ATTACHMENT 1

Letter from M. L. Marchi (WPSC)

to

Document Control Desk (NRC)

Dated

August 6, 1998

Request for Exemption to 10 CFR 50.60

ASME Code Case N-514

and

ASME Code Case N-588

INTRODUCTION

Title 10 CFR 50.60 states that all light water nuclear power reactors must meet the fracture toughness and material surveillance program requirements for the reactor coolant pressure boundary as set forth in Appendices G and H to 10 CFR Part 50. More specifically, Appendix G of 10 CFR Part 50 defines pressure/temperature (P/T) limits during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests to which the pressure boundary may be subjected to over its service lifetime. 10 CFR 50.60 specifies that proposed alternatives to the described requirements of 10 CFR Part 50, Appendices G and H may be used when an exemption is granted by the Commission under 10 CFR 50.12.

BACKGROUND

Wisconsin Public Service Corporation (WPSC) is currently in the process of preparing a proposed technical specification amendment request to update the LTOP system enabling temperature and the pressure/temperature limit curves for heatup and cooldown for KNPP. With assistance from Westinghouse Electric Corporation and ATI Consulting, WPSC has developed an alternative approach for determining the RT_{NDT} and RT_{PTS} based on the master curve methodology. The basis for the use of this approach and a corresponding additional exemption request will be included with the forthcoming technical specification amendment. With NRC approval, WPSC plans to use this new methodology for determining RT_{NDT} and RT_{PTS} along with ASME Code Cases N-514 and N-588 for assessing the integrity of the KNPP reactor vessel relative to the requirements of 10 CFR 50.60, 10 CFR 50.61, and Appendices G and H to 10 CFR Part 50, which encompass pressurized thermal shock (PTS) and upper shelf energy (USE) evaluations, and any potential impact on low temperature overpressure limits or pressure/temperature limits.

To support this larger effort, and in accordance with 10 CFR 50.12, WPSC is hereby requesting NRC approval to utilize ASME Code Cases N-514 and N-588 for determining the LTOP system enabling temperature and for establishing pressure/temperature limits for heatup and cooldown, respectively. Application of these Code Cases will provide for a larger operating window during startup/shutdown of the plant (at least 40°F) and eliminate unnecessary operational restrictions on starting/operating the reactor coolant pumps at low temperature and pressure.

DISCUSSION

Pressure/temperature (P/T) limits for low temperature overpressure (LTOP) events can be characterized by two parameters: the system enable temperature and the LTOP system set point. According to current regulatory guidelines, the LTOP system must be enabled at temperatures less than or equal to RT_{NDT} + 90°F, where RT_{NDT} is the limiting adjusted reference temperature, including margin, at the one quarter thickness location. At temperatures greater than RT_{NDT} + 90°F, the LTOP system need not be provided. The maximum LTOP system pressure is determined based upon system specific considerations, but is chosen such that the maximum pressure attained in the vessel will not exceed the P/T limit as defined by Appendix G of 10 CFR Part 50.

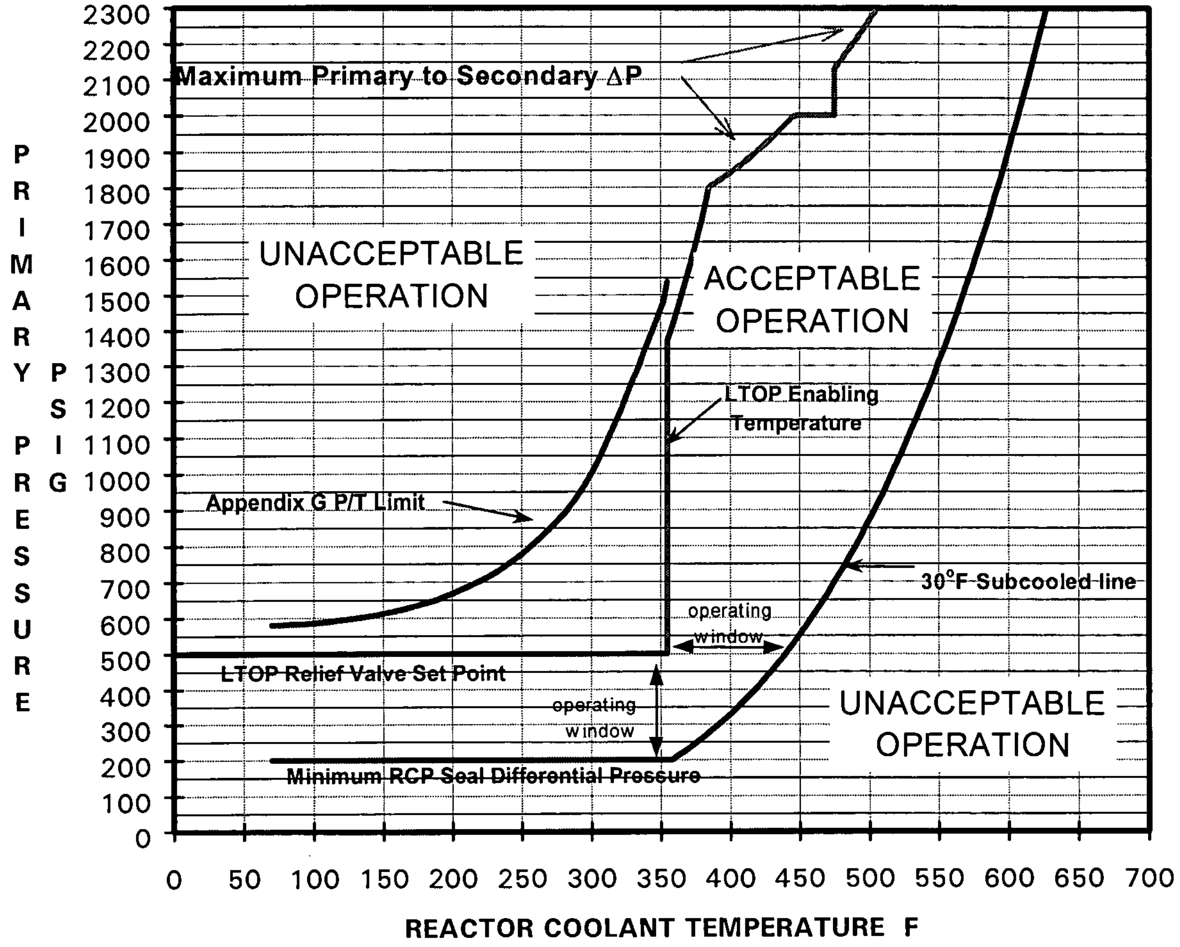
The current LTOP system set point and enabling temperature produce operational constraints by restricting the temperature where both reactor coolant pumps may operate, thereby limiting the means available to the operator to heat up or cool down the plant. The LTOP system with the existing set point of 500 psig has been demonstrated adequate to maintain the reactor pressure vessel within the limits of Appendix G during energy input and mass input induced LTOP transients for reactor coolant system (RCS) temperatures greater than or equal to 140°F. However, when the RCS temperature is less than 140°F, one of the reactor coolant pumps must be administratively prevented from starting by placing the control room switch position in PULL-TO-LOCK. This must be done to ensure that the Appendix G curve is not violated should a low-temperature mass input transient occur.

The "operating window" through which the operator can heat up or cool down the reactor coolant system is determined by the difference between the maximum allowable pressure determined by Appendix G and the minimum required pressure for the reactor coolant pump seals (adjusted for measurement uncertainty) and also the temperature difference between the system enabling temperature and the 30°F subcooled curve. The purpose of the subcooling curve is to ensure that the reactor coolant system remains below saturation conditions. The current operating window is shown in Figure 1. The current LTOP enabling temperature is 355°F and the set point of the LTOP relief valve is 500 psig. Referring to Figure 1, it can be seen that the horizontal portion of the operating window is controlled by the LTOP enabling temperature and the 30°F subcooling curve, while the vertical portion of the operating window is controlled by the LTOP relief valve set point and minimum pump seal differential pressure, with the former determined by the Appendix G P/T limit curve and the latter established as 200 psig. The actual limits may in fact be further restricted by other system design parameters, for example, residual heat removal system design pressure.

The pressure/temperature limits for heatup and cooldown are derived by combining the stress intensity factors for pressure and thermal loadings. The current ASME Section XI, Appendix G approach mandates the consideration of an axial flaw in circumferential welds for purposes of calculating pressure/temperature limits. Consideration of an axial reference flaw for a circumferential weld results in a stress intensity value due to pressure that is essentially twice the magnitude of the stress intensity factor due to pressure derived from a circumferential reference flaw. The consequence of requiring the use of a longitudinal reference flaw to derive the stress intensity due to pressure in a circumferential weld is that the allowable pressure is reduced by a factor of two. Thus, the vertical portion of the operating window is significantly reduced. The use of a circumferentially oriented reference flaw in the circumferential weld instead of the current axial reference flaw to establish pressure/temperature limits will eliminate the restriction on operation of the second reactor coolant pump below 140°F.

Figure 1

KEWAUNEE RCS COMPOSITE
PRESSURE / TEMPERATURE LIMITATIONS



TECHNICAL BASIS FOR CODE CASE N-514

ASME Code Case N-514 is contained in Attachment 2. This Code Case provides benefits in two areas. First, the Code Case requires that the LTOP system must be enabled at coolant temperatures less than 200°F or at coolant temperatures corresponding to a reactor vessel metal temperature less than RT_{NDT} + 50°F, whichever is greater. RT_{NDT} is the limiting adjusted reference temperature, including margin, at the one quarter thickness location. This new definition for enabling temperature provides for opening the horizontal portion of the operating window by an additional 40°F over the definition provided in Branch Technical Position RSB 5-2, "Overpressurization Protection of PWRs While Operating at Low Temperatures," attached to the Standard Review Plan Section 5.2.2. The second benefit is that the Code Case limits the maximum pressure in the vessel to 110% of the pressure determined to satisfy Appendix G of Section XI.

The ASME Section XI Working Group on Operating Plant Criteria (WGOPC) has prepared a technical bases document for Code Case N-514. The technical bases document is contained in Attachment 3. This technical bases document provides justification for limiting the maximum pressure in the vessel to 110% of the pressure determined to satisfy Appendix G of Section XI and enabling the LTOP system at temperatures less than 200°F or at coolant temperatures corresponding to a reactor vessel metal temperature less than RT_{NDT} + 50°F, whichever is greater.

The WGOPC, which has responsibility for Appendix G of Section XI, has considered the burden and safety impact imposed by the LTOP criteria, and has developed Code guidelines for determining the LTOP set point pressure and the required enabling temperature. These guidelines will relieve some operational restrictions, yet provide adequate margins to prevent failure of the reactor vessel. Further, by relieving the operational restrictions, these guidelines result in a reduced potential for activation of pressure relieving devices, thereby improving nuclear plant safety.

TECHNICAL BASIS FOR CODE CASE N-588

Code Case N-588 (included as Attachment 4) provides benefits in terms of calculating pressure/temperature limits by revising the Section XI, Appendix G reference flaw orientation for circumferential welds in reactor vessels. The reference flaw is a postulated flaw that accounts for the possibility of a prior existing defect that may have gone undetected during the fabrication process. When considering a reference flaw with respect to a weld, the reference flaw would represent any prior existing defect that may have been introduced during fabrication. Thus, the intended application of a reference flaw is to account for prior existing defects that could physically exist within the geometry of the weldment. The current ASME Section XI, Appendix G approach mandates the consideration of an axial reference flaw in circumferential welds for purposes of calculating pressure/temperature limits. Postulating the Appendix G reference flaw in a circumferential weld is physically unrealistic and overly conservative, because the length of the flaw is 1.5 times the vessel thickness, which is much longer than the width of the reactor vessel girth weld. The possibility that an axial flaw may extend from a circumferential weld into a plate/forging or axial weld is already adequately covered by the requirement that axial flaws be postulated in plates/forging and axial welds. The fabrication of reactor pressure vessels for nuclear power plant operation involved precise welding procedures and controls designed to optimize the resulting weld microstructure and to provide the required material properties. These procedural controls were also designed to minimize defects that could be introduced into the weld during the fabrication process. Industry experience with the repair of weld indications found during pre-service inspection, and data taken from destructive examination of actual vessel welds, confirms that any remaining flaws are small, laminar in nature, and do not cross transverse to the weld bead orientation. Therefore, any potential defects introduced during the fabrication process, and not detected during subsequent non-destructive examinations, would only be expected to be oriented in the direction of weld fabrication. For circumferential welds this indicates a postulated defect with a circumferential orientation.

Due to progress made in NDE techniques over the last thirty years, it is very unlikely to have large, undetected flaws present in the beltline region of reactor vessels. It is further unlikely to have axial cracks originating from a circumferential weld perpendicular to the weld seam orientation in reactor vessels. Both experience and engineering studies indicate that the primary degradation mechanism affecting the beltline region of the reactor vessel is neutron embrittlement. No other service induced degradation mechanism exists at a pressurized water reactor to cause a prior existing defect located in the beltline region of the reactor vessel to grow while inservice. Based on these considerations, and the fact that the pressure/temperature limit for reactor operation is the limiting pressure for any of the materials in the vessel, it is not necessary to include additional conservatism in the assumed flaw orientation for circumferential welds. ASME Section XI Code Case N-588 and the accompanying Appendix G Code change corrected this inconsistency in assumed flaw orientation for circumferential welds in vessels when calculating operating P/T limits. During development of Code Case N-588 and the accompanying Code change, the Section XI WGOPC developed a solution of the stress intensity factors for inside and outside surface reference flaws, performed a circumferential flaw margin assessment, and provided justification of the Code change. The bases for the stress intensity factor solution for a circumferential semi-elliptical surface flaw in a cylinder and circumferential flaw margin assessment have been reproduced below from the "Technical Basis Document for Revised Section XI, Appendix G Reference Flaw Orientation for Circumferential Welds in Reactor Vessels (ISI-97-11), 5/1/97," and "ASME Section XI, Appendix G Heatup and Cooldown Curves for Circumferential Welds (Draft), 12/2/97," respectively. These documents are included as Attachment 5.

