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

Attn: Mr. Edmund J. Sullivan
Materials and Chemical Engineering Branch

Subject: Laser Welded Sleeves Weld Width Information

Dear Mr. Sullivan:

During the past several months, the laser welded sleeve weld width issues reported in WCAP-13088, Rev. 4, Addendum 1, "Westinghouse Series 44 and 51 Steam Generator Generic Sleeving Report, Laser Welded Sleeves" have been discussed with representatives of the NRC Staff. This WCAP report applies to Westinghouse plants with steam generators with 7/8 inch outside diameter tubes. Similar reports have been prepared for each of our customers where Westinghouse has provided licensing documentation in support of the repair of degraded steam generator tubes using laser welded sleeves. WCAP-13698, Rev. 2, Addendum 1 applies to Westinghouse and Combustion Engineering steam generators with 3/4 inch outside diameter tubes. WCAP-14596, Rev. 1, Addendum 1 applies to Westinghouse plants with steam generators with 11/16 inch outer diameter tubes. In one instance, Revision 3 of WCAP-13698 contains the addendum material. These reports may or may not have already been submitted to the NRC staff.

The current understanding of the conclusions of these discussions with the NRC staff and actions to be taken to resolve the laser welded sleeve weld width issues are as follows:

1. There are no safety concerns regarding the structural adequacy or leak resistance of the welds, including existing welds.

2. Westinghouse committed to prepare a report documenting the width expectations for the existing welds. This information is attached and consists of calculations performed to characterize the statistical distribution of the test data reported in the WCAPs. It was recommended that this be a non-proprietary report.

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3. Westinghouse committed to modify the inspection procedure for future welds to include a criterion for an average width of each weld in order to meet the requirements of Section III of the ASME Code for design-by-analysis. Any welds determined to have an average weld width of less than 21 mils will be subject to an engineering disposition process. Special considerations may then be made that result in infrequently accepting welds with average widths as small as, but not less than 19 mils.

4. Westinghouse has committed to send a letter to each utility holding licensing documentation to install laser welded sleeves recommending that they inform the NRC staff of their commitment to implement the new inspection procedure in 3) above. The NRC staff is expected to respond with a letter advising the utility that the transmittal has been received.

The attached report has been prepared to address the Westinghouse commitments made regarding the installed weld widths of existing Laser Welded Sleeves. It is concluded that it is unlikely that existing welds were made with average weld widths less than that needed to meet the ASME Code design-by-analysis. Moreover, it is more unlikely that welds were made with failure strengths less than the burst strength of the installed sleeves, or for that matter, the tubes in which the sleeves were installed.

This submittal provides information that might be helpful to the NRC staff when evaluating plant-specific license amendment requests. Such reviews are exempted under §170.21, Schedule of Facility Fees. Footnote 4 to the special projects provision of §170.21 states, "Fees will not be assessed for requests/reports submitted to the NRC...[a]s a means of exchanging information between industry organizations and the NRC for the purpose of supporting generic regulatory improvements or efforts."

Please contact Gary Whiteman (412-374-5175) or Bob Keating (724-722-5086) if you have any questions or comments.

Very truly yours,

H.A. Sepp, Manager
Regulatory and Licensing Engineering

cc: S. Bloom, NRR

Weld Width of Laser Welded Sleeved Tubes

1.0 Introduction

The Westinghouse laser welded sleeve (LWS) was originally designed in the late 1980's to be an effective repair of degraded steam generator (SG) tubes at nuclear power plants. The design and analysis of the sleeve and weld are documented in References 1, 2 and 3 for 7/8", 3/4", and 11/16" diameter tubes respectively. A schematic illustration of the weld is provided on Figure 1. The principal loads on the weld are from the primary-to-secondary end-cap pressure difference and differences in thermally induced axial growth between the sleeve and the tube. The structural analyses were performed to verify that the designed configuration was in compliance with the design-by-analysis requirements of Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PV), hereinafter referred to as the Code, Reference 4. The results of finite element analyses of the installed weld configuration indicated that welds with a minimum width of 15 mils would meet the analysis requirements of the Code. Because the sleeves are designed for installation in tubes in SGs which have been in operation, the governing section of the code is Section XI, Reference 5. However, justification of the sleeve design is based on meeting the original code for the construction of the plant. Westinghouse interpreted the requirement for the sleeve to also apply to the weld. Because a weld is involved, the qualification of the installation process is done in accord with the requirements of Section IX of the code, Reference 6.

