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November 14, 1996

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

SUBJECT: Industry Position Paper on Steam Generator Tube Deterministic Structural Limits **(Project Number 689)**

The purpose of this letter is to forward the enclosed EPRI letter and industry position paper on the appropriate deterministic safety margin requirements for steam generator tubing. We request that these safety margin requirements and bases be reflected in the draft Regulatory Guide X.XX, "Steam Generator Tube Integrity," in lieu of what is currently proposed.

The EPRI letter and associated attachment provide the industry with suggested safety margin requirements and technical bases. We believe the industry proposal is better aligned with ASME code requirements. This position was explained by Tom Pritterle of Westinghouse at the recent November 5, 1996, ACRS subcommittee meeting. Mr. Pitterle indicated that a position paper would be submitted to the NRC staff for review. Mr. Strosinder agreed that the position paper would be reviewed by the NRC staff.

Inasmuch as the industry proposed safety margins differ from those proposed in the draft regulatory guide, we respectfully request a decision be made regarding our proposal before the draft regulatory guide is issued for public comment.

If you have any questions regarding the enclosure, please contact David Steininger at the Electric Power Research Institute (EPRI) at 415/855-2019 or me at 202/739-8114.

Sincerely,

R. Clive Callaway

R. Clive Callaway

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bc: NEI Task Force on Steam Generator Rulemaking w/enclosure
Ralph Beedle w/o enclosure
File: Steam Generator Issues

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EPRI
Electric Power
Research Institute ____ Leadership in Science and Technology

October 22, 1996

Mr. Clive Callaway
NEI-Nuclear Engineering Institute
1776 "I" Street NW, Suite 300
Washington, DC 20006-1280

Subject: Transmittal of Industry's Position Paper on Steam Generator Deterministic Structural Limits.

Dear Clive,

The purpose of this letter is to provide industry's position on appropriate deterministic safety margin requirements for steam generator tubing. This position is different than what has been proposed in NRC's regulatory guide supporting the proposed steam generator rule. The main difference of opinion between NRC and industry on the subject of steam generator tube structural integrity safety margin is explained below.

The attached document titled, "Technical Bases for SG Tube Deterministic Structural Limits," compares the safety margin requirements of ASME Section III (which is the original design basis for non-degraded steam generator tubes) and those in Draft Regulatory Guide 1.121 (which establishes limiting safe conditions for degraded steam generator tubes). This document shows that Draft Regulatory Guide 1.121 imposes more conservative safety margin requirements on steam generator tube structural integrity than does the ASME code. Specifically, imposing the Draft Regulatory Guide 1.121 requirement of margin to burst of 3 times normal operating pressure translates into an ASME Code safety factor, which is applied to the ultimate strength of the material, of approximately 3.5. The Code's safety factor is specified as 3.0.

ASME Code Section III requires a safety factor of at least 3 based on the ultimate strength of the tube. On the other hand Regulatory Guide 1.121 specifies a safety factor against failure by bursting under normal operating conditions of not less than 3 at any tube location. The ASME Code is normally based on design condition which in most cases has a slightly higher pressure than normal operating condition. However for the purpose of this evaluation, it will be assumed that the design condition is synonymous with normal operating conditions. With this assumption, it appears on the surface that the safety margin requirements of the Code is the same as the Regulatory Guide. However a careful evaluation of the events leading to

burst of a tube will show that the safety factor required by the Regulatory Guide is above and beyond that which is required by the ASME Code.

Under purely linear elastic consideration (small strains) which is the basis for the ASME Code, the maximum normal operating pressure differential (ΔP_{nop}) can be determined as:

$$\Delta P_{nop} = \frac{S_u \cdot t}{SF_c \cdot R_m}, \tag{1}$$

where S_u = ultimate strength,
t = thickness,
R_m = mean radius, and
SF_c = ASME Code Safety factor = 3.

Because of the ductile behavior of Alloy 600, there is considerable plastic deformation during pressurization of a steam generator tube such that at burst, the mean radius increases significantly from the initial state. If ξ represents the hoop strain prior to burst, the burst pressure can be approximated as:

$$P_B \cong \frac{S_u \cdot t}{R_m(1 + \xi)}. \tag{2}$$

The value of ξ is in the range of 15 - 20% for Alloy 600. One way of interpreting Equation (2) is that the large plastic deformation leads to a reduction in the burst pressure compared to what will be calculated based on purely elastic consideration. It is for this reason that the burst pressure for steam generator tubes is not simply a function of S_u but of both S_u and S_y and written as:

$$P_B = \frac{0 \cdot 6(S_y + S_u)t}{R_m}. \tag{3}$$

This correlation was established from several burst pressure tests of non-degraded tubes. The safety factor against burst (SF_B) can be established by dividing the burst pressure in Eq. (3) by the normal operating pressure differential in Eq. (1),