Stress Intensity Factor Solution for a Circnmferential Semi-elliptical Surfacc Flaw in a Cylinder (Developed by Ken Yoon, Framatome Technologies)

I. Stress Intensity Factor for a Circumferential Inside Surface Flaw in a Cylinder under Internal Pressure Load

A stress intensity factor for a circumferential inside surface flaw in a cylinder can be found in Welding Research Council Bulletin 413 - equation 3.11:

$$K_{Ip} = (SF)\, p[1 + (R_i/(2t))]\sqrt{\pi a}\, F2$$

and

$$F2 = 0.885 + 0.233(a/t) + 0.345(a/t)^2$$

The effect of crack face pressure load is not considered to be consistent with the axial flaw equation in Appendix G. The safety factor (*SF*) is set to one in this equation since the safety factor of 2 is included in equation 1 in G-2215. The revised stress intensity factor equation is:

$$K_{Ip} = pR_i/(2t)\sqrt{\pi a}\, F2$$

Since the M_m term in Appendix G in G-2214 is defined as follows,

$$K_{Ip} = M_m\ [pR_i/t]$$

and $R_i/t = 10$ and $a/t = 0.25$

$$M_m = pR_i/(2t)\ \sqrt{\pi a}\ F2\ [t/(pR_i)] = 0.5\ \sqrt{\pi/4}\ F2\ \sqrt{t}$$

$$F2 = 0.885 + 0.233(a/t) + 0.345(a/t)^2$$
$$F2 = 0.964813$$

$$M_m = 0.4274\ \sqrt{t}$$

This is slightly lower than the M_m factor for an outside flaw shown below. To simplify the Code procedure, it is made to be equal to the M_m for an outside flaw of $0.443\ \sqrt{t}$. This is an increase of 3.8%.

II. Stress Intensity Factor for a Circumferential Outside Surface Flaw in a Cylinder for Internal Pressure Load.

Attachment 5 provides a stress intensity factor equation for a circumferential outside surface flaw in a cylinder as:

$$K_I = \sigma\ F\ (\pi\ 0.25/Q)^{0.5}\sqrt{t}$$

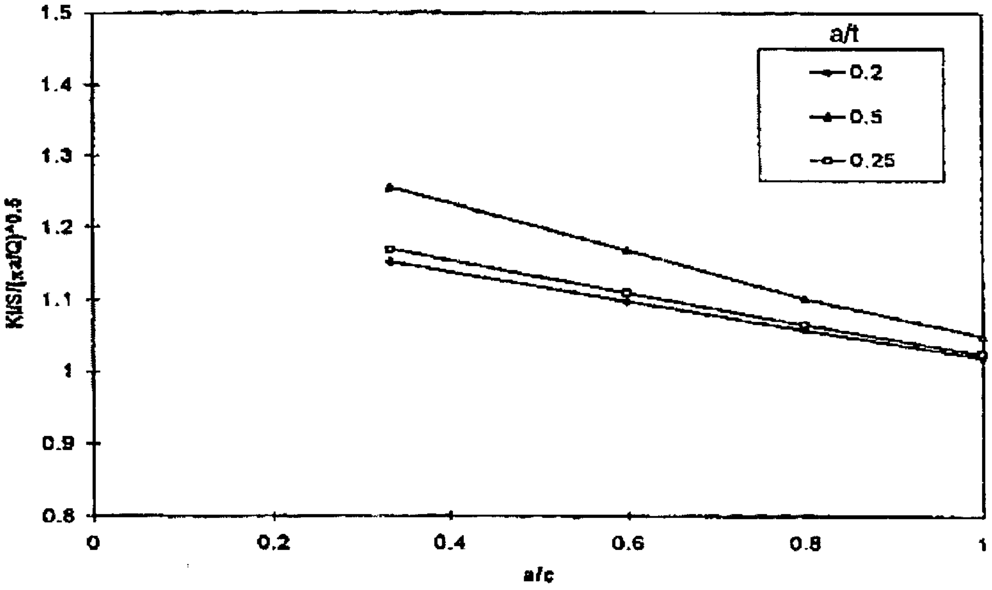
For R/t = 10, a/t = 0.25, and a/c = 1/3, F can be obtained from Figure 2

$$F = 1.168$$

$$K_{Ip} = M_m[pR_i/t]$$

$$M_m = 0.442733\ t^{0.5}$$

Figure 2. Extrapolation of Geometric Factor for Stress Intensity Factor Equation



III. Stress Intensity Factor for Thermal Load

In WRC Bulletin 413, the stress intensity factors for thermal load, K_{It}, for both axial and circumferential flaws were discussed. It was revealed that at the one quarter wall thickness location, the K_{It} values for both axial and circumferential flaws are nearly identical and subsequently the K_{It} equation for an axial flaw was adopted in Appendix K. Since this same expression was used for Appendix G, the K_{It} equations for an axial flaw in Appendix G are applicable for a circumferential flaw as well.

IV. Summary of Stress Intensity Factor Solutions for Circumferential Oriented Reference Flaw

For both inside and outside circumferential reference flaws

$K_{Ip} = M_m\ [pR_i/t]$ ksi √in

where

$M_m = 0.886$ for $t<4$

$M_m = 0.443\sqrt{t}$ for $4 \leq t \leq 12$

$M_m = 1.535$ for $t>12$

Margins for Circumferential Flaws (Developed by Ron Gamble, Sartrex Corp.)

This section assesses the margins associated with the ASME Code Case N-588, demonstrates the change maintains margins consistent with the margins historically used for postulated axial flaws, and shows the margins associated with the historical methodology are unnecessarily conservative for circumferential welds.

I. Appendix G Margin Assessment

The general Code criterion for establishing P/T limits is defined in Appendix G as

$$2K_{Ip} + K_{It} = K_{Ia} \qquad (1)$$

where

K_{Ip} = calculated stress intensity factor for pressure loading,
K_{It} = calculated stress intensity factor for thermal loading during reactor cooldown, and
K_{Ia} = reference stress intensity factor.

The margin against extension of the postulated quarter thickness reference flaw is

$$\text{Margin} = K_{Ia} / (K_{Ip} + K_{It}). \qquad (2)$$

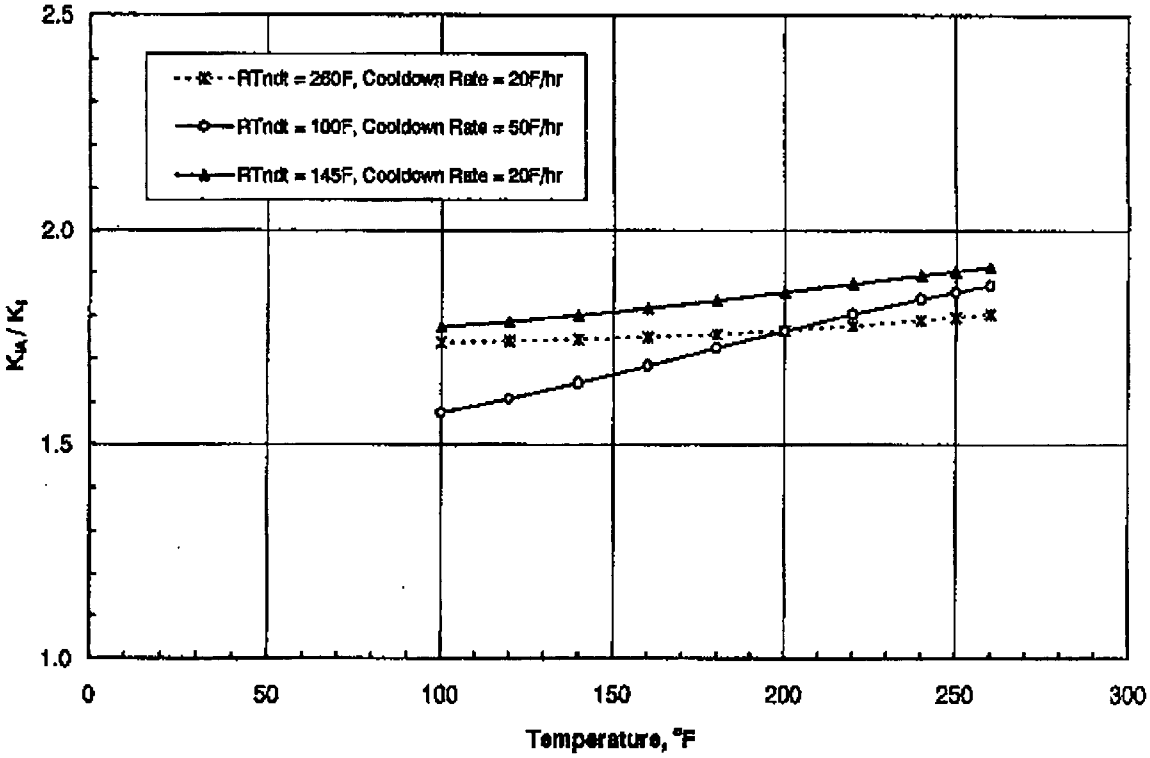
Solving for K_{Ip} from Equation 1 and substituting into Equation 2 the margin can be written as

$$\text{Margin} = 2K_{Ia} / (K_{Ia} + K_{It}). \qquad (3)$$

Equation 3 is the margin obtained by operating the vessel on the P/T limit curve defined by the Appendix G procedure. Because K_{Ia} and K_{It}, respectively, are the same for either the axial or circumferential flaw orientations, the margins for the two orientations are identical as can be seen from equation 3. In other words, postulating a circumferential reference flaw in a circumferential weld provides the same margin as an axial flaw postulated in a plate/forging or axial weld, for any specific temperature, RT_{NDT}, and heatup or cooldown rate.

It can be seen from equation 3 that the margin varies during heatup or cooldown and is a maximum of 2 when the thermal stress is negligible, and less than 2 depending on the heatup or cooldown rate and material toughness. The margin ranges from 1.5 to 2 for the material conditions and heatup or cooldown rates used for reactor cooldown. This is illustrated in Figure 3 for some different values of RT_{NDT} and cooldown rates.

Figure 3. Illustration of K_{IA}/K_I Margins for Axial Flaws in Plate and Axial Welds, and Circumferential Flaws in Circumferential Welds as a Function of Cooldown Rate and RT_{NDT}



When an axial flaw is postulated in a circumferential weld the margins are significantly greater than those for axial flaws postulated in plates/forgings or axial welds. The following illustrates the large degree of conservatism when the historical Code methodology is applied to a vessel with a postulated inside surface flaw in a circumferential weld.

The value of K_{Ip} for an inside surface axial flaw is

$$K_{Ip} = 0.926\,pR_i/t^{0.5}, \qquad (4)$$

And the value of K_{Ip} for a circumferential flaw is

$$K_{Ip} = 0.443pR_i/t^{0.5} \qquad (5)$$

where

p = pressure, and
R_i = vessel inner radius.

Substituting equation 4 into equation 1 and solving for p gives

$$p = 0.54(K_{Ia}-K_{It})t^{0.5}/R_i. \qquad (6)$$

The pressure in equation 6 is the allowable pressure assuming an axial reference flaw.

If a circumferential weld having a postulated circumferential flaw is required to operate at the allowable pressure defined using an axial reference flaw, the value of K_{Ip} for the circumferential flaw is obtained by substituting equation 6 into equation 5, or

$$K_{Ip} = 0.239\,(K_{Ia} - K_{It}). \qquad (7)$$

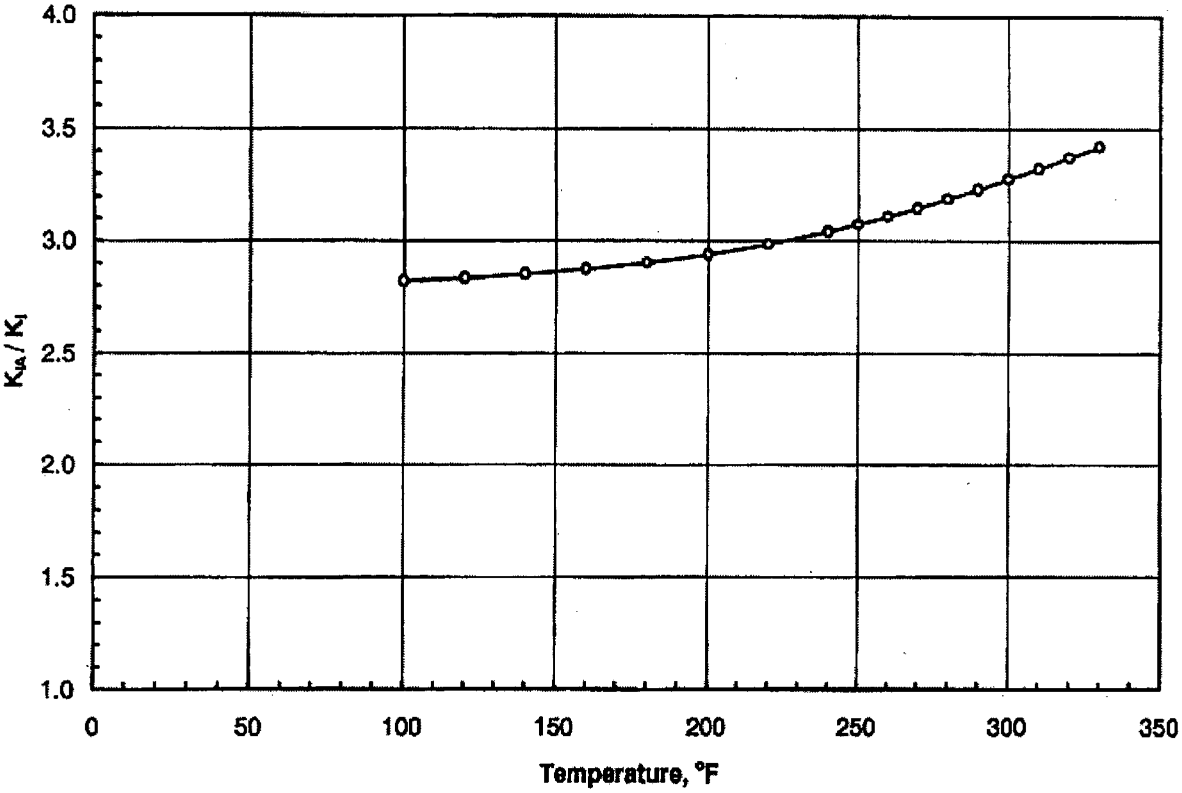
The margin for a circumferential weld when the P/T limit is defined using a postulated axial flaw is obtained by substituting equation 7 into equation 2, or

$$\text{Margin} = 4.18K_{Ia} / (K_{Ia} + 3.18K_{It}). \qquad (8)$$

Equation 8 shows the margin is a maximum, constant value of 4.18 when the thermal stress is negligible. When there is a non zero thermal stress the margin is less than 4.18 and depends on the heatup or cooldown rate and RT_{NDT}.

The margin from equation 8 is illustrated in Figure 4 for a cooldown rate of 20°F/hr and RT_{NDT} = 260°F. The information presented in equation 8 and Figure 4 illustrates that the prior Code procedure, which postulates axial flaws in circumferential welds, provides margins substantially greater than Code margins for axial welds and plates/forgings (as shown in Figure 3), and is unnecessarily conservative for defining P/T limits for circumferential welds. Application of ASME Code Case N-588 corrects this inconsistency regarding the magnitude of the margins applied to axial flaws in plate and axial welds, and circumferential flaws in circumferential welds.