In 1998, Westinghouse reported in References 7, 8, and 9, that "recent analysis to evaluate revised operating conditions for steam generators relative to the integrity of laser welded sleeves determined that the finite element model used to initially qualify the minimum acceptable weld width of 0.015 inch under-predicted the shear stress in the welds." It was further reported that two design-by-analysis requirements of Section III of the Code would not be met if the specified minimum allowable weld width were considered to be the average weld width. The two analysis requirements which are not met by a uniform, 15 mil wide weld are: the safety factor (SF) of three between the applied stress and the Code specified minimum ultimate tensile strength, and the $3S_m$ requirement for the range of stress intensity to justify performing only an elastic fatigue analysis. Regarding the second requirement, References 7, 8, and 9 did report that a simplified fatigue analysis had been performed and the results confirmed that the expected usage factor during service would be less than the allowable value of unity. Subsequent elastic-plastic fatigue analysis results confirmed the conclusions from the simplified fatigue analysis.

To address the conclusion that the SF requirement was not met for design-by-analysis, an intensive analysis and test program was also performed in 1998. The description of and the results from the program for 7/8" diameter tubes are also documented in Reference 7, 8, and 9. The results of the test program demonstrated that the minimum weld width, when adjusted to account for the potential minimum ultimate strength, exhibited a resistance to burst of greater than four times the Code design primary-to-secondary pressure difference across the tube wall (6500 psi versus 1600 psi). In that regard the weld was demonstrated to also comply with the requirements of References 10 and 11 which are used for establishing the acceptability of degraded SG tubes for continued operation. The basis for meeting the requirements of these documents is that compliance may be demonstrated by test instead of theoretical analysis. The issue of the weld width affects the requirements for future sleeve installations and requires consideration of existing sleeve installations. These are discussed in Sections 1.1 and 1.2.

There are no open questions regarding the conclusion that the weld meets ASME code Section IX and XI requirements relative to weld process qualification and implementation. In addition, there are no known questions regarding the conclusion that the weld design does meet the applicable requirements of Regulatory Guide 1.121, Reference 10, and NEI 97-06, Reference 11, which are used to determine whether or not degraded tubes may remain in service.

1.1 Future Sleeve Installations

Westinghouse's initial approach to demonstrate compliance with the SF requirement was to verify the structural integrity of the welds based on Code Section III design-by-test requirements. These, however, are biased toward the attachment of butt welded fittings, and there is no geometry specified in the Code that correlates directly to the geometry of the LWS weld joint, i.e., a weld joint that is effectively loaded in pure shear, see Figure 1. This means that the demonstration of compliance with the Code requires interpretation of the intent of the Code authors and may be construed to be subjective. In addition, structural analyses were performed to characterize the average weld width that would be necessary to demonstrate compliance with the Code design-by-analysis requirements and to achieve estimated strengths greater than the burst resistance of the sleeve. The results from the analysis work demonstrate that:

1. An average weld width of 19 mils or larger meets the requirements of the Code for performing an elastic fatigue analysis, i.e., the range of stress intensity would be less than $3S_m$. The associated usage factor is less than unity.
2. An average weld width of slightly less than 19 mils results in a weld failure strength greater than the burst strength of the installed sleeves considering Code minimum material properties.
3. An average weld width of 21 mils meets all of the design-by-analysis requirements (no required structural tests) of the Code for all currently available LWS sleeve and tube combinations.