i.e.,

$$SF_B = \frac{P_B}{\Delta P_{nop}} = \frac{0.6 SF_c (S_y + S_u)}{S_u}$$

$$= 0.6\ SF_c \left(1 + \frac{S_y}{S_u}\right). \qquad (4)$$

Using a value of 3 for the ASME Code Safety Factor and a value of 0.44 for the value of S_y/S_u which is typical, the safety factor against burst $SF_B = 2.6$. Hence, it can be seen that the ASME Code safety factor 3 translates into a safety factor of 2.6 against burst for a Code designed, non-degraded tube. Alternatively, imposing the Draft Regulatory Guide 1.121 requirement of margin to burst of 3 times normal operating pressure translates into an ASME Code safety factor of approximately 3.5. Hence, requiring a minimum safety factor of 3 with respect to burst tests on degraded tubes would impose a greater safety factor for degraded tubes than the nominal safety factor that is inherent in ASME Section III for the design of new tubes. This additional amount of conservatism relative to the ASME Code requirement, imposed by Draft Regulatory Guide 1.121 as referenced by the proposed regulatory guide in support of the steam generator rule, is not warranted.

Sincerely,

David A. Steininger
Program Manager
Steam Generator Management Program

ENCLOSURE 2

Technical Bases for SG Tube Deterministic Structural Limits

September, 1996

Prepared By:

EPRI ARC AdHoc Committee

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Technical Bases for SG Tube Deterministic Structural Limits

Report Outline

1.0 INTRODUCTION

This report provides proposed deterministic structural limits for application to steam generator (SG) tube integrity assessments and alternate repair criteria (ARC) development. The technical bases supporting the criteria are included in this report. The structural limits given in Section 3 are intended for incorporation into an industry document supporting implementation of the NRC SG rule relating to tube integrity.

The structural limits are developed consistent with ASME Code requirements summarized in Section 2. ASME Code requirements are intended to be generic and apply to a wide variety of applications. Special considerations are provided herein for the derivations of the structural limits for SG tube indications based on experimentally determined burst correlations. For application of a burst correlation, it is necessary to assure that the required safety factors are consistent with the analysis based limits identified in the Code. This evaluation is included in the bases for the proposed structural limits in Section 4 of this document.

2.0 ASME CODE REQUIREMENTS

2.1 Applicable ASME Code, Section III, Subsection NB Requirements

Normal and Upset Conditions

The Subsection NB requirements for normal and upset conditions are given by:

- $P_m \leq S_m$ = smaller of $S_y/1.5$ or $S_u/3$

This requirement can be expressed in terms of the primary to secondary pressure differential at normal operating conditions and the structural limit (SL) as:

- $\Delta P_{NO} \leq S_u t/(3R_m)$ or $SL \geq 3\Delta P_{NO}$

This form is the typical basis for the NRC Regulatory Guide 1.121 guideline for applying a safety factor of 3 on burst at normal operating conditions. However, it needs to be recognized that this form is with respect to the result of a linear elastic stress analysis, i.e., an analytical estimate, and is not representative of the results of a test based burst pressure correlation. Nor is this form representative of limits associated with inelastic analyses. This consideration is further addressed in Section 3.1.

For local membrane stresses, the following limits apply:

- $P_L + P_b \leq 1.5\ S_m = S_y$ or $S_u/2$

This requires a safety factor of 2 on ultimate stress compared to the factor of 3 for the primary membrane stress.

For application of the Code requirements, linear elastic stress analyses are applied. ASME material properties at temperature, typical of minimum values are used in the associated analyses.

Emergency and Faulted (Accident) Conditions

The Subsection NB requirements for emergency and faulted conditions are:

- $P_m \leq$ lesser of 0.7 S_u ($\sim S_u/1.4$) or 2.4 S_m

This requirement can be expressed in terms of the primary to secondary pressure differential at accident conditions and the structural limit as:

- $\Delta P_{ACC} \leq S_u t/(1.4 R_m)$ or $SL \geq 1.4 \Delta P_{ACC}$

This form is the typical basis for the NRC Regulatory Guide 1.121 guideline for applying a safety factor of 1.4 on burst at accident conditions. Again, it needs to be recognized that this form is an analytical estimate and does not represent the true burst behavior of SG tubes. This consideration is further addressed in Section 3.1.

2.2 ASME Code Section XI, Appendix C (Flaws in Austenitic Piping) Requirements

This section of the Code has been issued since the NRC Regulatory Guide 1.121 was prepared and is not referenced in the regulatory guide. This section applies to flaws in austenitic piping and is provided as an optional analysis basis. Separate requirements are given for circumferential and axial flaws in piping as noted below. The requirements from the Code are given in terms of applicable safety factors.