Figure 4. Illustration of K_{IA}/K_I Margin for Prior Code Procedure Where Axial Flaws are Postulated in Circumferential Welds, CR = 20°F/hr, RT_{NDT} at t/4 = 260°F

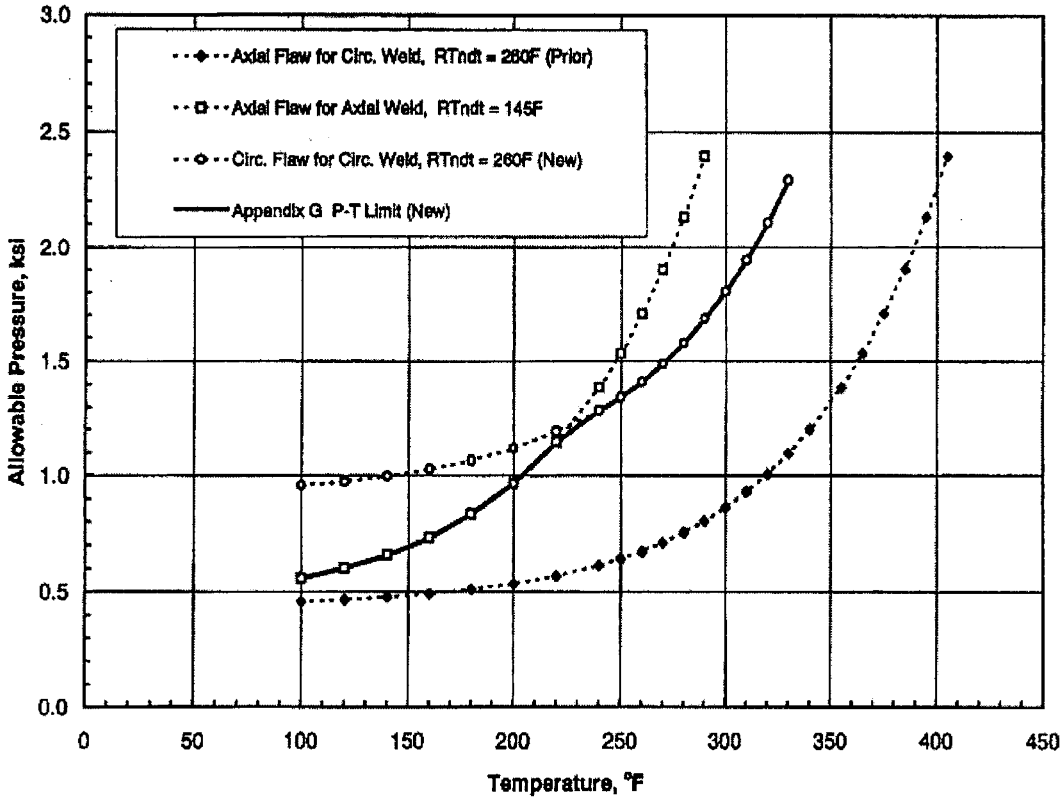


II. Illustration of ASME Code Case N-588

The effect of the Code change (i.e., a circumferential rather then an axial reference flaw is postulated in a circumferential weld) on the vessel P/T limit curve is illustrated in Figure 5. Included in the figure are P/T curves for : (1) the prior Code procedure where an axial reference flaw is postulated in a circumferential weld, (2) the new procedure where a circumferential reference flaw is postulated in a circumferential weld, (3) an axial reference flaw in an axial weld, and (4) the overall P/T curve determined using the Code procedure to determine the limiting allowable pressure at any specific temperature.

In conclusion, the results in Figure 5 indicate that Code Case N-588 provides less restrictive P/T limits for circumferential welds compared to prior Code guidelines where axial flaws were postulated in circumferential welds. At the same time, Code Case N-588 provides margins equivalent to those intended by the Code for plates/forgings and axial welds as indicated by the results presented in Figures 3.

Figure 5. Illustration of Cooldown P-T Limit Curves for Axial and Circumferential Flaws, CR = 20°F/hr



Application of Code Case N-514 and N-588 at KNPP

WPSC requests approval to use Code Case N-514 to establish the temperature for enabling the LTOP system and Code Case N-588 to establish pressure/temperature limits for the KNPP reactor vessel. The KNPP reactor vessel is fabricated of ring forgings and circumferential welds. There are no longitudinal welds in the KNPP reactor vessel. Approval to use Code Case N-514 and Code Case N-588 will continue to allow KNPP to maintain the existing LTOP set point throughout the end of plant life, thereby eliminating the need to modify the LTOP system or replace the relief valve, and eliminate the need to restrict operation of the second reactor coolant pump below 140°F. With approval to use Code Case N-588, KNPP will not need to apply the portion of Code Case N-514 which allows the maximum pressure in the vessel to reach 110% of the pressure determined to satisfy Appendix G of Section XI.

INHERENT MARGINS TO 10 CFR PART 50 APPENDIX G

There are numerous conservative assumptions in the development of Appendix G pressure/temperature curve calculations. These include:

1. A safety factor of 2.0 on the primary membrane (pressure) stresses.

2. A margin factor applied to the shift in RT_{NDT} of one or two standard deviations, by Regulatory Guide 1.99, Rev. 2.

3. The use of the reference stress intensity curves (K_{IR}) by ASME Sections III and XI, Appendix G bounds the dynamic crack initiation and crack arrest toughness. Further, the use of reference stress intensity curves bounds the crack initiation fracture toughness (K_{IC}) properties.

4. Lower bound material propcrties are used in analyses. Further, increased mechanical properties of the vessel which accompany material embrittlement are not considered (increased yield strength and flow stress).

Also, there are numerous additional margins specific to KNPP which support these Code Cases, including:

5. The assumption of a 1/4 thickness surface flaw. No flaws exceeding the ASME Section XI allowable flaw size for volumetric examination have been detected in the beltline weld of the KNPP reactor vessel during the preservice examination or either of the two inservice examinations performed in 1985 and 1995.

6. A margin of 16.6 psig to account for setting uncertainty is included in the LTOP relief valve set point determination.

7. Use of very conservative heat transfer coefficients (7000 Btu/ hr-ft^2-°F), and neglecting the effects of cladding conductivity in the analysis of thermal stress in the P/T curves. Further, the thermal stress is calculated for fixed and constant rates of temperature change and does not reflect the intermittent rates actually experienced by the vessel. That is, hold points for items such as crud burst cleanup during shutdown and removing residual heat removal from service during startup act as a thermal soak period and reduce the integrated effect on thermal stress.

BASES FOR EXEMPTION

WPSC has concluded that this request meets the criteria in 10 CFR 50.12(a)(2) in that special circumstances are present. These special circumstances include:

10 CFR 50.12(a)(2)(ii)

Application of the regulation in the particular circumstances would not serve the underlying purpose of the rule or is not necessary to achieve the underlying purpose of the rule.

Basis: The purpose of the LTOP system enabling temperature and relief valve set point is to preclude reactor coolant system pressure from exceeding the Appendix G limits when there is a potential for non-ductile failure of the vessel material. ASME Code Cases N-514 and N-588 recognize the conservatism of the Appendix G curves and allow establishing a set point and enabling temperature which preserve an acceptable margin of safety while maintaining an adequate heatup/cooldown window and permitting multiple reactor coolant pump operation at low temperatures and pressures. Opening the heatup/cooldown window will also reduce the likelihood of actuation of protection system pressure relieving devices. The guidelines developed by the WGOPC for the LTOP system enabling temperature and relief valve set point provide the same range of margin against vessel failure for conditions where experience indicates these events occur, as ASME Section III and Section XI, Appendix G provides for the normal heatup and cooldown conditions. Code Case N-588 preserves the current ASME Section XI, Appendix G approach for developing pressure/temperature limits by postulating a circumferentially oriented reference flaw in a circumferential weld instead of an axially oriented reference flaw. These limits do not significantly change the likelihood of vessel failure associated with the normal heatup and cool down. Therefore, establishing the LTOP system enabling temperature and relief valve set point in accordance with ASME Code Cases N-514 and N-588 criteria satisfies the underlying purpose of the 10 CFR 50.60.

Based on the above, application of the regulation in the particular circumstances is not necessary to achieve the underlying purpose of the rule.

10 CFR 50.12(a)(2)(iii)

Compliance would result in undue hardship or other costs that are significantly in excess of those contemplated when the regulation was adopted, or that are significantly in excess of those by others similarly situated.

Basis: Administrative restrictions on the reactor coolant pump operation while at low reactor coolant system temperatures currently result in the inability to operate the two reactor coolant pumps concurrently thus preventing the simultaneous venting of both reactor coolant loops at a temperature below 140°F. This can delay the unit startup by approximately two hours. Additionally, the small operating window requires significant effort, beyond what is considered reasonable, to control the RCS temperature within the acceptable heatup and cooldown limits for this condition. This burden is unnecessary and can be alleviated by the application of these Code Cases. Without approval to use these Code Cases, WPSC may need to redesign the LTOP system or replace the current LTOP system relief valve.

Therefore, compliance would result in undue hardship or other costs that are significantly in excess of those contemplated when the regulation was adopted.

CONCLUSION

ASME Code Cases N-514 and N-588 allow setting the LTOP actuation set point and enabling temperature such that the 10 CFR 50 Appendix G and ASME Section XI Appendix G limits are not exceeded. WPSC is proposing to use Code Case N-588 to derive pressure/temperature limits that will sufficiently open the vertical portion of the operating window such that the maximum pressure in the vessel will not exceed 100% of the pressure determined to satisfy Appendix G of Section XI. The ASME Code Committee has concluded that the LTOP guidelines provide acceptable margin against crack initiation and failure in reactor vessels, and will reduce the likelihood of actuation of protection system pressure relieving devices.

The approval of this exemption request to authorize the use of Code Cases N-514 and N-588 will not present an undue risk to public health and safety, and is consistent with the common defense and security. Without this exemption and approval to use these Code Cases, WPSC is required to comply with Appendix G requirements referenced by 10 CFR 50.60. Compliance with these requirements for pressure/temperature limits is not necessary to meet the intent of the rule and results in a hardship to WPSC and its customers, without a compensating increase in the level of quality or safety.

ATTACHMENT 2

Letter from M. L. Marchi (WPSC)

to

Document Control Desk (NRC)

Dated

August 6, 1998

ASME Code Case N-514

Approval Date: February 12, 1992
*See Numerical Index for expiration
and any reaffirmation dates.*

Case N-514
Low Temperature Overpressure Protection
Section XI, Division 1

Inquiry: Section XI, Division 1, IWB-3730, requires that during reactor operation, load and temperature conditions be maintained to provide protection against failure due to the presence of postulated flaws in the ferritic portions of the reactor coolant pressure boundary. For those plants having low temperature overpressure protection (LTOP) systems, what load and temperature conditions under IWB-3730 may be used to provide protection against failure during reactor start-up and shutdown operation due to low temperature overpressure events that have been classified as Service Level A or B events?

Reply: It is the opinion of the Committee that for those plants having LTOP systems the following load and temperature conditions may be used to provide protection against failure during reactor start-up and shutdown operation due to low temperature overpressure events that have been classified as Service Level A or B events. LTOP systems shall be effective at coolant temperatures less than 200°F or at coolant temperatures[1] corresponding to a reactor vessel metal temperature[2] less than RT_{NDT} + 50°F, whichever is greater. LTOP systems shall limit the maximum pressure in the vessel to 110% of the pressure determined to satisfy Appendix G, para. G-2215 of Section XI, Division 1.

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[1] The coolant temperature is the reactor coolant inlet temperature.

[2] The vessel metal temperature is the temperature at a distance one-fourth of the vessel section thickness from the inside surface in the vessel beltline region. RT_{NDT} is the highest adjusted reference temperature for weld or base metal in the beltline region at a distance one-fourth of the vessel section thickness from the vessel inside surface, as determined by Regulatory Guide 1.99, Rev. 2.

ATTACHMENT 3

Letter from M. L. Marchi (WPSC)

to

Document Control Desk (NRC)

Dated

August 6, 1998

ASME Code Case N-514

Technical Basis Document

COMMITTEE CORRESPONDENCE

mittee: Section XI

address writer care of:

Westinghouse Elec. Corp.
P.O. Box 355
Pittsburgh, PA 15230

subject: Technical Basis for Code Case N514, LTOP

date: May 10, 1993

copy to: Owen Hedden

to:

Dr. Michael Mayfield
U.S. Nuclear Regulatory Commission
Mail Stop 217C NL/5
Washington, DC 20555

Dear Mike:

Per our discussion, I am enclosing the technical basis for the recently approved code case N514 on low temperature overpressure protection for your use. This code case was passed as a code change in essentially identical form by the ASME Code Main Committee on May 7, 1993, and subject to letter ballot and approval by the Board on Nuclear Codes and Standards, will appear in the 1993 Addenda.

W. H. Bamford
Chairman
Section XI Subgroup on Evaluation - Standards

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Enclosure

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BASES FOR ASME SECTION XI GUIDELINES FOR LOW TEMPERATURE OVERPRESSURE PROTECTION CRITERIA

1.0 INTRODUCTION AND BACKGROUND

1.1 LTOP SERVICE EXPERIENCE

In the late 1970's there were a total of approximately 30 events that produced pressure excursions above the technical specification pressure temperature (P/T) limits while reactors were operating at low temperatures (1). The frequency of these overpressure events was high enough for the NRC to classify them as anticipated operational occurrences. Based on this classification PWR licensees implemented procedures to reduce the potential for overpressure events and installed equipment modifications to mitigate such events. The protection systems used to mitigate and reduce the potential for these events are termed low temperature overpressure protection (LTOP) systems.

Service experience during the peried 1980 to the end of 1986 indicates that LTOP events occur with frequency of about 0.1 events per operating year (2) -- 30 events at 55 Westinghouse and Combustion Engineering plants . This frequency was determined by the number of times that the LTOP system was challenged, e.g., the system pressure exceeded the LTOP set-point pressure. This service experience also indicates that LTOP events are isothermal, occur during heat-up, and that most events occur at temperatures greater then 100°F but less than 200°F (2).

An update of the service experience was performed in support of the WGOPC effort to develop guidelines for LTOP criteria. During the time peried 1986 through 1991, 16 challenges to the LTOP system occurred, producing an event frequently of approximately 0.06 events per operating year. However, several situations were identified where at least one of the two required channels of the LTOP system was not available. Further, other conditions were identified where the LTOP pressure relieving devices were found to be outside the specification, which could have resulted in higher then anticipated pressures being achieved had an LTOP event occurred.

