876-304, Rev. 0

- Objective of current meeting is to introduce intent, scope, and summarize significant conclusions of each LTR to the NRC.

Summary

- SIR-05-044, Rev. 1
  - Incorporates instrument nozzle fracture mechanics methods, previously applied for plant specific submittals, into the existing P-T curve LTR
- 0900876-401, Rev. 0
  - Provides a general LEFM solution for water level instrument nozzles based on parametric evaluation of the WLI nozzle design. Intended to eliminate need for plant specific WLI nozzle FEA.