Circumferential Flaws

The following safety factors applied to nominal membrane plus bending stress:

- Normal and upset conditions - SF = 2.77

- Emergency and faulted (accident) conditions - SF = 1.39

Axial Flaws

The following safety factors applied to nominal hoop stress:

- Normal and upset conditions - SF = 3.0
- Emergency and faulted (accident) conditions - SF = 1.5

Material properties applied with these criteria are typically wrought stainless steel at 550°F as given in EPRI report, "Evaluation of Flaws in Austentic Steel Piping", NP4690-SR, July, 1986.

2.3 Applicability to SG Tube Structural Integrity

Section III, Subsection NB

SG tubing has been designed to Section III, Subsection NB. The question of applicability for Section III is related to tube degradation in operating SGs and the potential differences in required safety factors between design using analytical stress formulations of the Code and operational analyses using tube burst margins based on test data as the basis for safety factors.

The SF of 3.0 in Section III of the Code is with regard to the ultimate tensile strength of the material and not with regard to the true burst/failure behavior of the component(s). The allowable wall thickness is based on performing an elastic analysis. Such analysis is particularly suited to nonductile materials with little strain hardening behavior. Alloy 600, however, is a very ductile material and significant plastic deformation of Alloy 600 tubes takes place prior to burst. If a plastic strain of 20% takes place prior to burst, the hoop stress is 20% higher in the deformed state (ignoring radial strain) than in the analyzed state because of the increase in axial sectional area over which the pressure is acting. The SF of 3.0 is likely present if the deformed condition is analyzed, however, the basis for elastic analysis is of the undeformed state. This has been demonstrated by the burst testing on nondegraded tubes. Adding recent test results to our database for throughwall indications results in eighty-six test results for nondegraded tubes. This includes model boiler specimen tubing, pulled tube sections, control specimens,

and data from NUREG/CR-0718. The average margin, i.e., the factor of safety, of the actual burst to the allowable operating pressure, determined using the ultimate tensile stress and the Code equation, is 2.7 (about 2.65 at 95% confidence), with a minimum of 2.5 and a maximum of 3.1. The results shown in Figure 2-1 indicate that the observed results may be considered to be normally distributed, thus, SF values even lower than 2.5 could be expected in a small percentage of additional tests. These differences between safety factors for analysis and for burst test data are further discussed in Section 4.1.

Overall, it is concluded that Section III, Subsection NB is the applicable section for SG tubing using the analytical basis given in Subsection NB but the safety factors require revision for applications based on use of a test based burst correlation. Without revision of the safety factors for operational analyses based on burst tests, tubing designed to satisfy Subsection NB could be unacceptable for operation based on a SF of 3.0 for burst.

Section XI, Appendix C

The SF of Appendix C for austenitic piping during normal/upset conditions is given as 2.77 which is less than the usual SF of 3.0. The factor of 2.77 is the average of 2.55, the factor for pure bending (which corresponds to a factor of 3.0 for pure tension adjusted for the shape factor associated with plastic collapse in bending), and 3.0, the factor for pure tension. The factor of 1.39 for emergency and faulted conditions is simply 2.77 divided by 2, corresponding to the use of 1.5 for pure tension for these conditions. Since there is very little applied bending loads to the SG tubes, it would be more appropriate to consider the continued use of a factor of 3.0 for normal operating conditions if a factor for normal operation is desired. Thus the circumferential flaw criteria are not applicable to SG tubing.