In summary, service experience continues to indicate challenges to the LTOP systems, suggesting that a physical system to limit pressure to values near the technical specification P/T limit value is needed. Based on this experience, the philosophy adopted by the WGOPC in considering guidelines for LTOP limits was that administrative controls should be imposed to ensure that the P/T limits were not exceeded, and that physical protection system must provide adequate protection against failure of the reactor pressure vessel below the enable temperature where experience indicates the events occur.

1.2 CURRENT REGULATORY GUIDELINES AND OPERATING CONSIDERATIONS

Current regulatory guidelines (3) require that a system be "designed and installed to prevent exceeding the applicable technical specifications and Appendix G limits for the reactor coolant system while operating at low temperatures." The technical specification and Appendix G limits, commonly termed the P/T limits, are determined in accordance with 10CFR50,

Appendix G and Appendix G of Section XI (4,5). This physical protection system is termed the low temperature overpressure protection (LTOP) system.

The LTOP system can be characterized by two parameters: the enable temperature and the set-point pressure for the pressure relieving device. The LTOP system must be enabled at temperatures less than or equal to RT_{NDT} + 90°F, where RT_{NDT} is the adjusted reference temperature, including margin (6), at the quarter thickness location. At temperatures greater than RT_{NDT} + 90°F, LTOP protection need not be provided. The maximum allowable pressure is determined based on system-specific considerations but is chosen so that the maximum pressure attained in the vessel will not exceed the Section XI, Appendix G P/T limit curve.

The pressure relieving devices used in LTOP systems are characterized as either fixed set-point relief valves or variable set-point PORVs. The variable set-point PORVs typically can be adjusted to "follow" the P/T limit curve during heat-up and cooldown while the LTOP system is enabled. However, fixed set-point systems have a constant set-point pressure below the enable temperature, and that pressure is determined for the lowest temperature at which the system can be pressurized, e.g., the minimum bolt-up temperature.

Figure 1 illustrates the relationship between the P/T limit curve and the LTOP system set-point pressure and enable temperature for a fixed set-point system. Also illustrated are several operational constraints. For exemple, the maximum "operating window" pressure is determined by subtracting from the LTOP set-point pressure a margin term introduced to avoid lifting the pressure relief valve and a margin introduced to compensate for pressure measuring system error or the gauge error. The minimum "operating window" is determined by adding to the minimum pump seal pressure a margin to account for the pressure difference between the seal and the pressure measuring device, and a margin to account for gauge error. In eddition to these constraints on the pressure "operating window", the pressure must be high enough to preclude cavitation on the main coolant pump impeller as illustrated by the subcooling curve.

For an embrittled reactor pressure vessel, the LTOP system requirements can impose significant burden on plant operations in two ways. First, with increasing levels of embrittlement, the allowable pressure for a givon temperature is lowered -- a lower P/T limit curve. Second, the enable temperature increases. For fixed pressure set-point systems, this creates a narrow "window" between the LTOP curve and the pump seal and subcooling curves (see Figure 1). The burden imposed by the LTOP system can have a significant economic impact by extending plant start-up time (slower heat-up), and restricting plant operation. Further, the narrow operating window has an adverse safety impact because it increases the likelihood of activating the pressure relieving device, and there is a possibility that once the device is activated it will fail to close, thereby creating a LOCA.

The Working Group on Operating Plant Criteria (WGOPC), which has responsibility for Appendix G to Section XI, has considered the burden and safety impact imposed by the LTOP criteria , and has developed Code guidelines for determining the LTOP set-point pressure and the required enabling temperature. These guidelines will relieve some operational restrictions, yet provide adequate margins against failure for the reactor pressure vessel. Further, by relieving the operational restrictions, these guidelines result in a reduced potential for activation of pressure relieving devices, thereby improving plant safety.

2.0 ASME CODE GUIDELINES FOR LTOP LIMITS

The philosophy adopted by the WGOPC in considering guidelines for LTOP limits was that administrative controls should be imposed to ensure that the technical specification P/T limits were not exceeded, and that physical protection system must provide adequate protection against failure of the reactor pressure vessel below the enable temperature where experience indicates the events occur. The following guidelines implement this philosophy and have been developed for events that have been classified as Service Level A or B events.

> **LTOP systems shall be effective at coolant temperatures less than 200°F or at coolant temperatures corresponding to a reactor vessel metal temperature less than RT_{NOT} + 50°F, whichever is greater.** [1,2] **LTOP systems shall limit the maximum pressure in the vessel to 110% of the pressure determined to satisfy Appendix G of Section XI, Article G-2215.**

The justification for the guidelines is presented in the following section.

3.0 BASIS FOR LTOP SYSTEM PRESSURE TEMPERATURE LIMITS

The following vessel dimensions and material properties were used in the LTOP evaluation:

Vessel inner radius:	86.9 inch,
Vessel wall thickness:	8.9 inch,
Surface Fluence:	2.3×10^{19} n/om^2,
Chemistry Factor:	217°F,
Initial RT_{NDT}:	0.0°F, and
RT_{NDT} Margin Term:	66°F

The vessel dimensions were selected to be typical of the population of U.S. commercial PWRs. The fluence and chemistry factor conditions were selected because they represent the largest projected value of RT_{NDT} at end of design life for any of the U.S. plants. Also, at this value of RT_{NDT} the allowable pressure is low enough, after accounting for various gage errors and margins, so that the operating window essentially will be closed for practical heat-up or cooldown conditions.

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[1] The coolant temperature is the bulk reactor coolant temperature.

[2] The vessel metal temperature is the temperature at a distance one fourth of the vessel section thickness from the inside wetted surface in the vessel beltline region. RT_{NDT} is the highest adjusted reference temperature (for weld or base metal in the beltline region) at a distance one fourth of the vessel section thickness from the vessel wetted inner surface as determined by Regulatory Guide 1.99, Rev. 2.

3.1 MARGIN EVALUATION

3.1.1 Allowable Pressure

Appendices G of 10CFR50 and Section XI of the ASME Code define the P/T limits for normal heat-up and cool down operation by using a factor of two on pressure, the ASME, Section XI, Appendix G reference stress intensity factor, K_{Ia}, and a postulated flaw having depth equal to one fourth the vessel wall thickness and length equal one-and-one-half times the wall thickness. To determine the effect of allowing the maximum LTOP pressure to be no more than 110% of the allowable pressure defined by ASME, Section XI, Appendix G the factor on pressure was computed using the ASME reference toughness and postulated flaw size. This factor was then compared to the normal factors provided by Appendix G guidelines for normal heat-up and cooldown.

The basic Section XI, Appendix G criteria can be expressed as

$$pR/t \cdot M_m \cdot F + K_{I,t} < K_{Ia} \qquad (3\text{-}1)$$

where

p = pressure, ksi,

R = vessel mean radius, inch,

t = base metal wall plus cladding thickness, inch,

M_m = factor for membrane loading,

F = Code margin on pressure = 2.0,

$K_{I,t}$ = stress intensity factor from thermal loading , ksi $\sqrt{in}$, and

K_{Ia} = ASME reference stress intensity factor, ksi $\sqrt{in}$.

Several different flaw location and heat-up and cooldown rates conditions were considered to evaluate the LTOP system maximum allowable pressure . These conditions included: (1) an inside surface flaw where the cooldown rate was 20°F/hr, (2) an inside surface flaw where $K_{I,t}=0$ ($K_{I,t}$ ranges from 0 to a negative value for an inside surface flaw and heat-up conditions; $K_{I,t} = 0$ is used to obtain a conservative allowable pressure), and (3) an outside surface flaw with a 20°F/hr heat-up. The pressure temperature curves determined from ASME, Section XI, Appendix G for these flaw location and thermal conditions are presented in Figure 2 and indicate that the 20°F/hr cooldown is limiting overall. For heat-up conditions the 20°F/hr heat-up for an outside flaw is limiting up to about 190°F; at temperatures greater than 190°F the inside flaw during heat-up is limiting.

To assess the recommended criteria it is convenient to express Eq. 3-1 as

$$p \cdot F = (K_{Ia} - K_{I,t}) \cdot (t/RM_m) \qquad (3-2)$$

To evaluate the LTOP pressure limit in the low temperature region the limiting condition shown in Figure 2 is considered first. For an inside surface flaw with depth equal to a quarter of the wall thickness the RT_{NDT}, including margin, is 300°F, and K_{Ia} at 100°F is 27.5 ksi√in. For the indicated vessel dimensions M_m from Appendix G to Section XI is 2.81. And for a 20°F/hr cooldown the $K_{I,t}$ is 4.4 ksi √in. Using these values Eq. 3-2 becomes

$$p \cdot F = 0.8 \text{ ksi}. \qquad (3-3)$$

The allowable pressure at 100°F determined from ASME, Section XI, Appendix G is determined from Eq. 3-3 using F= 2, or

$$p = 0.4 \text{ ksi}. \qquad (3-4)$$

If the maximum pressure allowed by the LTOP system is 110% of the allowable pressure then from Eq. 3-4 the allowable LTOP pressure = 0.44 ksi, and from Eq. 3-3 the associated factor on pressure is 0.8/0.44 = 1.8.

To determine the implications of the 1.8 factor on pressure for LTOP limits, vessel integrity is assessed by the ratio of reference stress intensity factor to the applied stress intensity factor, or

$$\text{Margin} = K_{Ia}/(K_{Ip} + K_{It}) \qquad (3-5)$$

where

$$K_{Ip} = pRM_m/t.$$

From Eq. 3-1 the value of K_{Ip} associated with the allowable pressure determined from ASME, Section XI, Appendix G is

$$K_{Ip} = (K_{Ia} - K_{It})/2 \qquad (3-6)$$

Substituting Eq. 3-6 into Eq. 3-5 gives

$$\text{Margin} = 2K_{Ia}/(K_{Ia} + K_{It}). \qquad (3-7)$$

For events where there is no thermal stress (i.e., $K_{It} = 0$) the margin from Eq. 3-7 is equal to 2. For events where there is thermal stress the margin from Eq. 3-5 will be less than 2. For example, using K_{It} = 4.4 ksi√in. (obtained for an inside surface flaw and a 20°F/hr cooldown), and K_{Ia} = 27.5 ksi√in (obtained for a temperature = 100°F and RT_{NDT} equal to 300°F) in Eq. 3-7 gives

$$\text{Margin} = 2(27.5)/(27.5 + 4.4) = 1.7 \qquad (3-8)$$

The results indicated by Eq. 3-7 for no thermal stress and Eq. 3-8 for a 20°F/hr cooldown show margins with respect to toughness between 1.7 and 2.0 are provided by ASME, Section XI, Appendix G. Because service experience indicates low temperature overpressure events are essentially isothermal, the margin with respect to toughness for these events is within the range associated with normal heat-up and cooldown in the low temperature range. Consequently, setting the LTOP allowable pressure at no greater than 110% of the Appendix G allowable provides essentially the same margin against vessel failure as is provided by ASME, Section XI, Appendix G for normal vessel heat-up and cooldown operation.

3.2.2 LTOP Enabling Temperature

The LTOP enabling temperature assessment involved determining the temperature that would allow the pressure to reach 110% of the design pressure, or typically about 2,750 psi for PWRs, without initiation of a postulated quarter-thickness depth flaw having RT_{NDT} at the tip of the flaw equal to 300°F. This assessment was performed for conditions simulating resctor heat-up (i.e. $K_{It} = 0$) consistent with service experience with these events; an evaluation for a 20F/hr cooldown also was included for reference. The results are presented in Figure 3 and indicate that pressure greater than 110% of design pressure is achieved at temperature equal to approximately RT_{NDT} + 50°F.

Based on the results in Figure 3 and service experience that indicates that LTOP events occur below 200°F, the LTOP enabling temperature was selected as the greater of 200°F or RT_{NDT} + 50°F. This value provides protection by ensuring the LTOP limit is outside the temperature range where the events may occur and is protected from failure by the safety relief valves.

4.0 REFERENCES

1. NUREG 0224, "Reactor Vessel Pressure Transient Protection For Pressurized Water Reactors", September 1978.

2. NUREG 1326, "Regulatory Analysis for Resolution of Generic Issue 94, December 1989.

3. Standard Review Plan 5.2.2, Rev. 2, "Overpressure Protection".

4. 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements".

5. ASME Boiler and Pressure Vessel Code, Section XI, Appendix G, " Fracture Toughness Criteria for Protection Against Failure".

6. Regulatory Guide 1.99, Rev. 2, "Radiation Embrittlement of Reactor Vessel Materials".

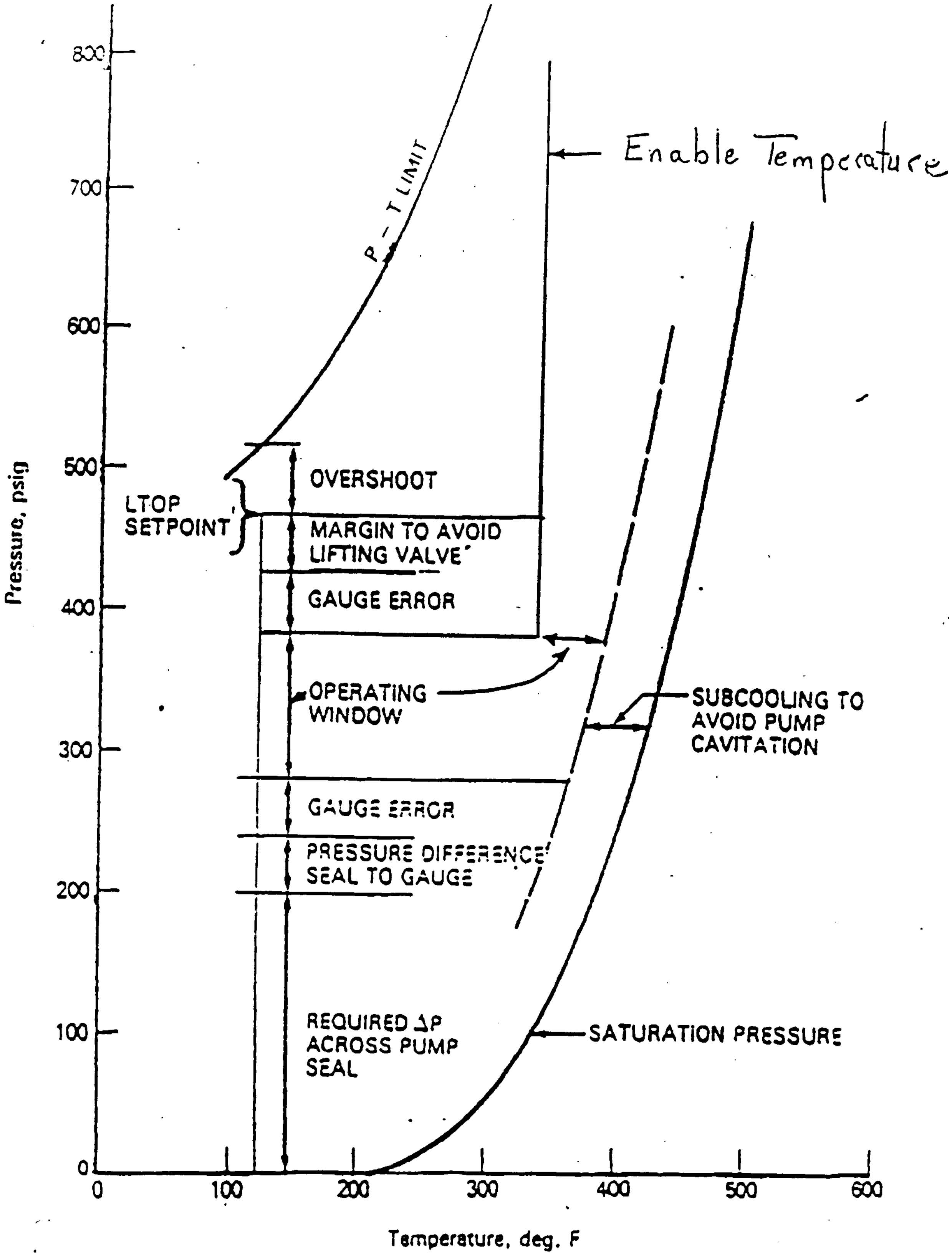


Figure 1. Several Factors Reduce the Operating Window in Pressure when the P-T Limit is Protected by an LTOP System

