Response to NuScale Technical Report Audit Question

Question Number: A-5.PTLR-14

Receipt Date: 10/20/2023

Question:

NuScale provided EC-107452 R1 in response to audit Questions A-5.PTLR-2, 3, 4, and 5. Based on the information provided in EC-107452 R1:
Page 102: 3.5.1.3 – Please provide a high-level description of the overall analytical approach. Specifically, please confirm or correct the following description of the analytical approach: (1) The 2-Dimensional (2D) 1000 psi calculation was just to identify limiting locations, and a different pressure could have been chosen. (2) the 3-Dimensional (3D) 1 psi model is to calculate stress-intensity factor (SIF) coefficients and then scale up as function of actual applied stress via linear superposition.

A follow-up question was received on December 5, 2023:

- The response did not clarify how the Kim value would be scaled proportionally.

Follow-up question received on January 19, 2024:

- The response about not needing to scale K_{Im}/p is acceptable. However, the staff <u>disagrees</u> that the equation $KImp=Mm\times Rit$ is equivalent to the equation $KIm=Mm\times Rit$. Specifically, these two equations are only equivalent at one point: p=1psi. The equivalence cannot be generalized.

The equation should be written as: $KImpp=1psi=Mm\times Rit$,

which means $KImp=1psi=Mm\times Rit$

So, the inequality in the response to PTLR-14 should be corrected to *p<KIc-KIt2KImp=1psi*

Equations 3-14, 3-15, and 3-16 in the SDAA should be corrected such that K_{Im} is replaced by $(K_{Im})_{p=1psi}$

Response:

Original Response:

The basis for determining allowable pressure is specified in ASME Section XI Non-mandatory Appendix G, Paragraph G-2215. The requirement to be satisfied shall be:

$$2K_{Im} + K_{It} < K_{Ic}$$

The above criteria is rearranged using substitution to solve for allowable pressure as follows.

$K_{Im} = f(p) = M_m\left(\frac{pR_i}{t}\right)$ Noting $\frac{f(p)}{p} = \left(\frac{M_m \times R_i}{t}\right)$= Constant at a given location and flaw orientation.

This is a linear equation whereby the output divided by the input is constant.

Requirement of ASME Section XI Non-mandatory Appendix G, Paragraph G-2215 then becomes.

$$2\left(\frac{M_m \times R_i}{t}\right)p \; + \; K_{It} < K_{Ic}$$

$$p < \frac{K_{Ic} - K_{It}}{2\left(\frac{M_m \times R_i}{t}\right)}$$

$$p < \frac{K_{Ic} - K_{It}}{2\left(\frac{f(p)}{p}\right)}$$

In this specific analysis, K_{Im} is determined using a pressure of 1 psig. Therefore, the basis criteria as it applies to the methodology outlined by TR-130877 can be rewritten as:

$$p < \frac{K_{Ic} - K_{It}}{2\left(K_{Im}\right)_{p=1\ psi}}$$

The following outlines the high level approach on how the above parameters are obtained to determine the allowable pressure.

1) Section 3.3.2 of TR-130877-P identifies critical regions of the RPV as the most limiting regions for both thermal and pressure stress locations. The two-dimensional (2D) model uses the thermal transients to identify the critical time point and global locations for thermal stresses. The 2D model uses an internal pressure of 1000 psi to identify both global and local critical locations for pressure stresses.
2) For the critical locations identified in item 1, the 2D thermal transient analysis:
   a) determines the temperature at the crack tip required for calculating the critical stress intensity factory (SIF) measuring fracture toughness (K_{IC}), as described in Section 3.3.3.3 and Equation 3-1 of TR-130877-P.
   b) determines the 3rd order polynomial coefficients (c_0, c_1, c_2, c_3,) for calculation of SIFs due to thermal stress (K_{IT}), as described in Section 3.3.3.4.2 and Equation 3-7 of TR-130877-P.
3) For the critical locations identified in item 1, the three-dimensional (3D) pressure (1-psig) application model:
   a) singularly simulates critical location flaws with no other flaws present.
   b) calculates the maximum SIF (K_{Im}) due to internal pressure for one loadstep in the analysis (p = 1 psi), as discussed in Section 3.3.3.4.1 and Equation 3-2 and Equation 3-5 of TR-130877-P. K_{Im}/psi in this analysis is a constant equal to M_m x R_i/T. I does not require scaling to determine allowable pressure.
   c) calculates the SIFs due to transient thermal stresses (K_{It_c0}, K_{It_c1}, K_{It_c2}, K_{It_c3}) by superposition, as discussed in Section 3.3.3.4.2 and Equation 3-10 of TR-130877-P.
4) NuScale uses the results of items 1 through 3 above to calculate the following parameters:
   a) the maximum SIF (K_{IT}) for any axial or circumferential surface crack inside or outside the RPV
   b) the RPV allowable pressures for preservice hydrostatic testing, normal heatup and cooldown transients, and inservice leak and hydrostatic testing conditions, as Section 3.3.3.5 of TR-130877-P describes.