Based on these findings, Westinghouse decided to modify the field inspection procedure to verify that the average width of new LWS installed sleeves is ≥ 21 mils. The results from the analysis efforts also demonstrate that there is no other change needed, nor is one planned, relative to the design and installation of the sleeves or the fabrication of the weld of the sleeve to the tube.

1.2 Existing Sleeve Installations

The current applicable design requirement for installed sleeves is that the minimum weld width be ≥ 15 mils. This means that the criterion in place for previous installations could have led to the acceptance of a weld with an average width of 15 mils if one were made. Such a weld would also have to be of uniform width for the minimum and average width to be the same. This is likely to be a practical impossibility. The development and other test data indicate that the specified minimum width is significantly less than the actual average width expected of LWS installations. Hence, it is expected that no welds with an average width of 15 mils were actually made and/or accepted. The same data also indicate that the installation process most likely results in welds which meet the Code design-by-analysis criterion of ≥ 21 mils. Those same test results were used to quantify the likelihood of making a weld smaller than the design-by-analysis requirement of Section III of the Code, see Section 4.0.

2.0 Weld Procedure Specification & Procedure Qualification Record

The process for qualifying the weld procedure and operators involves making test welds and verifying that the characteristics are in accord with the Weld Procedure Specification (WPS). The results are recorded in the Procedure Qualification Record (PQR). When a test weld is made, the width is measured at one location and recorded. Thus, while not appropriate for establishing the average width of the weld, the data do provide indirect corroboration of the weld width testing verification program. A cursory review of the qualification records indicates a predominance of welds with widths greater than 30 mils.

3.0 Weld Width Verification Testing Program

Reference 7, 8, and 9 report the results from a series of pressure tests performed on LWS specimens. Twenty-seven welded specimens were prepared according to the field installation procedures with the exception that fifteen of the welds were made with the beam power deliberately set below the acceptable process range in an attempt to fabricate welds with widths on the order of the specified minimum. The beam power was deliberately set at the lower end of the allowable power range for the remaining thirteen welds. Nineteen of the specimens were pressurized to failure in order to quantify the shear strength of the weld under differential pressure loading conditions. Sixteen of the tubes burst before the welds failed. The length of the sleeve portion of the test specimens was short enough to preclude burst of the sleeve before the tube. However, the tube would be expected to have a burst pressure about 6 to 7% greater than that of the sleeve. The specimens with the failed welds were all welded at a power level that was lower than the allowable procedure minimum value. Twelve of the specimens were welded at a power level at the lower end of the acceptable range for field installations and all exhibited acceptable widths by the UT measurement. The specimens were destructively examined to ascertain the widths of the welds at 15° intervals. One of the specimens was scarred to the extent that the width measurements could not be made reliably. The results from the analysis of the data from the eleven specimens with measurable widths and made at the minimum acceptable power level are reported Section 4.0.

4.0 Analysis of the Test Data

The data from the strength testing program specimens was analyzed to characterize the distribution of weld widths that would result from the weld process. Only the data from the eleven specimens welded at the minimum acceptable power level were analyzed. The average weld widths would be expected to be less than the average welds made in the field because the laser power used for these specimens was lower than nominal. The analysis of the data consisted of evaluation of the distribution of the data, calculation of confidence and prediction limits, estimation of tolerance limits for the average weld widths, and analysis of the distribution of the standard deviations and the range of individual weld widths.

An optical technique was used to measure the weld widths. The process was later found to provide conservative results relative to those obtained by sectioning and polishing the specimens. A comparison of several measurements indicates that the optical measurement technique underestimates the actual width by about 4 to 5 mils.

All of the analysis results reported in this document were based on using the optically measured widths. This means that the estimated probabilities for fabricating widths less than criteria values are conservative.