Figure 2. P/T Curves to Evaluate LTOP Pressures in the Low Temperature Region

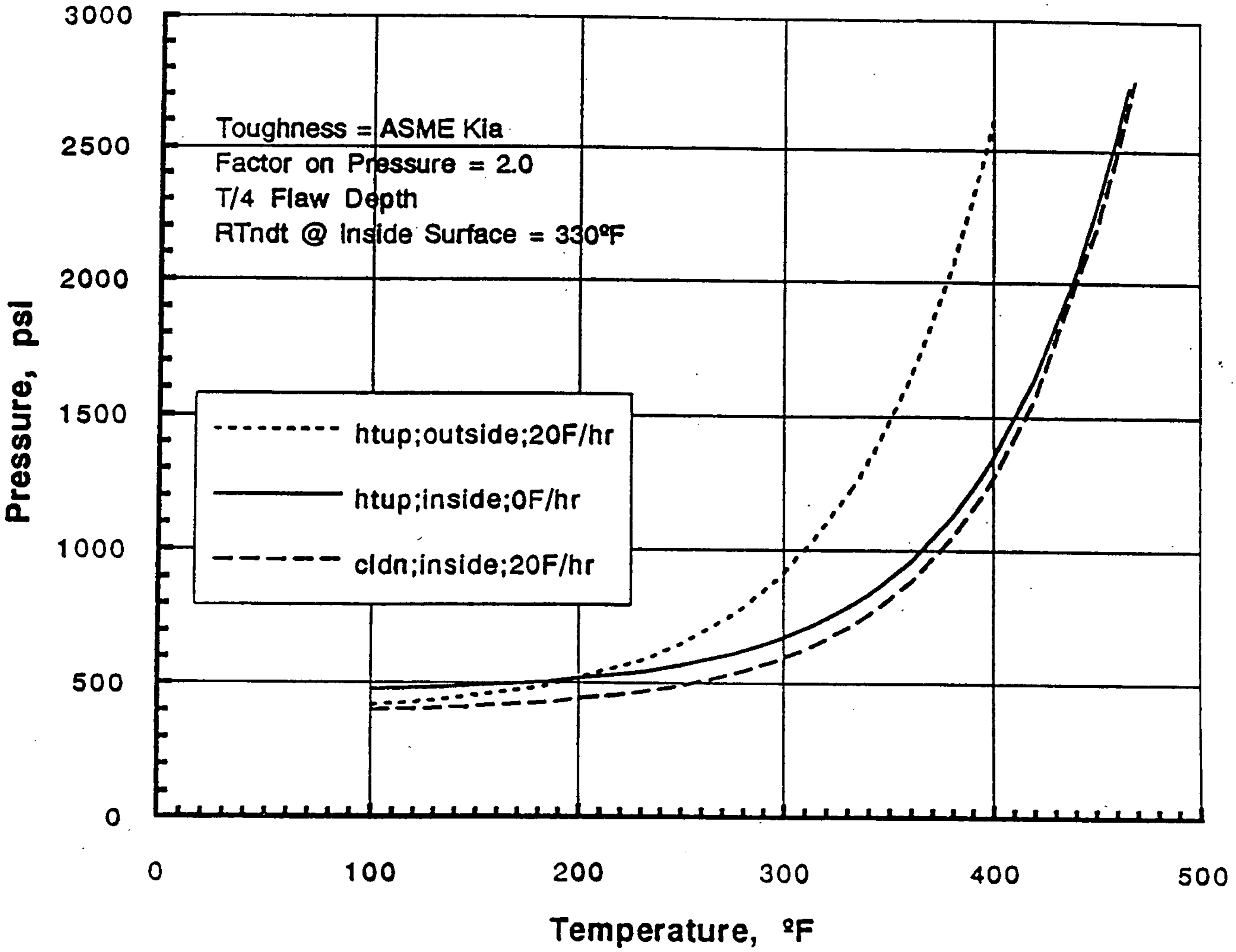
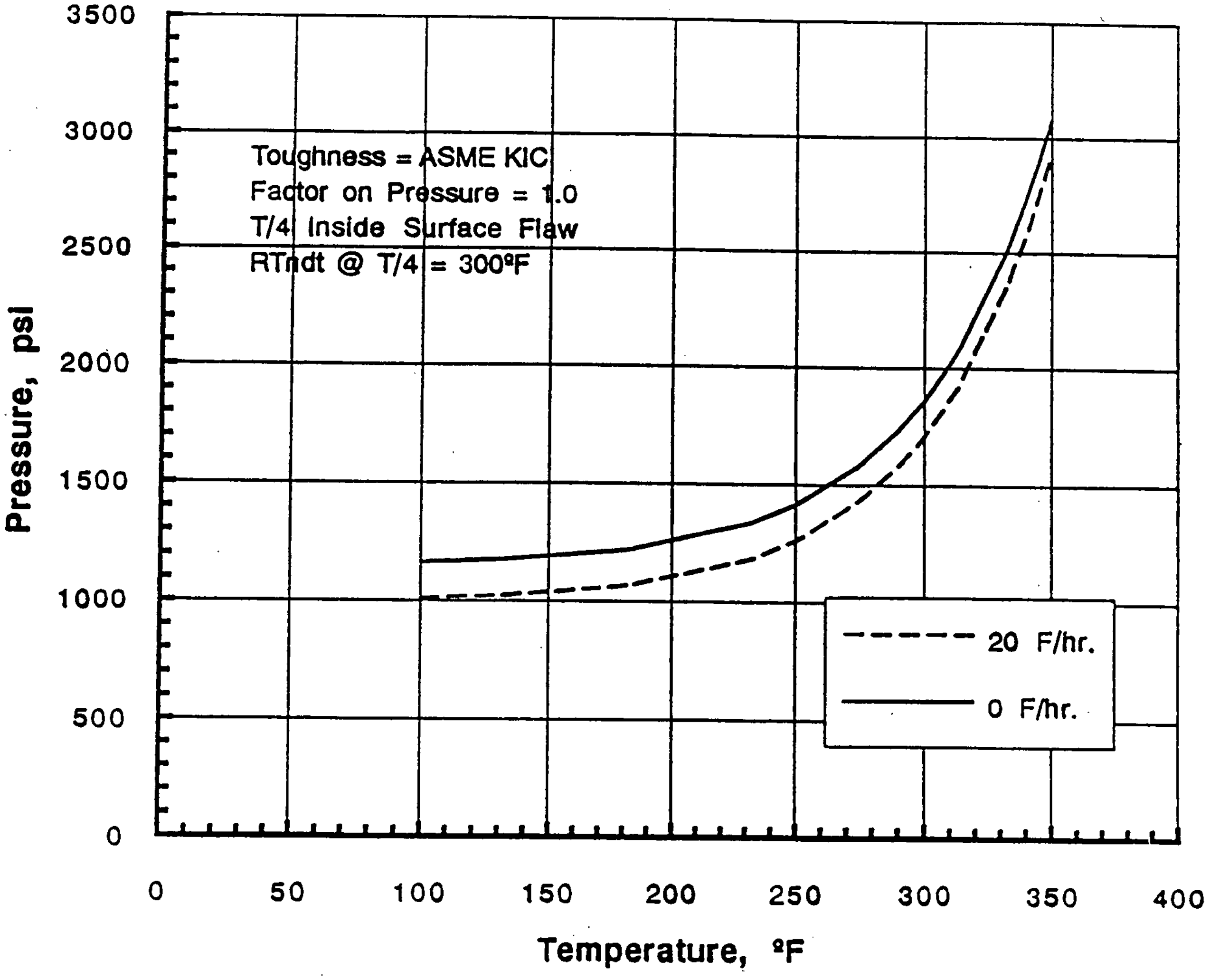


Figure 3. P/T Curves to Define LTOP System Enable Temperature



ATTACHMENT 4

Letter from M. L. Marchi (WPSC)

to

Document Control Desk (NRC)

Dated

August 6, 1998

ASME Code Case N-588

Approval Date: December 12, 1997

See Numerical Index for expiration and any reaffirmation dates.

Case N-588
Attenuation to Reference Flow Orientation of Appendix G for Circumferential Welds in Reactor Vessels
Section XI, Division I

Inquiry: Paragraph G-2120 specifies that postulated reference defects should be sharp, surface defects oriented normal to the direction of maximum stress. What alternative rules may be used for postulating a reference defect in a circumferential welds?

Reply: It is the opinion of the Committee that, as an alternative to the procedure for assuming axially oriented reference defects in all welds and base metal per G-2120, a circumferential orientation may be used specifically for circumferential welds.

CONTENTS

-1000 INTRODUCTION

-1100 Scope

This Case presents an alternative procedure for calculating applied stress intensity factors during normal operation and pressure test conditions. The procedure is based on the principles of linear elastic fracture mechanics. At each location being investigated a maximum postulated defect is assumed, and the *mode I stress intensity factor* K_I is produced by each of the specified pressure and thermal loadings. Different procedures are recommended for axial and circumferential weld orientations.

-2100 GENERAL REQUIREMENTS

-2120 Maximum Postulated Defects

The postulated defect used in this recommended procedure are sharp, surface defects oriented axially for plates, forgings and axial welds, and oriented circumferentially for circumferential welds. For section thicknesses of 4 in. to 12 in. The postulated defects have a depth of one-fourth of the section thickness and a length of $1\frac{1}{2}$ times the section thickness. Defects are postulated at both the inside and outside surfaces. For sections greater than 12 in. thick, the postulated defect for the 12 in. section is used. For sections less than 4 in. thick, the 1 in. deep defect is conservatively postulated. Smaller defect sizes[1] may be used on an individual case basis if a smaller size of maximum postulated defect can be ensured. Due to the safety factors recommended here, the prevention of nonductile fracture is ensured for some of the most important situations even if the defects were to be about twice as large in linear dimensions as this postulated maximum defect.

-2200 LEVEL A AND LEVEL B SERVICE LIMITS

-2210 Shells and Heads Remote from Discontinuities

-2211 Recommendations

The assumptions of this Subarticle are recommended for shell and head regions during Level A and B Service Limits.

-2212 Material Fracture Toughness

-2212.1 Reference Critical Stress Intensity Factor for Material. The K_{Ia} values of Fig. G-2210-1 are recommended.

-2212.2 Irradiation Effects. Subarticle A-4400 of Appendix A is recommended to define the change in reference critical stress intensity factor due to irradiation.

-2213 Maximum Postulated Defects

The recommended maximum postulated defects are described in -2120.

-2214 Calculated Stress Intensity Factors

-2214.1 Membrane Tension. The K_I corresponding to membrane tension for the postulated axial defect of -2120 is $K_{Im} = M_m \times (pR_i/t)$, where M_m for an inside axial surface flaw is given by

$M_m = 1.85$ for $\sqrt{t} < 2$
$M_m = 0.926 \sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$
$M_m = 3.21$ for $\sqrt{t} > 3.464$

Similarly, M_m for an outside axial surface flaw is given by

$M_m = 1.77$ for $\sqrt{t} < 2$
$M_m = 0.893 \sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$
$M_m = 3.09$ for $\sqrt{t} > 3.464$

where

$p =$ internal pressure (ksi)
$R_i =$ vessel inner radius (in.)
$t =$ vessel wall thickness (in.)

The K_I corresponding to membrane tension for the postulated circumferential defect of -2120 is $K_{Im} = M_m \times (pR_i/t)$, where M_m for an inside circumferential surface defect is given by

$M_m = 0.89$ for $\sqrt{t} < 2$
$M_m = 0.443 \sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$
$M_m = 1.53$ for $\sqrt{t} > 3.464$

Similarly, M_m for an outside circumferential surface defect is given by

$M_m = 0.89$ for $\sqrt{t} < 2$
$M_m = 0.443 \sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$
$M_m = 1.53$ for $\sqrt{t} > 3.464$

-2214.2 Beuding Stress. The K_I corresponding to bending stress for postulated axial or circumferential defects of -2120 is $K_{Ib} = M_b \times$ maximum bending stress, where M_b is two-thirds of M_m.

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[1] WRCB 175 (Welding Research Council Bulletin 175) "PVRC Recommendations on Toughness Requirements for Ferritic Materials" provides procedures in para. 5(c)(2) for considering maximum postulated defects smaller than those described.

-2214.3 **Radial Thermal Gradient.** The maximum K_I produced by a radial thermal gradient for a postulated axial or circumferential inside surface defect of -2120 is $K_{It} = 0.953 \times 10^{-3} \times \mathrm{CR} \times t^{2.5}$, where CR is the cooldown rate in F/hr., or, for a postulated axial or circumferential outside surface defect, $K_{It} = 0.753 \times 10^{-3} \times \mathrm{HU} \times t^{2.5}$, where HU is the heatup rate in F/hr.

The through-wall temperature difference associated with the maximum thermal K_I can be determined from Fig. G-2214-1. The temperature at any radial distance from the vessel surface can be determined from Fig. G-2214-2 for the maximum thermal K_I.

(a) The maximum thermal K_I and the temperature relationship in Fig. G-2214-1 are applicable only for the conditions in -2214.3(a)(1) and (2).

(1) An assumed shape of the temperature gradient is approximately as shown in Fig. G-2214-2.

(2) The temperature change starts from a steady state condition and has a rate, associated with startup and shutdown, less than about 100°F/hr. The results would be overly conservative if applied to rapid temperature changes.