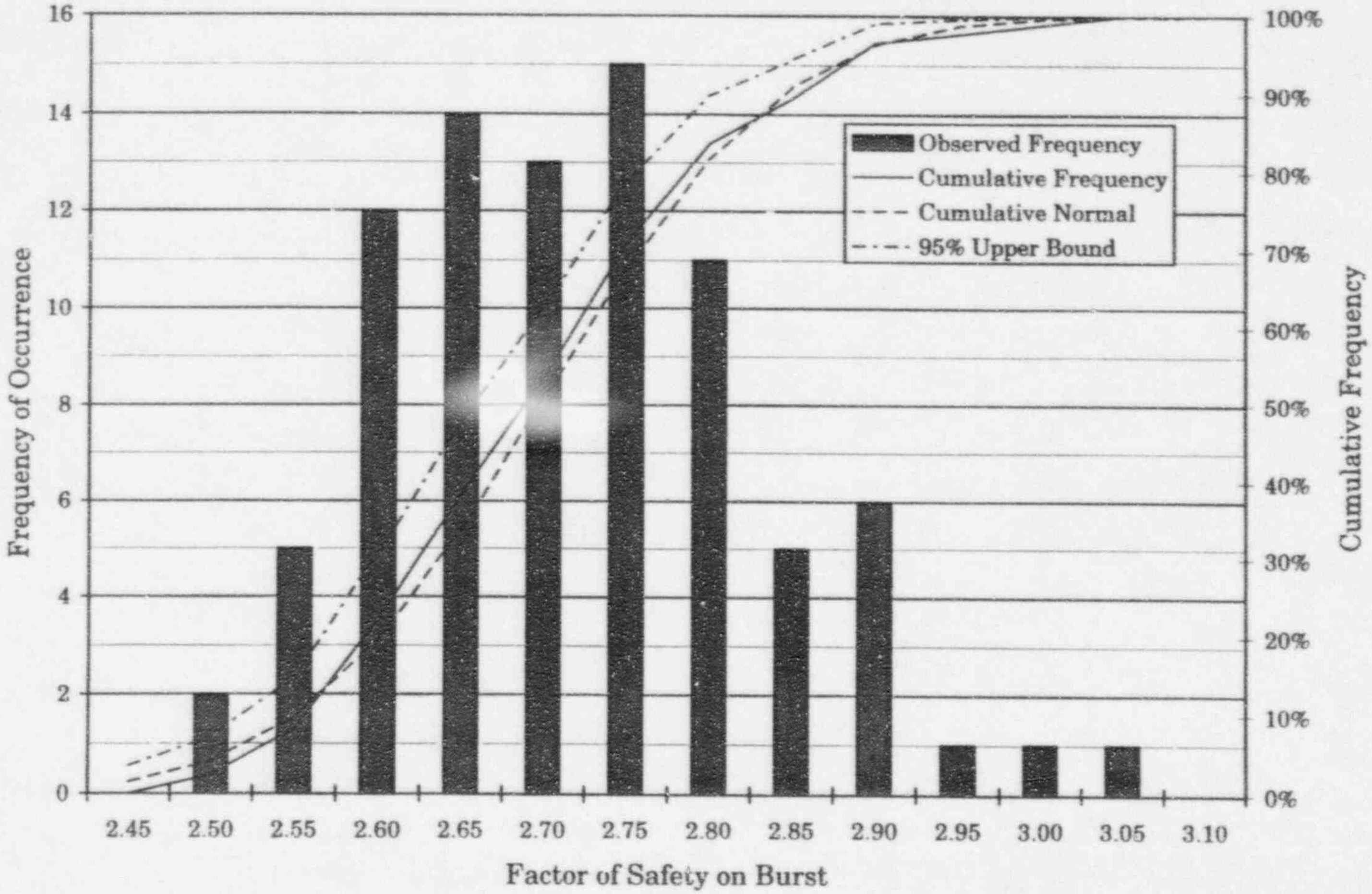
The value of 1.5 appears to arise from the limit on the sum of the tensile plus bending stresses of $1.5 \cdot S_m$ which would be $S_u/1.5$. The basis for this is not clear, however, in the reference document for Appendix C, it is stated that the SF for emergency/faulted conditions is taken as one-half of the SF for normal/upset conditions, and that this is consistent with the Code design basis. Examination of NB-3640 (1986 Edition) does not directly result in a clarification of this point, but, NB-3656(b) states that, as an alternative to the rules in Appendix F per NB-3656(a), the permissible pressure shall not exceed 2.0 times the pressure P_a calculated in accordance with Eq. (3) of NB-3641.1. Thus, if Eq. (3) provides a SF of 3.0, then this paragraph allows the use of a SF of 1.5 as an alternative to the requirements of Appendix F. Section XI also provides Appendix C for the evaluation

of flaws in austenitic piping as optional, i.e., non-mandatory. In summary then, the use of 1.5 is an option in lieu of the faulted requirements of Appendix F which result in a SF of 1.43.

Overall, it is concluded that Section XI, Appendix C is less applicable to SG tubing than Section III, Subsection NB. Bending stresses are a significant influence in the Appendix C safety factors and are not significant for SG tubing.

Figure 2-1: Distribution of Factor of Safety Against Burst

Alloy 600 SG Tubes of Various Sizes



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3.0 PROPOSED STRUCTURAL LIMITS

3.1 Burst Margin Requirements

The proposed structural limits are given in Table 3-1. The ASME safety factors, as summarized in Section 2, are based on the yield and/or ultimate strength of the material in conjunction with linear elastic structural analyses formulae. It is necessary to recognize that an empirical tube burst correlation may be used for SG tube integrity assessments. In this case, it is necessary to ensure that SG tubing designed to Section III is consistent with application of a burst correlation after the SG is in service. This topic is addressed in Sections 2.2 and 4.1.

The proposed criteria of Table 3-1 provide separate safety factors for SG tube evaluations based on analysis and on burst test results. As noted in Section 4.1, this difference is necessary to assure consistency between design to ASME Code Section III and operational analyses utilizing an empirical burst correlation. This results in the different safety factors for normal operation as given in Table 3-1.

As can be seen in Table 3-1, there are differences in the safety factors between the analytical and empirical burst correlation approaches for normal operating conditions. The burst based requirements establish a minimum pressure differential of 3600 psi as a supplement to maintaining the accident condition safety factor of $1.43\Delta P_{SLB}$ at normal operating conditions. Various steam generator designs and operating conditions result in a range of 1250 to 1500 psi for the normal operating tube pressure differential. The minimum 3600 psi pressure differential assures a normal operation safety factor ranging from 2.4 to 2.9 dependent on the specific SG steam pressure. The fixed minimum pressure differential assures that this margin range would not be reduced if accident condition pressure differentials are lowered such as by application of pressure operated relief valves rather than safety valves for the accident condition pressure differential. In addition, application of the minimum 3600 psi structural limit requires that the normal operating pressure differential be less than or equal to 1600 psi.