4.1 Average Width Measurements

It was expected that a normal or Student's *t* distribution would be appropriate for describing the distribution of the data owing to the number of variables involved in the process. However, several distribution functions were considered for potentially characterizing the data because of the limited number of specimens. These ranged from the standard normal, the Student's *t*, the logistic, the Cauchy, and the four extreme value distributions (Gumbel, Fréchet, Weibull and Kunin). Some calculations were performed using the logarithm of the weld width, but this provided no significant benefit in describing the data. For each of these the average width of the weld was taken as the independent variable and the median rank of the cumulative probability was the dependent variable. Each of the distributions was fitted to the data using a Generalized Linear Model (GLM) algorithm; the GLM algorithm yields parameter estimates that minimize the deviance of the observed cumulative probabilities from the model. The best results were obtained with the standard calculation of normal distribution parameters, GLM estimates of the parameters of the normal distribution, the Gumbel distribution of maxima, and the Kunin distribution of minima. The latter two distributions belong to the family of extreme value distributions.

The optimum fit of the Kunin distribution was obtained using a minimum possible weld width of 25 mils. This value is judged to be too large for the distribution to be considered suitable and was omitted from further evaluation. The GLM solution for the normal distribution effectively coincided with the Weibull distribution of maxima. The GLM solution for the normal distribution minimized the overall deviance by reducing the deviance contributions from the midrange data at the expense of the data in the tails of the sample distribution. Based on this observation it was judged that the use of the normal and Gumbel maxima distributions would provide adequate and reliable descriptions of the population of weld widths. The fit of the normal, Student, and Gumbel maxima models are depicted on Figure 2 and Figure 3.

It is quite apparent from the data that an extreme value distribution of maxima provides a closer approximation to the actual data, however, the normal distribution results in consideration of a longer lower tail and affords a conservative evaluation. This is quite clear from Figure 3. Using the normal distribution parameters, i.e., a mean of 28.0 mils and a standard deviation of 1.79 mils, the probability of a single weld having an average width < 21 mils is about 0.005%, and the probability of an average width of < 19 mils is 0.00005%.

4.1.1 Prediction Limit

A prediction limit is a value of the random variable, the weld width in this case, which is calculated to be a bound on a single observation of that variable at a specified level of confidence. If the mean and standard deviation of the population are known, the bound is calculated using a normal distribution with those parameters. If only the mean and standard deviation of a sample of N values are known, m_w and s_w respectively, the bound is calculated using a Student's t distribution with the sample parameters. Thus, a 99% lower prediction bound for the weld width is found as,

$$w_{0.01} = m_w + t_{0.01,\nu}\, s_w \sqrt{1+\frac{1}{N}}, \nu$$

where $t_{0.01,\nu}$ is the value of t corresponding to the 1st percentile of the Student's t distribution for ν degrees of freedom, i.e., N-1 or 10. The mean value of the test data from eleven specimens was 28.0 mils for the average width with a standard deviation of 1.79 mils. Each specimen was measured at 24 evenly spaced locations around the circumference of the weld. Using the above equation, the 99.8% lower prediction bound for the average weld width is calculated to be 21 mils. The same calculation for the 99.964% lower prediction bound yields 19 mils. Thus, a deterministic evaluation of the prediction limits leads to the conclusion that it is very unlikely that a weld would be fabricated with a mean width of less than 21 mils, and even more unlikely of fabricating a weld with a mean width of less than 19 mils. Because the tails of the Student t distribution are longer than those of the corresponding normal distribution, the width of the weld is predicted to be less than the normal values illustrated on Figure 3.

4.1.2 Algebraic Calculation of the Lower Tolerance Limit

In order to obtain tolerance bounds, a specified confidence is identified for the proportion of the population of interest, e.g., 95% confident that 99% of the population is larger than the bounding value. A lower tolerance bound for the 99th percentile of the weld width at 95% confidence may be calculated algebraically using the following expression:

$$w_{LTL} = m_w - k s_w ,$$

where m_w is the mean width from the test data and s_w is the standard deviation from the test data. The constant k in the equation is based on the desired percentile and confidence level. The value obtained from Reference 12 is 4.354. For the mean value of 28.0 mils and the standard deviation of 1.79 mils, the lower tolerance limit is effectively 21 mils. This means that 95% of the time, the chance of making a weld with an average width less than 21 mils is about 0.01. The corresponding probability associated with making a weld with an average width of less than 19 mils is about 0.0005. The determination of k is based strictly on the assumption of normality and reflects increasing uncertainty associated with the fewer data. This is the most conservative calculation of the lower bound values and ignores the fact that the variation of the weld width around the circumference would likely lead to rejection of the weld based on the results from the UT examination.