(b) Alternatively, the K_I for radial thermal gradient can be calculated for any thermal stress distribution at any specified time during cooldown for a $\frac{1}{4}$-thickness axial or circumferential surface defect.

For an inside surface defect during cooldown

$$K_{It} = (1.0359C_0 + 0.6322C_1 + 0.4753C_2 + 0.3855C_3)\sqrt{\pi a}$$

For an outside surface defect during heatup

$$K_{It} = (1.043C_0 + 0.630C_1 + 0.481C_2 + (0.401C_3)\sqrt{\pi a}$$

The coefficients C_0, C_1, C_2, and C_3 are determined from the thermal stress distribution at any specified time during the heatup or cooldown using

$$\sigma(x) = C_0 + C_1(x/a) + C_2(x/a)^2 + C_3(x/a)^3$$

where x is a dummy variable that represents the radial distance, in., from the appropriate (i.e., inside or outside) surface and a is the maximum crack depth, in.

(c) For the startup condition, the allowable pressure . temperature relationship is the minimum pressure at any temperature, determined from (1) the calculated steady state results for the $\frac{1}{4}$-thickness inside surface defect, (2) the calculated steady state results for the $\frac{1}{4}$-thickness outside surface defect, and (3) the calculated results for the maximum allowable heatup rate using a $\frac{1}{4}$-thickness outside surface defect.

-2215 Allowable Pressure

The equations given in this Subarticle provide the basis for determination of the allowable pressure at any temperature at the depth of the postulated defect during Service Conditions for which Level A and Level B Service Limits are specified. In addition to the conservatism of these assumptions, it is recommended that a factor of 2 be applied to the calculated K_I values produced by primary stresses. In shell and head regions remote from discontinuities, the only significant loadings are: (1) general primary membrane stress due to pressure; and (2) thermal stress due to thermal gradient through the thickness during startup and shutdown. Therefore, the requirement to be satisfied and from which the allowable pressure for any assumed rate of temperature change can be determined is:

$$2K_{Im} + K_{It} < K_{Ia} \qquad (1)$$

throughout the life of the component at each temperature with K_{Im} from -2214.1, K_{It} from -2214.3, and K_{Ia} from Fig. G-2210-1.

The allowable pressure at any temperature shall be determined by the following procedure:

(a) For the startup condition, consider postulated defects in accordance with -2120, perform calculations for thermal stress intensity factors due to the specified range of heatup rates from -2214.3, calculate the K_{Ia} toughness for all vessel beltline materials from -2212 using temperatures and RT_{NDT} values for the corresponding locations of interest, and calculate the pressure as a function of coolant inlet temperature for each material and location. The allowable pressure vs. temperature relationship is the minimum pressure at any temperature determined from (1) the calculated steady-state (K_{It} = 0) results for the $\frac{1}{4}$ thickness inside surface postulated defects using the equation:

$$p = \frac{K_{Ia}}{2M_m} \cdot \left(t / R_i \right)$$

and (2) the calculated results from all vessel beltline materials for the heatup stress intensity factors using the corresponding $\frac{1}{4}$ thickness outside surface postulated defects and the equation

$$p = \frac{K_{Ia} - K_{It}}{2M_m} \cdot \left(t / R_i \right)$$

(b) For the cooldown condition, consider postulated defects in accordance with -2120, perform calculations for thermal stress intensity factors due to the specified range of cooldown rates from -2214.3, calculate the K_{Ia} toughness for all vessel beltline materials from -2212 using temperatures and RT_{NDT} values for the corresponding locations of interest, and calculate the pressure as a function of coolant inlet temperature for each material and location using the equation:

$$p = \frac{K_{Ia} - K_{It}}{2M_m} \cdot \left(t / R_i \right)$$

The allowable pressure vs temperature relationship is the minimum pressure at any temperature, determined from all vessel beltline materials for the cooldown stress intensity factors using the corresponding $\frac{1}{4}$ thickness inside surface postulated defects.

ATTACHMENT 5

Letter from M. L. Marchi (WPSC)

to

Document Control Desk (NRC)

Dated

August 6, 1998

Technical Basis Document for Revised Section XI, Appendix G Reference Flaw Orientation for Circumferential Welds in Reactor Vessels (ISI-97-11), 5/1/97

and

ASME Section XI, Appendix G Heatup and Cooldown Curves for Circumferential Welds (Draft), 12/2/97

ISI-97-11

TECHNICAL BASIS DOCUMENT
FOR
REVISED SECTION XI, APPENDIX G REFERENCE FLAW ORIENTATION FOR CIRCUMFERENTIAL WELDS IN REACTOR VESSELS

WORKING GROUP ON OPERATING PLANT CRITERIA

May 1, 1997

ISI 97-11

TECHNICAL BASIS DOCUMENT FOR REVISED SECTION XI, APPENDIX G REFERENCE FLAW ORIENTATION FOR CIRCUMFERENTIAL WELDS IN REACTOR VESSELS

1. Introduction

For the progress made in NDE techniques over the last thirty years, it is very unlikely to have large cracks present in the beltline region of reactor vessels. It is further unlikely to have axial cracks originating from a circumferential weld perpendicular to the weld seam orientation in reactor vessels. Based on fabrication practices it is proposed that a circumferentially oriented reference flaw should be postulated in a circumferential weld instead of current axial flaw postulation requirement in Appendix G. This document provides a justification of this change and the origin of the stress intensity factors for inside and outside surface reference flaws.

2. Technical Justification for Revised Section XI, Appendix G Reference Flaw Orientation for Circumferential Welds in Reactor Vessels

The current ASME Section XI, Appendix G approach mandates the consideration of an axial flaw in circumferential welds for purposes of calculating pressure-temperature limits. Postulating the Appendix G reference flaw in a circumferential weld is physically unrealistic because the length of the reference flaw is 1.5 times the vessel thickness, and is much longer than the width of the vessel girth welds. The fabrication of reactor pressure vessels (RPVs) for nuclear power plant operation involved precise welding procedures and controls designed to optimize the resulting weld microstructure and to provide the required material properties. These procedural controls were also designed to minimize defects that could be introduced into the weld during the fabrication process. Experience with the repair of weld indications found during pre-service inspection, and data taken from destructive examination of actual vessel welds, confirms that any remaining flaws are small, laminar in nature, and do not cross transverse to the weld bead orientation. Because of this, any defects potentially introduced during the fabrication process and not detected during subsequent non-destructive examinations should only be oriented along the direction of weld fabrication. For circumferential welds this indicates a postulated defect with a circumferential orientation.

Based on these considerations, and the fact that the pressure-temperature limit for reactor operation is the limiting pressure for any of the materials in the vessel (usually the vessel beltline), it is not necessary to include additional conservatism in the assumed flaw orientation for circumferential welds. This proposed Section XI, Appendix G Code Change corrects this inconsistency in assumed flaw orientation for circumferential welds in vessels when calculating operating P-T limits.

(Section XI WGOPC 3/4/97)

3. Stress Intensity Factor Solution for a Circumferential Semi-elliptical Surface Flaw in a Cylinder

3.1. Stress Intensity Factor for a Circumferential Inside Surface Flaw in a Cylinder under Internal Pressure Load

A stress intensity factor for a circumferential inside surface flaw in a cylinder can be found in WRC Bulletin 413 (reference 1) - equation 3.11:

$$KIp = (SF)\ p[1 + (Ri/(2t))]\sqrt{\pi a}\ F2$$

and

$$F2 = 0.885 + 0.233(a/t) + 0.345(a/t)^2$$

The effect of crack face pressure load is not considered to be consistent with the axial flaw equation in Appendix G. The safety factor (SF) is set to one in this equation since the safety factor of 2 is included in equation 1 in G-2215. The revised stress intensity factor equation is

$$KIp = pRi/(2t)\ \sqrt{\pi a}\ F2$$

Since the Mm term in Appendix G in G-2214 is defined as follows,

$$KIp = Mm\ [pRi/t]$$

and R/t =10 and a/t = 0.25

$$Mm = pRi/(2t)\ \sqrt{\pi a}\ F2\ \ [t/(pRi)] = 0.5\ \sqrt{\pi/4}\ F2\ \sqrt{t}$$

$$F2 = 0.885 + 0.233(a/t) + 0.345(a/t)^2$$
$$= 0.964813$$

$$Mm = 0.4274\ \sqrt{t}$$

This is slightly lower than the Mm factor for an outside flaw shown in 3.2.. To simplify the code procedure, it is made to be equal to the Mm for an outside flaw of 0.443 $\sqrt{t}$. This is an increase of3.8%.

3.2. Stress Intensity Factor for a Circumferential Outside Surface Flaw in a Cylinder for Internal Pressur Load

A stress intensity factor equation for a circumferential outside surface flaw in a cylinder can be found in reference 2;

$$KI = \sigma F (\pi\ 0.25/Q)^{0.5}\sqrt{t}$$

For R/t = 10, a/t = 0.25, and a/c = 1/3, F can be obtained from Figure 1

$$F = 1.168$$

$$KIp = Mm^{*}[pRi/t]$$

$$Mm = 0.442733\ t^{\wedge}0.5$$

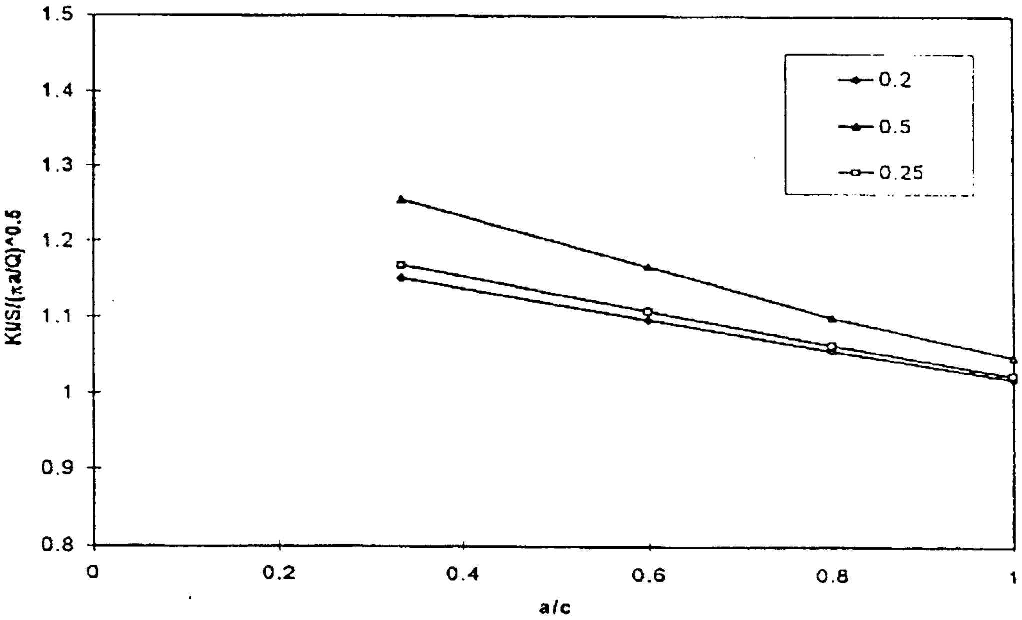


Figure 1. Extrapolation of Geometric Factor for Stress Intensity Factor Equation

3.3 Stress Intensity Factor for Thermal Load

In WRC Bulletin 413, the stress intensity factors for thermal load, K_{IT}, for both axial and circumferential flaws were discussed. It was revealed that at the quarter of the wall thickness location, two K_{IT}'s are very close and subsequently the K_{IT} equation for an axial flaw was adopted in Appendix K. Since this same expression was used for Appendix G, the K_{IT} equations for an axial flaw in Appendix G are applicable for an circumferential flaw as well.

3.4 Summary

For both inside and outside circumferential reference flaws

$$KIp = Mm*[pRi/t] \qquad ksi\sqrt{in}$$

where

$$Mm = 0.886 \qquad \text{for } t < 4$$

$$Mm = 0.443*\sqrt{t} \qquad \text{for } 4 < t < 12$$

$$Mm = 1.535 \qquad \text{for } t > 12$$

References

1. Working Group on Flaw Evaluation of ASME Section XI, "Development of Criteria for Assessment of Reactor Vessels with Low Upper Shelf Fracture Toughness, Part 2: Implementation of Evaluation Procedures in ASME Code Section XI," *Welding Research Council, Inc.*, WRC Bulletin 413, July 1996.

2. Raju, I. S. and Newman, J. C., "Stress Intensity Factor for Circumferential Surface Cracks in Pipes and Rods under Tension and Bending Loads," *Fracture Mechanics: Seventeenth Volume, ASTM STP 905*, J. L. Underwood, R.Chait, C. W. Smith, et al., Eds., American Society for Testing and Materials, Philadelphia, 1986, pp. 789~805

ASME Section XI, Appendix G Heatup and Cooldown Curves for Circumferential Welds.

Background

Section XI of the ASME Code (1) and Title 10 of the Code of Federal Regulations, Part 50 (2) (10 CFR50) define procedures for establishing pressure temperature (PT) limits for reactor start-up and shutdown. Early in plant life the PT limits provide a methodology to ensure safe, as well as efficient and economic operation. However, as neutron irradiation levels increase with plant operation, the PT limits become more restrictive (lower allowable pressure at any given temperature in the low temperature region) and can have significant economic impact by extending plant start-up and shutdown time. This is especially true when there is a low temperature overpressure protection (LTOP) system, and the reactor vessel material has relatively high radiation sensitivity.

In the most severe cases plant start-up may not be possible at some time prior to the end of the license period, and modifications or implementation of extensive and expensive remedial measures would be necessary for continued operation. In addition, more restrictive limits can have an adverse safety impact because there is a possibility that devices installed to provide protection against overpressure may fail to close if they are activated.

To allow nuclear plants to continue to be operated in a safe, efficient, and economic manner, less restrictive requirements for defining PT and LTOP system limits recently have been developed and incorporated into Section XI of the ASME Code. These Code guidelines include: (1) a methodology for establishing less restrictive LTOP system limits (3, 4) compared to previous limits defined in NRC guidelines (5), (2) an updated computational procedures for PT limit curves(6), (3) and use of a circumferential rather than an axial orientation for the reference flaw when constructing PT limits for circumferential welds(6).

This document presents a comparison of the margins and PT limit curves provided by prior and new Code guidelines (6) for the orientation of postulated flaws in circumferential welds. This comparison was determined using updated computational procedures for calculating stress intensity factor, K_I, and defining PT limit curves (6).

Code Change

Prior guidelines in Appendix G to Section XI of the ASME Code used postulated axial flaws to define PT limits for circumferential welds, as well as plates and axial welds. This procedure can result in PT limits that are unnecessarily restrictive for vessels where the RT_{NDT} for circumferential welds is greater than RT_{NDT} for plates or axial welds.

