Fauske & Associates, Inc.

16W070 West 83rd Street, Burr Ridge, Illinois 60521

Phone: (630) 323-8750 • Fax: (630) 986-5841 • email: info@fauske.com

Technical Bulletin **No. 0298-2**

Thermally-Induced Pressurization of Isolated Water-Filled Piping Sections

OVERVIEW

On September 30, 1996, the U. S. Nuclear Regulatory Commission (NRC) issued Generic Letter 96-06 requesting that addressees determine if piping systems that penetrate the containment are susceptible to thermal expansion of fluid so that overpressurization of piping could occur.

The Generic Letter reports actual and postulated situations in which the thermal expansion of water in piping systems within containment could product undesirable consequences including degraded operability, loss of function of safety systems, or breach of containment integrity via bypass leakage.

Classic analytical methods have been developed and successfully implemented, using MathCad 6.0, to provide a detailed technical basis for evaluation of the integrity of isolated water-filled pipe sections. The methodology performs heat transfer and stress analyses based on best-estimate modeling of the relevant phenomena. These methods indicate that even though particular containment penetrations may undergo elastic deformation, they will not experience complete wall rupture or even significant deformation.

RELEVANT PHENOMENA

During postulated LOCAs, the pipe segment inside the containment is mainly heated by steam condensation onto the pipe surface. The heated segment, in return, heats water inside it by natural convection.

Natural convection inside the pipe causes water in the heated segment to convect to the unheated segment, resulting in a rise in temperature of water in the unheated segment, but to a lesser extend than water in the heated segment.

A rise in temperature of water in the unheated segment leads to heat transfer to the pipe wall of the unheated segment which eventually transfers heat by natural convection to air (and to much less extent by radiation) in the auxiliary building.

The relevant heat transfer processes are depicted in Figure 1.

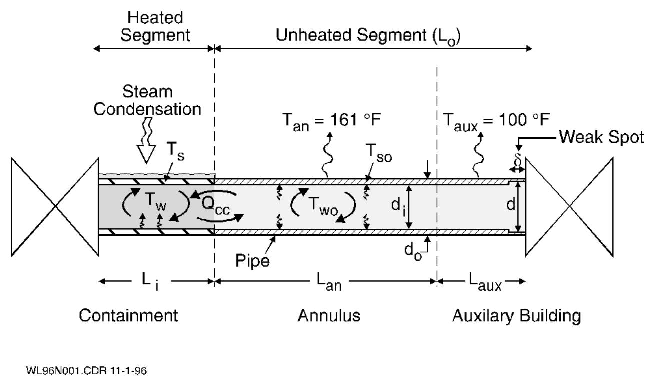

Figure 1

ANALYTICAL METHODS

Based on these heat transfer processes, separate energy balances on the heated and unheated portions of the isolated pipe segment can be written and integrated over time to yield the transient temperature rise of the water.

Next, the temperature rise of the water must be related to the pipe pressurization. This is accomplished with the thermodynamic equation of state for compressible substance which can be written as,

$$dP = \left(\frac{\partial P}{\partial T}\right)_v dT + \left(\frac{\partial P}{\partial V}\right)_T dV \qquad (1)$$

where P is pressure, T is temperature, and V is volume of the substance.

Eq. (1) indicates that the pressure rise is related to both the temperature and volume change of the substance. Since the pipe that contains compressed water will expand in response to increased internal pressure as well as increased pipe wall temperature, the actual pressure increase per unit temperature is reduced (i.e., the second term on the right hand side of Eq. (1) is negative).

Assuming that the pipe behaves in an elastic manner, the pipe expansion due to internal pressurization can be related to the modulus of elasticity and Poisson's ratio for the pipe. Similarly, the pipe wall expansion due to temperature rise can be related to the linear coefficient of thermal expansion for the pipe material.

Thus, the expressions for thermal heatup, water convection within the pipe, pipe expansion, and the equation of state for a compressed substance must be combined to arrive at a final prediction of the pipe pressurization.

SUMMARY

Figures 2 and 3 depict the temperature distribution and internal pressurization of an isolated 6" stainless steel pipe segment when subjected to LOCA conditions inside containment. A maximum pressure rise of 1900 psi occurs at 2000 seconds. This exceeds the ASME yield limit of the pipe which occurs when internal pressure exceeds 1770 psi for the specified pipe size and material type. Additional calculations indicate that the level of pipe strain calculated for this case would only result in a small yield according to the ASME code and would not lead to pipe rupture or significant pipe deformation.

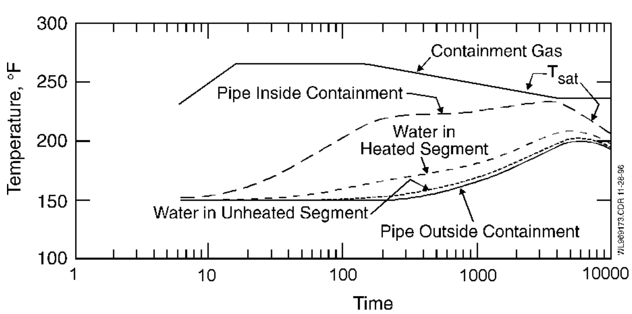

Figure 2

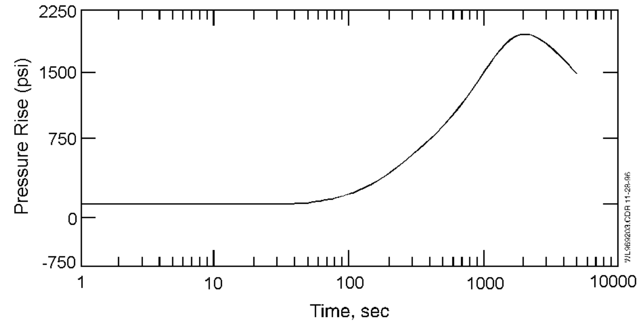

Figure 3

The results presented here are for a particular set of geometric and accident conditions. Plant-specific results would be dependent on the actual pipe geometry and material type as well as the assumed LOCA conditions.

Technical contact:

Damian Stefanczyk
Phone: (630) 887-5208
email: stefanczyk@fauske.com

Visit our web site at www.fauske.com for a complete set of FAI Technical Bulletins.