It can also be noted that use of a multiple of the normal operating pressure differential, ΔP_{NO}, for the structural limit results in a value that is difficult to define for a SG. Steam pressure varies typically by up to 10 psi and occasionally up to 20 psi over an operating cycle and can vary by an addition 10 psi between SGs in an given plant. Also the steam pressure in a given steam generator can vary from cycle

to cycle due to changes in tube plugging and changes in operating temperature, such as a T_{hot} reduction to reduce corrosion rates. Thus, a specific ΔP_{NO} to use for a structural limit is somewhat subjective as further discussed in Section 4.2. The proposed structural limits eliminate this subjectivity.

Table 3-1. Deterministic Structural Limits for SG Tube Integrity

Plant Condition	SG Tube Evaluation Based on Analysis	SG Tube Evaluation Based on Burst Test Data Correlation[1]
Normal operation	ASME Code, Section III, Subsection NB requirements for normal and upset conditions. SF typically 3.0: • SL = 3.0 x ΔP_{NO}	All flaws: • SL = Larger of 3600 psi or 1.43 x ΔP_{ACC} Application of the lower bound 3600 psi structural limit requires $\Delta P_{NO} \leq 1600$ psi. Results in $2.4 \leq SF \leq 2.9$ relative to ΔP_{NO} in steam generator operating range of 1250 to 1500 psi.
Accident conditions	ASME Code, Section III, Subsection NB requirements for emergency and faulted conditions. SF typically 1.43: • SL = 1.43 x ΔP_{ACC}	All flaws: SF = 1.43 • SL = 1.43 x ΔP_{ACC}

Notes:

1. For application of a burst correlation, it must be demonstrated that the burst correlation is independent of applied bending stresses or the influence of the bending stresses must be accounted for in the analyses. Mechanical loading conditions should be considered in this assessment.
2. Abbreviations:

   SF - safety factor

   SL - structural limit

   ΔP_{NO} - steam generator tube differential pressure during normal operations

   ΔP_{ACC} - steam generator tube differential pressure during accident conditions

4.0 BASES FOR PROPOSED STRUCTURAL LIMITS

The tube integrity criteria of Table 3-1, as proposed for industry structural guidelines, apply the ASME Section III, Subsection NB structural margins when linear elastic analysis evaluations are performed for tube burst. The analysis basis is consistent with the requirements of the Code. When a test based burst correlation is used, a structural limit based on the larger of 3600 psi or $1.43\Delta P_{ACC}$ is applied for normal operation and $1.43\Delta P_{ACC}$ is applied for accident conditions with the safety factor of 1.43 obtained from the faulted criteria of Section III of the Code. This application represents a very specific condition for SG tubing, whereas the Code is intended to be sufficiently conservative to span a broad range of applications/components. In addition, the use of a burst correlation for the accident condition pressure differential reduces analytical uncertainties compared to the analytical estimates permitted by the Code.

The bases for the normal operation requirements are further developed in this section. It is shown that the Code based linear elastic analysis estimate for the stress limit at normal operation with a factor of safety of three on the ultimate tensile strength is consistent with applying a factor of safety of 2.4 to 2.7 on a tube burst estimate using tube integrity requirements based on a burst correlation. Additional qualitative and quantitative support for the structural integrity requirements are also given in Section 4.2 and 4.3. The quantitative support is based on demonstrating that the requirements lead to a very low burst probability at normal operating conditions.

4.1 ASME Code Section III Safety Factor Considerations

The recommended deterministic structural limit for tube integrity with a test based correlation is based on the more limiting of 3600 psi or $1.43\Delta P_{ACC}$ for normal operation. The current NRC guideline standard, i.e., Reference 1, specifies that the margin against burst during normal operation should be based on a factor of safety of three. In general, the controlling accident condition with regard to tube burst is a postulated main steam line break (SLB) event with an associated differential pressure of 2560 psi at the hot leg operating temperature. Thus, the margin against burst during an accident is demonstrated if the burst pressure of the tube section with the indication is greater than 2560/0.7 or 3657 psi. For most Westinghouse plants with nominal 3/4" diameter tubes, the normal operating differential pressure is on the order of 1250 psi. The margin to burst with a safety factor of 3.0 during

normal operation is demonstrated if the burst pressure of the affected tube section is greater than 3750 psi. For most Westinghouse plants with nominal 7/8" nominal diameter tubes, the operating differential pressure is more on the order of 1400 to 1500 psi. Therefore, demonstrating a structural margin of 3 would require the burst pressure of the affected tube section to be on the order of 4200 psi. Since, $3\Delta P_{NO}$ is greater than $1.43\Delta P_{ACC}$ in both cases, the margin during normal operation would be more limiting in the sense of the allowable size of the degradation.