The purpose of the Code change is to use a postulated circumferential reference flaw to define PT limits for circumferential welds, while still using a postulated axial reference flaw for plates and axial welds. The PT limit curve for the vessel overall is determined as the most limiting pressure at any specified temperature for all materials in the vessel beltline.

This change is consistent with the flaw orientations defined in Appendix K to Section XI, "Assessment of Reactor Vessels With Low Upper Shelf Charpy Impact Energy Levels".

Technical Justification for Revised Reference Flaw Orientation for Circumferential Welds

Postulating an axial reference flaw in a circumferential weld is unrealistic physically because the length of the reference flaw is 1.5 times the vessel thickness, and, consequently, is much longer than the width of the vessel girth welds. The possibility that an axial flaw may extend from a circumferential weld into a plate or axial weld is already adequately covered by the requirement that axial flaws be postulated in plates and axial welds. Based on these considerations and the fact that the PT limit for reactor operation is the limiting pressure for any of the materials in the vessel beltline, it is not necessary to include additional conservatism for the reference flaw orientation postulated for circumferential welds.

The remainder of this section assesses the margins associated with the Code change, demonstrates the change maintains margins consistent with the margins historically used for postulated axial flaws, and shows the margins associated with prior Code requirements are unnecessarily conservative for circumferential welds.

The general Code criterion for establishing PT limits is defined in Appendix G as

$$2K_{Ip} + K_{It} = K_{Ia} \qquad (1)$$

where

K_{Ip} = calculated stress intensity factor for pressure loading,
K_{It} = calculated stress intensity factor for thermal loading during reactor cooldown, and
K_{Ia} = reference stress intensity factor.

The margin against extension of the postulated quarter thickness reference flaw is

$$\text{Margin} = K_{Ia} / (K_{Ip} + K_{It}). \tag{2}$$

Solving for K_{Ip} from Eq. 1 and substituting into Eq. 2 the margin can be written as

$$\text{Margin} = 2\,K_{Ia} / (K_{Ia} + K_{It}). \tag{3}$$

Eq. 3 is the margin obtained by operating the vessel on the PT limit curve defined by the Appendix G procedure. Because K_{Ia} and K_{It}, respectively, are the same for either the axial or circumferential flaw orientations the margins for the two orientations are identical as can be seen from Eq. 3. In other words, postulating a circumferential reference flaw in a circumferential weld provides the same margin as an axial flaw postulated in a plate or axial weld, for any specified temperature, RT_{NDT}, and heatup or cooldown rate.

It can be seen from Eq. 3 that the margin varies during heatup or cooldown and is a maximum of 2 when the thermal stress is negligible, and is less than 2 depending on the heatup or cooldown rate and material toughness. The margin ranges from about 1.5 to 2 for the material conditions and heatup or cooldown rates normally used for reactor cooldown. This is illustrated in Figure 1 for some different values of RT_{NDT} and cooldown rates.

When an axial flaw is postulated in a circumferential weld the margins are significantly greater than those for axial flaws postulated in plates or axial welds. The following illustrates the large degree of conservatism when the prior Code procedure is applied for a vessel with a postulated inside surface flaw in a circumferential weld.

The value of K_{Ip} for an inside surface, axial flaw is (6)

$$K_{Ip} = 0.926\, pR_i / t^{0.5}\,, \tag{4}$$

and the value of K_{Ip} for a circumferential flaw is (6)

$$K_{Ip} = 0.443\, pR_i / t^{0.5} \tag{5}$$

where

p = pressure, and
R_i = vessel inner radius.

Substituting Eq. 4 into Eq. 1 and solving for p gives

$$p = 0.54\,(K_{Ia} - K_{It})\,t^{0.5}/R_i\,. \tag{6}$$

The pressure in Eq. 6 is the allowable pressure assuming an axial reference flaw.

If a circumferential weld having a postulated circumferential flaw is required to operate at the pressure defined using an axial reference flaw the value of K_{Ip} for the circumferential flaw is obtained by substituting Eq. 6 into Eq. 5, or

$$K_{Ip} = 0.239\,(K_{Ia} - K_{It})\,. \tag{7}$$

The margin for a circumferential weld when the PT limit is defined using a postulated axial flaw is obtained by substituting Eq. 7 into Eq. 2, or

$$\text{Margin} = 4.18\,K_{Ia} \;/\; (K_{Ia} + 3.18K_{It})\,. \tag{8}$$

Eq. 8 shows the margin is a maximum, constant value of 4.18 when the thermal stress is negligible. When there is a non zero thermal stress the margin is less than 4.18 and depends on the heatup or cooldown rate and RT_{NDT}.

The margin from Eq. 8 is illustrated in Figure 2 for a cooldown rate of 20°F/hr and RT_{NDT} = 267°F. The information presented in Eq. 8 and Figure 2 illustrates that the prior Code procedure, which postulates axial flaws in circumferential welds, provides margins substantially greater than Code margins for axial welds and plate (as shown in Figure 1), and is unnecessarily conservative for defining PT limits for circumferential welds.

Illustration of the Code Change

The effect of the Code change (i.e., a circumferential rather then an axial reference flaw is postulated in a circumferential weld) on the vessel PT limit curve is illustrated in Figure 3. Included in the figure are PT curves for: (1) the prior Code procedure where an axial reference flaw is postulated in a circumferential weld, (2) the new procedure where a circumferential reference flaw is postulated in a circumferential weld, (3) an axial reference flaw in a plate or axial weld, and (4) the overall PT limit curve determined using the new Code procedure to determine the limiting allowable pressure at any specified temperature.

The results in Figure 3 indicate the Code change can provide less restrictive PT limits for circumferential welds with relatively high values of RT_{NDT} compared to prior Code guidelines where axial flaws were postulated in circumferential welds. At the same time, the Code change provides margins equivalent to those intended by the Code for plates and axial welds as indicated by the results presented in Figures 1 and 2.

References

1. ASME Boiler and Pressure Vessel Code, Section XI, Appendix G "Fracture Toughness Criteria for Protection Against Failure", American Society of Mechanical Engineers, New York, NY, 1995.

2. Title 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements", US Government Printing Office, Washington, DC

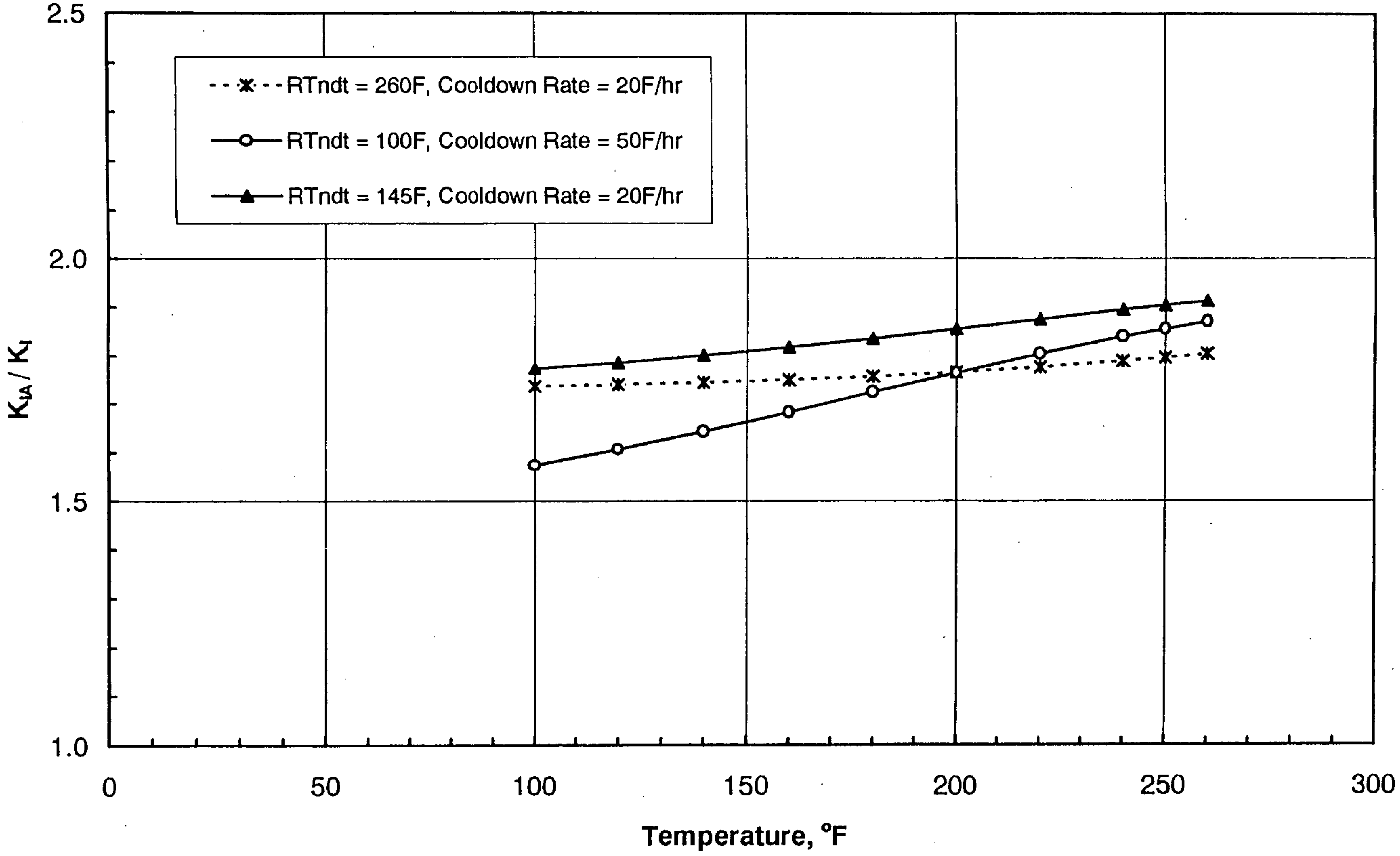
3. R.M. Gamble, "ASME Code Guidelines for PWR Low Temperature Overpressure Protection System Limits", PVP-Vol. 285, American Society of Mechanical Engineers, New York, NY, 1994.

4. ASME Code Case N-514, "Low Temperature Overpressure Protection", February 12, 1993

5. Standard Review Plan 5.2.2, Revision 2, "Overpressure Protection", NUREG-0800, US Nuclear Regulatory Commission, Washington, DC July 1981.

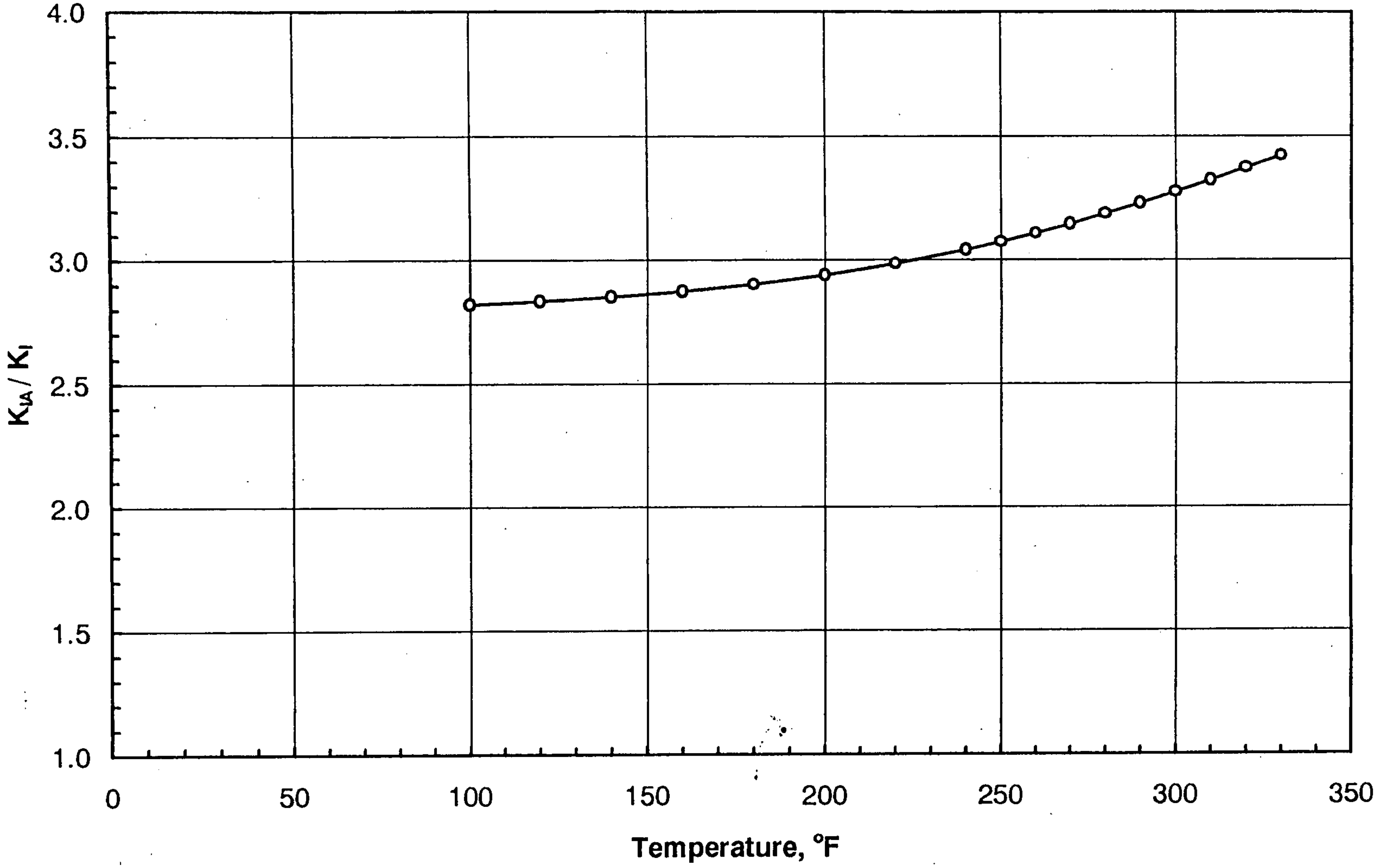
6. ASME Code Case N-588, "Revised Section XI Appendix G Reference Flaw Orientation for Circumferential Welds in Reactor Vessels", May 1, 1997.