Revision 2 of EC-107452 is in the electronic reading room (eRR) in response to audit question A-5.PTLR-18.

Response to NRC Follow-up Question received on December 4, 2023:

NuScale and the NRC discussed the follow-up question on December 11, 2023. The NRC noted that there should be a p term in Equation 3-13 of TR-130877-P. NuScale noted that p is equal to 1 psi, so Equation 3-13 did not include the pressure term. The markups to TR-130877-P attached to this response add the pressure term to Equation 3-13 in TR-130877-P and include a clarification that p = 1 psi.

Response to NRC Follow-up Question received on January 19, 2024:

The inequality in the original response to audit question A-5.PTLR-14,

$$p < \frac{K_{Ic} - K_{It}}{2K_{Im}}$$

has been revised to:

$$p < \frac{K_{Ic} - K_{It}}{2\left(K_{Im}\right)_{p=1\ psi}}$$

Equations 3-13 through 3-16 in TR-130877-P, Pressure and Temperature Limits Methodology, have been revised to replace $K_{Im}/1\ psi$ with $(K_{Im}/p)_{p\ =\ 1\ psi}$.

Markups of the affected changes, as described in the response, are provided below:

Audit Question A-5.PTLR-14, Audit Question A-5.PTLR-17

The allowable pressure associated with a specified temperature along a P-T limits curve is:

$$P = \frac{(K_{IC} - K_{IT})t}{SF \cdot M_m \cdot R_i} = \frac{K_{IC} - K_{IT}}{SF \cdot (K_{Im}/p)_{p\,=\,1\,psi}} \quad \text{Eq. 3-13}$$

The appropriate K_{IT} and SF values used for various conditions are:

- For preservice hydrostatic tests, a steady-state condition ($K_{IT} = 0$) is applied, and the required structural factor $SF = 1$.

Audit Question A-5.PTLR-14, Audit Question A-5.PTLR-17

$$P = \frac{K_{IC}t}{M_m \cdot R_i} = \frac{K_{IC}}{(K_{Im}/p)_{p\,=\,1\,psi}} \quad \text{Eq. 3-14}$$

Performance of the allowable pressure calculation occurs for the crack with highest M_m that bounds other cracks. The basis for the preservice limiting pressure is NUREG-0800, Section 5.3.2 (Reference 6.1.4).

For the heat up and cooldown transients, the thermal SIF K_{IT} calculation occurs at selected time points, and the required structural factor $SF = 2$.

Audit Question A-5.PTLR-14, Audit Question A-5.PTLR-17

$$P = \frac{(K_{IC} - K_{IT})t}{2M_m \cdot R_i} = \frac{K_{IC} - K_{IT}}{2(K_{Im}/p)_{p\,=\,1\,psi}} \quad \text{Eq. 3-15}$$

For ISLH, the SIF K_{IT} from heat up and cooldown transients conservatively apply to the most limiting crack, and the required structural factor $SF = 1.5$.

Audit Question A-5.PTLR-14, Audit Question A-5.PTLR-17

$$P = \frac{(K_{IC} - K_{IT})t}{1.5M_m \cdot R_i} = \frac{K_{IC} - K_{IT}}{1.5(K_{Im}/p)_{p\,=\,1\,psi}} \quad \text{Eq. 3-16}$$

3.3.4.6 10 CFR 50, Appendix G, Pressure and Temperature Limits

Appendix G of Reference 6.1.3 requires that the P-T limits are at least as conservative as limits obtained by following the Appendix G of Reference 6.1.5, methods presented in Section 3.3.4.5. Additionally, Table 1 of Appendix G of Reference 6.1.3 requires further limitations (Table 3-3).