It is apparent that the guidelines presented in Reference 1 draw heavily from the structural margins presented in Reference 2, and can be summarized as follows,

> "The minimum acceptable tube wall thickness is determined by criteria that require a factor of safety of three against burst of the tubes during normal operation (just as required by the ASME Code, Section III for all other components of the reactor coolant pressure [boundary] and that the margins to failure under postulated accident loadings are comparable to those margins provided by Appendix F 'Rules for Evaluation of Faulted Conditions' of Section III of the ASME Code for such loading."

Thus, it is also apparent that the intent of the guidelines of Reference 1 are intended to result in margins to burst consistent with the original design requirements as specified by the ASME Code. In fact, this is specifically acknowledged within Reference 2 as follows:

> "(2) The margin between the maximum internal pressure to be contained by the tubes during normal plant conditions and the pressure that would be required to burst the tubes should remain consistent with the margin incorporated in the design rules of Section III of the ASME Code.
>
> (3) Loading associated with a LOCA or a steam line break, either inside or outside the containment and concurrent with the SSE, should be accommodated with the margin determined by the stress limits specified in NB-3225 of Section III of the ASME Code and by the ultimate tube burst strength determined experimentally at the operating temperature."

Although there are specific references to a margin to burst of 3 within Reference 1, it is apparent that such statements are made in the context of compliance with item (2) above. The use of the design rules of the ASME Code Section III will result in

calculating an allowable limit on the normal operating differential pressure for SG tubes of,

$$\Delta P_{NO} \leq \frac{\sigma_u t}{3 R_m}, \tag{1}$$

where σ_u is the ultimate tensile strength of the tube material, t is the tube thickness and R_m is the tube mean radius. The number 3 in the denominator is the factor of safety of 3 alluded to in Reference 1. This does not, however, provide for a margin of 3 against burst. To see this, we note that the burst pressure correlation of Reference 3 for throughwall axial cracks results in a predicted burst pressure for tubes without cracks of,

$$P_B = \frac{0.6(\sigma_y + \sigma_u) t}{R_m}, \tag{2}$$

where σ_y is the yield strength of the tube. Combining the above two equations, the ratio of the burst pressure to the allowed pressure, i.e., the safety factor, SF, is,

$$\mathrm{SF} = \frac{P_B}{P_{NO}} = 1.8\left(1 + \frac{\sigma_y}{\sigma_u}\right). \tag{3}$$

Information in Reference 4 shows that the yield to ultimate ratio for nominal 7/8" diameter mill annealed tubes is 0.44 at 650°F. For 3/4" tubes the corresponding ratio is 0.47. Thus, for each tube size, the true SF against burst is about 2.6, and not 3.0 as implied. As shown in Section 2.2 and Figure 2-1, the SF obtained using the ratio of measured burst pressures for undegraded tubes to Equation 1 is about 2.65 at 95% confidence which is consistent with the above derivation of the 2.6 factor of safety.

A similar result is obtained by considering that a uniform plastic hoop strain of about 15% occurs prior to tube rupture. Hence, the expected burst pressure, ignoring the radial strain, may be estimated as,

$$P_B \geq \frac{\sigma_u t}{1.15 R_m}. \tag{4}$$

Combining this estimate with the allowable pressure of Equation 1 implies a true factor of safety of about 2.6. In other words, the use of a factor of 3.0 on the ultimate tensile stress as in the ASME Code design equation results in an average true SF of about 2.6 to 2 [illegible] tube burst. This was confirmed by the test results presented on Figure 2-1. What is proposed for the tube integrity rule is a test derived structural limit at normal operation that results in a safety factor range of 2.4 to 2.9 for SG tubing which is consistent with the material ultimate tensile strength factor of 3.0 from Section III of the Code.

Regardless of tube size, the limiting accident differential pressure for Westinghouse SGs is 2560 psi. The application of a SF of 1.43 for accident conditions results in a required burst pressure of at least 3657 psi. For plants with a normal operation differential pressure of 1250 psi, the margin to burst is then 2.93 at normal operating conditions. For plants with normal operating differential pressures of 1400 to 1500 psi, the respective margins at normal operation based on the accident condition criterion are 2.61 to 2.44. As noted above and in Table 3-1, the resulting safety factor range of 2.4 to 2.9 based on applying a test based burst correlation is consistent with a safety factor of 3.0 for analysis per Section III of the Code.

It may be further noted that, with regard to considering localized degradation as a localized discontinuity, the local membrane stress is limited to $1.5 \cdot S_m$ per the ASME Code. Given that for SG tubing S_m is usually obtained as one-third of the ultimate tensile strength, the stipulated analysis based SF during normal operation for the local membrane stress is 2.0 instead of 3.0.