Figure 1. Illustration of K_{IA}/K_I Margins for Axial Flaws in Plate and Axial Welds, and Circumferential Flaws in Circumferential Welds as a Function of Cooldown Rate and RT_{NDT}



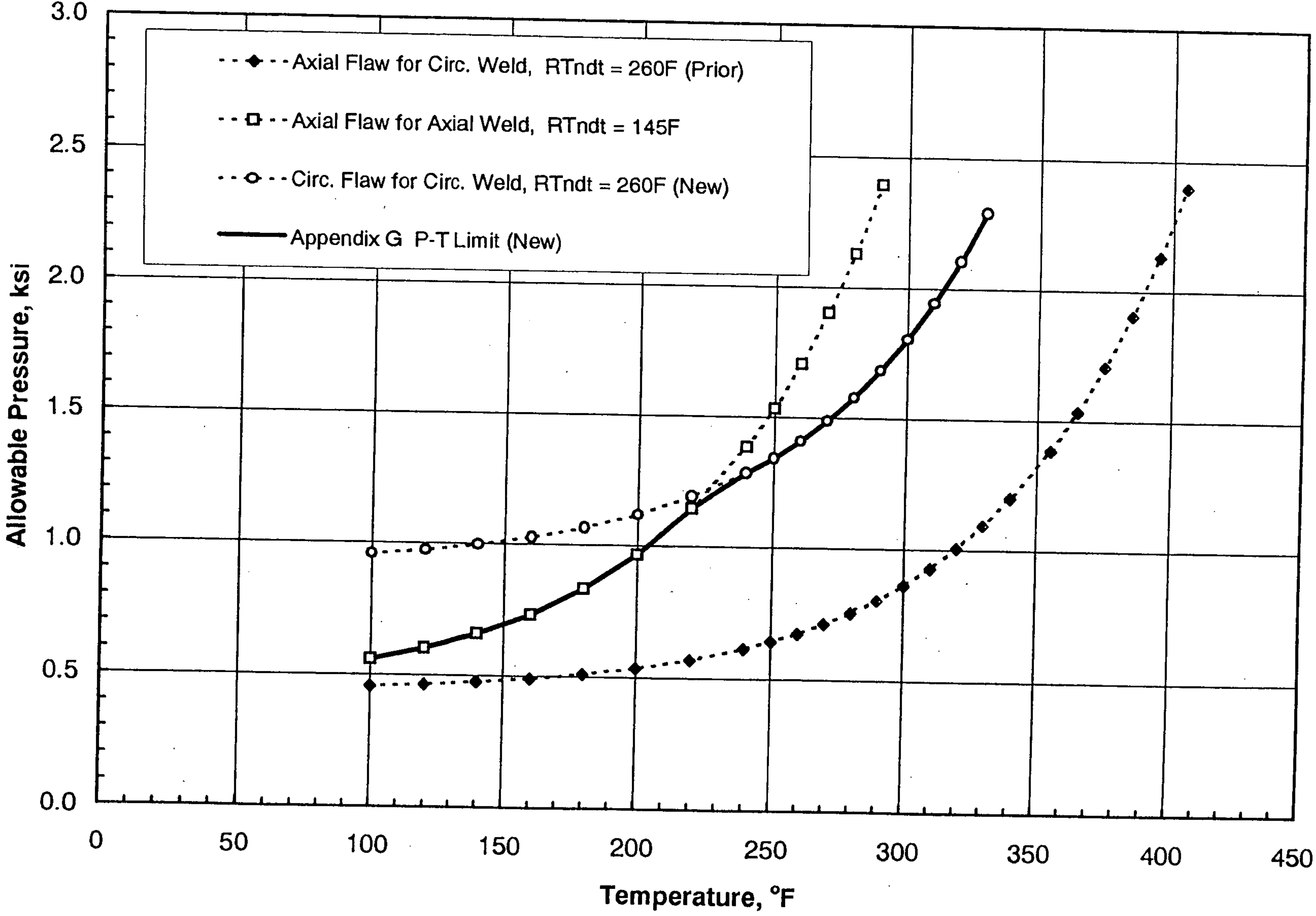
S1-CIR.XLS: PLOT-Margin

Figure 2. Illustration of K_{IA}/K_I Margin for Prior Code Procedure Where Axial Flaws are Postulated in Circumferential Welds, CR = 20°F/hr, RT_{NDT} at t/4 = 260°F



S2-CIR.XLS: PLOT-Margin

Figure 3. Illustration of Cooldown P-T Limit Curves for Axial and Circumferential Flaws, CR = 20°F/hr



S3-CIR.XLS: PLOT-PT Curves

G-2120 MAXIMUM POSTULATED DEFECTS

The postulated defects used in this recommended procedure ~~is a sharp, surface defect normal to the direction of maximum stress~~ are sharp, surface defects oriented axially for plates, forgings and axial welds, and oriented circumferentially for circumferential welds. For section thicknesses of 4 in. to 12 in., ~~it has~~ The postulated defects have a depth of one-fourth of the section thickness and a length of 1½ times the section thickness. Defects are postulated at both the inside and outside surfaces. For sections greater than 12 in. thick, the postulated defect for the 12 in. section is used. For sections less than 4 in. thick, the 1 in. deep defect is conservatively postulated. Smaller defect sizes[1] may be used on an individual case basis if a smaller size of maximum postulated defect can be ensured. Due to the safety factors recommended here, the prevention of nonductile fracture is ensured for some of the most important situations even if the defects were to be about twice as large in linear dimensions as this postulated maximum defect.

G-2200 LEVEL A AND LEVEL B SERVICE LIMITS

G-2210 SHELLS AND HEADS REMOTE FROM DISCONTINUITIES

G-2211 Recommendations

The assumptions of this Subarticle are recommended for shell and head regions during Level A and B Service Limits.

G-2212 Material Fracture Toughness

G-2212.1 Reference Critical Stress Intensity Factor for Material. The K_{Ia} values of Fig. G-2210-1 are recommended.

G-2212.2 Irradiation Effects. Subarticle A-4400 of Appendix A is recommended to define the change in reference critical stress intensity factor due to irradiation.

G-2213 Maximum Postulated Defects

The recommended maximum postulated defects ~~is that~~ are described in G-2120.

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[1] WRCB 175 (Welding Research Council Bulletin 175) "PVRC Recommendations on Toughness Requirements for Ferritic Materials" provides procedures in Paragraph 5(c)(2) for considering maximum postulated defects smaller than those described.

[illegible]2214 Calculated Stress Intensity Factors

G-2214.1 Membrane Tension. The K_I corresponding to membrane tension for the postulated defect of G-2120 is $K_{Im} = M_m \times (pR_i/t)$, where M_m for an inside surface is given by

axial

axial

flaw

$M_m = 1.85$ for $\sqrt{t} < 2$
$M_m = 0.926\sqrt{t}$ for $2 \le \sqrt{t} \le 3.464$
$M_m = 3.21$ for $\sqrt{t} > 3.464$

Similarly, M_m for an outside surface flaw is given by

axial

$M_m = 1.77$ for $\sqrt{t} < 2$
$M_m = 0.893\sqrt{t}$ for $2 \le \sqrt{t} \le 3.464$
$M_m = 3.09$ for $\sqrt{t} > 3.464$

where

p = internal pressure (ksi)
R_i = vessel inner radius (in.)
t = vessel wall thickness (in.)

The K_I corresponding to membrane tension for the postulated circumferential defect of G-2120 is $K_{IM} = M_m \times (p R_i/t)$, where M_m for an inside circumferential surface defect is given by

$M_m = 0.85$ for $\sqrt{t} < 2$,
$M_m = 0.424\sqrt{t}$ for $2 \le \sqrt{t} \le 3.464$,
$M_m = 1.47$ for $\sqrt{t} > 3.464$.

Similarly, M_m for an outside circumferential surface defect is given by

$M_m = 0.89$ for $\sqrt{t} < 2$,
$M_m = 0.443\sqrt{t}$ for $2 \le \sqrt{t} \le 3.464$,
$M_m = 1.53$ for $\sqrt{t} > 3.464$.

G-2214.2 Bending Stress. The K_I corresponding to bending stress for the postulated defect of G-2120 is $K_{Ib} = M_b \times$ maximum bending stress, where M_b is two-thirds of M_m.

axial or circumferential

G-2214.3 Radial Thermal Gradient. The maximum K_I produced by a radial thermal gradient for ~~the~~ a postulated inside surface defect of G-2120 is $K_{It} = 0.953 \times 10^{-3} \times CR \times t^{2.5}$, where CR is the cooldown rate [illegible] F/hr., or, for a postulated outside surface defect, [illegible] $= 0.753 \times 10^{-3} \times HU \times t^{2.5}$, where HU is the [illegible]eatup rate in F/hr.

axial or, circumferential

The through-wall temperature difference associated with the maximum thermal K_I can be determined from Fig. G-2214-1. The temperature at any radial distance from the vessel surface can be determined from Fig. G-2214-2 for the maximum thermal K_I.

(a) The maximum thermal K_I and the temperature relationship in Fig. G-2214-1 are applicable only for the conditions in G-2214.3(a)(1) and (2).

(1) An assumed shape of the temperature gradient is approximately as shown in Fig. G-2214-2.

(2) The temperature change starts from a steady state condition and has a rate, associated with startup and shutdown, less than about 100°F/hr. The results would be overly conservative if applied to rapid temperature changes.

(b) Alternatively, the K_I for radial thermal gradient can be calculated for any thermal stress distribution at any specified time during cooldown for a ¼-thickness surface defect.

axial or circumferential

For an inside surface defect during cooldown

$$[illegible] = (1.0359C_0 + 0.6322C_1 + 0.4753C_2 + 0.3855C_3)\sqrt{\pi a}$$

For an outside surface defect during heatup

$$K_{It} = (1.043C_0 + 0.630C_1 + 0.481C_2 + (0.401C_3)) \sqrt{\pi a}$$

The coefficients C_0, C_1, C_2, and C_3 are determined from the thermal stress distribution at any specified time during the heatup or cooldown using

$$\sigma(x) = C_0 + C_1(x/a) + C_2(x/a)^2 + C_3(x/a)^3$$

where x is a dummy variable that represents the radial distance, in., from the appropriate (i.e., inside or outside) surface and a is the maximum crack depth, in.

(c) For the startup condition, the allowable pressure vs. temperature relationship is the minimum pressure at any temperature, determined from (1) the calculated steady state results for the ¼-thickness inside surface defect, (2) the calculated steady state results for the ¼-thickness outside surface defect, and (3) the calculated results for the maximum allowable heatup rate using a ¼-thickness outside surface defect.

G-2215 Allowable Pressure

The equations given in this Subarticle provide the basis for determination of the allowable pressure at any temperature at the depth of the postulated defect during Service Conditions for which Level A and Level B Service Limits are specified. In addition to the conservatism of these assumptions, it is recommended that a factor of 2 be applied to the calculated K_I values produced by primary stresses. In shell and head regions remote from discontinuities, the only significant loadings are: (1) general primary membrane stress due to pressure; and (2) thermal stress due to thermal gradient through the thickness during startup and shutdown. Therefore, the requirement to be satisfied and from which the allowable pressure for any assumed rate of temperature change can be determined is:

$$2K_{Im} + K_{It} < K_{Iu} \qquad (1)$$

throughout the life of the component at each temperature with K_{Im} from G-2214.1, K_{It} from G-2214.3, and K_{Iu} from Fig. G-2210-1.

The allowable pressure at any temperature shall be determined by the following procedure:

(a) For the startup condition, consider postulated defects in accordance with G-2120, perform calculations for thermal stress intensity factors due to the specified range of heatup rates from G-2214.3, calculate the K_{IA} toughness for all vessel beltline materials from G-2212 using temperatures and RT_{NDT} values for the corresponding locations of interest, and calculate the pressure as a function of coolant inlet temperature for each material and location. The allowable pressure vs. temperature relationship is the minimum pressure at any temperature determined from (1) the calculated 0°F/hr. heatup results for the ¼-thickness inside surface postulated defects using the equation

$$p = \frac{K_{Ia}}{2M_m} \cdot (t/R_i),$$

and (2) the calculated results from all vessel beltline materials for the heatup stress intensity factors using the corresponding 1/4-thickness outside surface postulated defects and the equation

$$p = \frac{K_{Ia} - K_{It}}{2M_m} \cdot (t/R_i).$$

(b) For the cooldown condition, consider postulated defects in accordance with G-2120, perform calculations for thermal stress intensity factors due to the specified range of cooldown rates from G-2214.3, calculate the K_{Ia} toughness for all vessel beltline materials from G-2212 using temperatures and RT_{NDT} values for the corresponding locations of interest, and calculate the pressure as a function of coolant inlet temperature for each material and location using the equation

$$p = \frac{K_{Ia} - K_{It}}{2 M_m} \cdot \left(t/R_i \right).$$

The allowable pressure vs temperature telationship is the minimum pressure at any temperature, determined from all vessel beltline materials for the cooldown stress intensity factors using the corresponding 1/4-thickness inside surface postulated defects.

Those plants having low temperature overpressure protection (LTOP) systems can use the following load and temperature conditions to provide protection against failure during reactor start-up and shutdown operation due to low temperature overpressure events that have been classified as Service Level A or B events. LTOP systems shall be effective at coolant temperatures less than 200°F or at coolant temperatures corresponding to a reactor vessel metal temperature less than RT_{NDT} + 50°F, whichever is greater.[2,3] LTOP systems shall limit the maximum pressure in the vessel to 110% of the pressure determined to satisfy Eq. (1).

G-2220 NOZZLES, FLANGES, AND SHELL REGIONS NEAR GEOMETRIC DISCONTINUITIES

G-2221 General Requirements

The same general procedure as was used for the shell and head regions in G-2210 may be used for areas where more complicated stress distributions occur, but certain modifications of the procedures for determining allowable applied loads shall be followed in order to meet special situations, as stipulated in G-2222 and G-2223.

G-2222 Consideration of Membrane and Bending Stresses

(a) Equation (1) of G-2215 requires modification to include the bending stresses which may be important contributors to the calculated K_I value at a point near a flange or nozzle. The terms whose sum must be $<K_{Ia}$ for normal and upset operating conditions are:

(1) $2K_{Im}$ from G-2214.1 for primary membrane stress;

(2) $2K_{Ib}$ from G-2214.2 for primary bending stress;

(3) K_{Im} from G-2214.1 for secondary membrane stress;

(4) K_{Ib} from G-2214.2 for secondary bending stress.

(b) For purposes of this evaluation, stresses which result from bolt preloading shall be considered as primary.

(c) It is recommended that when the flange and adjacent shell region are stressed by the full intended bolt preload and by pressure not exceeding 20% of the preoperational system hydrostatic test pressure, mini-

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[2] The coolant temperature is the reactor coolant inlet temperature.

[3] The vessel metal temperature is the temperature at a distance one fourth of the vessel section thickness from the inside wetted surface in the vessel beltline region. RT_{NDT} is the highest adjusted reference temperature (for weld or base metal in the beltline region) at a distance one fourth of the vessel section thickness from the vessel wetted inner surface as determined by Regulatory Guide 1.99, Rev. 2.