In summary, the use of the more limiting of 3600 psi or $1.43\Delta P_{ACC}$ at normal operation in conjunction with test based tube burst correlations is consistent with the prior guidelines, including ASME Section III, which rely on linear elastic stress analysis based normal operation criteria.

4.2 Qualitative Arguments for Structural Limits

As noted above, the use of $3\Delta P_{NO}$ as a structural limit has a significant effect on Westinghouse SGs with 7/8" diameter tubing but has little effect on SGs with 3/4" tubing since the SGs with 3/4" tubing operate at higher steam pressures. The net effect of the requirement would be to penalize repair limits by tubing size. With the

proposed test based normal operation structural limit, the criteria do not have a significant preferential impact on one tube size versus another.

The use of $3\Delta P_{NO}$ as a structural limit results in a structural limit penalty on plants which improve tube integrity by reducing T_{hot}. The reduction in primary temperature results in a reduction in steam pressure which then leads to an increase in $3\Delta P_{NO}$. The real effect of the temperature reduction is to reduce potential tube corrosion and reduce the likelihood of a tube rupture but the plant would be required to increase the structural margin. The penalty on the structural limit as a result of reducing steam pressure to reduce tube corrosion is eliminated with the proposed normal operation criteria.

Tube ruptures that have occurred at normal operating conditions have been due to new or unexpected causes such as loose parts, new degradation mechanisms, etc. They were not a result of inadequate structural margin and would not have been affected by the tube integrity requirements. Thus the use of the proposed normal operation structural limit would not be expected to significantly change the likelihood of a rupture at normal operating conditions. This conclusion is also shown quantitatively in Section 4.3 by demonstrating that the proposed criteria result in a very low probability of a tube rupture at normal operating conditions.

For operating SGs, ΔP_{NO} is not a well defined or a constant value. Normal operating pressure differentials can change during one cycle, are different between SGs and also vary from cycle to cycle. As a result, the tube repair criteria based on ΔP_{NO} varies between SGs and can change from cycle to cycle. Since steam pressure can vary by 10 psi and occasionally up to 20 psi in one SG over an operating cycle, the value of ΔP_{NO} for one cycle is not a unique value. The differences in steam pressure result from variations in heat transfer coefficients over an operating cycle, differences in T_{hot} between SGs, differences in tube plugging between SGs or between operating cycles and variations in tube deposits between SGs. The use of $1.43\Delta P_{ACC}$ results in uniformity of tube repair criteria between plants of the same generic design and the same or different tube size as well as eliminating cycle dependence for changes in steam pressure.

4.3 Quantitative Arguments for Applying Burst Probability Analyses

The margins obtained at normal operating conditions with a $1.43\Delta P_{ACC}$ structural limit can be quantitatively assessed by evaluating the burst probability for an indication at the structural limit. Analyses to support the conservatisms or margins for the structural criteria are given in Table 4-1. The table includes analyses for 3/4" and 7/8" diameter tubing, application of the EPRI burst correlations for burst pressure versus bobbin voltage and versus throughwall crack length and margins relative to the correlations at lower tolerance limit (LTL, lower 95/95%) material properties as well as relative to the nominal correlation.

For the thru-wall axial length correlation, it is seen that the lower bound $1.43\Delta P_{ACC}$ structural criteria lead to crack lengths of 0.513" for 3/4" tubing and 0.571" for 7/8" tubing at the structural limit. For these crack lengths, the burst probabilities at normal operating pressure differentials (typically about 1250 psi for 3/4" tubing and 1450 psi for 7/8" tubing) are on the order of 10^{-12} and the burst probabilities at accident conditions are on the order of 10^{-5}. It is clearly seen that the $1.43\Delta P_{ACC}$ structural limit applied to the axial TW correlation results in an extremely small burst probability at normal operating conditions. Thus, there is no need to add conservatism by increasing the normal operation criterion to a $3\Delta P_{NO}$ structural limit. The burst probability for an indication at the $1.43\Delta P_{ACC}$ structural limit is also very low for burst under steam line break conditions It is also seen from Table 4-1 that the $1.43\Delta P_{ACC}$ criteria lead to crack length margins on normal operating conditions (ratio of length at ΔP_{NO} to length at $1.43\Delta P_{ACC}$) of 2.5 to 3.0 which is consistent with the proposed criterion at normal operation. The structural limit margin on length for burst at SLB conditions is a 1.5 factor.

Table 4-1 also shows the margins of the $1.43\Delta P_{ACC}$ criterion when a correlation for burst pressure versus bobbin voltage is applied. The burst pressure versus voltage correlations used for these analyses are those applicable in March, 1995. The conclusions of these analyses are insensitive to the specific correlation applied. The criterion leads to structural limits of 4.7 and 9.0 volts for 3/4" and 7/8" diameter tubing. The associated burst probability at normal operating conditions is $< 10^{-5}$ for both tubing sizes and about a factor of 100 lower than the burst probability at SLB conditions. The burst probability for normal operation is negligible and satisfaction of the conditional probability for burst limits at accident conditions further assures a negligible burst probability for normal operation. When the voltage correlation is applied at TSP intersections that prevent burst at normal operating conditions, it is only necessary to demonstrate acceptable burst probabilities at accident conditions. It is seen that the margin on volts between the $1.43\Delta P_{ACC}$ criterion and normal

operation is a ratio of 7.7 to 10.2 with 36 to 91 volt indications required for burst at normal operating pressure differential. Thus the $1.4\Delta P_{ACC}$ structural limit provides adequate margins at normal operating conditic

It is also seen in Table 4-1 that the $1.43\Delta P_{ACC}$ structural limit provides comparable burst probabilities between 3/4" and 7/8" diameter tubing. The use of a $3\Delta P_{NO}$ structural limit would result in the 7/8" burst probabilities being reduced well below that for 3/4" tubing since the 3/4" limit is not significantly affected by this criteria.

Table 4-1. Conservatism/Margins for Deterministic Structural Criteria		
Parameter	ODSCC Volt Corr. LTL @ 95% P	Axial TW Length Corr. LTL
Relative to Normal Operating and Accident Conditions for 3/4" Tubes		
Proposed Deterministic Structural Criteria		
Volts/Length @ $1.4 \cdot P_{SLB}$	4.70	0.513
Pr(Burst) @ ΔP_{NO}	6.87E-06	2.75E-13
Pr(Burst) @ P_{SLB}	1.04E-03	3.97E-05
Margins for Normal Operating Conditions (1250 psid)		
Volts/Length @ ΔP_{NO}	36.00	1.523
Margin Relative to Criteria Volts/Length	7.7	3.0
Margins for Accident Conditions		
Volts/Length @ P_{SLB}	11.93	0.747
Margin Relative to Criteria Volts/Length	2.5	1.5
Relative to Normal Operating and Accident Conditions for 7/8" Tubes		
Proposed Deterministic Structural Criteria		
Volts/Length @ $1.4 \cdot P_{SLB}$	9.01	0.571
Pr(Burst) @ ΔP_{NO}	9.85E-06	2.53E-12
Pr(Burst) @ P_{SLB}	8.35E-04	2.05E-05
Margins for Normal Operating Conditions (1450 psid)		
Volts/Length @ ΔP_{NO}	91.70	1.435
Margin Relative to Criteria Volts/Length	10.2	2.5
Margins for Accident Conditions		
Volts/Length @ P_{SLB}	28.66	0.838
Margin Relative to Criteria Volts/Length	3.2	1.5

4.4 Summary

The bases are summarized below for the use the more limiting of 3600 psi or $1.43\Delta P_{ACC}$ structural limits for normal operating conditions in conjunction with tube burst pressure correlations derived from tube burst tests:

- The ASME Code, Section III requirement for a factor of safety of 3.0 on ultimate strength corresponds to a factor of safety of about 2.6 for tube burst. The proposed normal operation structural limit of 3600 psi or $1.43\Delta P_{ACC}$ based on use of a burst correlation is consistent with the Section III analysis requirements.

- The use of a structural limit of $1.43\Delta P_{ACC}$ results in tube burst probabilities at normal operation of $< 10^{-5}$ for a voltage correlation and about 10^{-12} for a length correlation (3/4" diameter tubing with ΔP_{NO} = 1250 psi and 7/8" diameter tubing with ΔP_{NO} = 1450 psi). Thus, burst probabilities at normal operating conditions are negligible for the proposed structural criteria.

- The tube ruptures that have occurred at normal operating conditions have been the result of new or unexpected degradation mechanisms and were not the effect of inadequate structural margin. The use of $3\Delta P_{NO}$ versus $1.43\Delta P_{ACC}$ would not be expected to significantly change the likelihood of a rupture at normal operating conditions.

- For operating steam generators, it is difficult to uniquely define ΔP_{NO} since steam pressure varies over an operating cycle, varies between SGs of the same plant and varies between operating cycles. The use of structural limits based on accident condition pressure differentials avoids the issues with defining ΔP_{NO}.

4.5 References

1. Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes," United States Nuclear Regulatory Commission (Issued for Comment, August 1976)

2. Docket Nos. 50-282 and 50-306, "Before the Atomic Safety and Licensing Board, In the Matter of Northern States Power Company (Prairie Island Nuclear Generating Plant, Units 1 and 2), Testimony of James Knight," U.S. Nuclear Regulatory Commission (January 1975).

3. SG-95-03-010 (EPRI Licensable Information), "Burst Pressure Correlation for Steam Generator Tubes with Throughwall Axial Cracks," prepared for the Electric Power Research Institute (February, 1995).

4. WCAP-12522, "Inconel Alloy 600 Tubing-Material Burst and Strength Properties," Westinghouse Electric Corporation (January, 1990).