4.1.3 Monte Carlo Simulation of the Lower Tolerance Limit

The results from the algebraic analyses were checked by performing a Monte Carlo simulation (probabilistic) of the distribution of weld widths using the parameters estimated from the test program data. The simulation process consists of estimating a random value for the standard deviation of the population from which the sample data were drawn, followed by using that value to estimate a random value for the mean of the population and a random deviation from the mean.

The standard deviation of the population of weld widths, σ_w, from which the sample data were drawn was simulated as being from a Chi-Square distribution. For N data with a sample estimate of the population standard deviation, s_w, an estimate of the population standard deviation is calculated as follows,

$$\sigma_w = s_w \sqrt{\frac{N-1}{\chi^2_{N-1}}},$$

where χ^2 is a random value of the Chi-Square distribution for N-1 degrees of freedom. Given the value of the standard deviation of the population, a random value of the mean weld width, σ_w, is calculated from the mean of the sample data, m_w, as,

$$\mu_w = m_w + Z_1 \frac{\sigma_w}{\sqrt{N}},$$

where Z_1 is an independently drawn random value from the standard normal distribution. Finally, a randomly calculated value of the weld width, w, is found as,

$$w = \mu_w + Z_2 \sigma_w,$$

where Z_2 is another independently drawn random value from the standard normal distribution. The calculation was repeated 1000 times to obtain a simulated estimate of the cumulative distribution of the weld widths. Each Monte Carlo calculation requires three independent random variables, one from a Chi-square and two from standardized normal distributions. The Latin-Hypercube technique was employed for the simulations to minimize the variance of the results, thus increasing the accuracy of the estimates of the tails of the distribution. In addition, the rank of the tolerance values was conservatively calculated based on not using the Latin Hypercube technique.

The results of the simulation are illustrated on Figure 4. The minimum width simulated was 21.3 mils, with the 0.1% value being 22.8 mils at 95% confidence.

The parameters of the simulated distribution may also be used to estimate other statistics regarding the distribution of weld widths. The simulated widths have a mean of 28.0 mils and a standard deviation of 1.88 mils. The actual sample data have a mean of 28.0 mils and result in an unbiased estimate of the population standard deviation of 1.79 mils. Thus, the net effect of simulating the uncertainty in the mean and standard deviation of the population is to increase the standard deviation by 0.09 mils. Using the mean and standard deviation of the widths obtained from the simulation, 0.01% and 0.0001% normal distribution prediction bounds for a single weld are 21 mils and 19 mils respectively. Again, the likelihood of making such a weld is very small in itself, without consideration of the potential for rejection from the inspection process, which is treated in the next sections.

4.2 Variation of Individual Welds

The previous discussions are with regard to the characteristics of the average width of the welds. Actually, the individual welds do not have a uniform width around the circumference of the sleeve-to-tube interface. Consideration of the test data for the relative to the individual weld characteristics leads to the conclusion that welds made with average widths less than 20 to 21 mils would likely have minimum widths less than 15 mils and would not meet the current criterion applied to the results from the UT inspection. Conversely, welds which have passed the UT examination, i.e., have a width $\geq$ 15 mils, likely have average widths greater than 20 to 21 mils and even more likely greater than19 mils. The evaluation of the variation of width within a single weld considers the standard deviation of the weld width around the circumference of the weld and the range of the minimum width relative to the average width.

4.2.1 Standard Deviation of the Weld Widths

The test data from each weld have an average standard deviation of 2.8 mils associated with the measurements made at 24 locations around each weld. Thus, a weld with an average width of 21 mils, would be expected to have regions of minimum width in the range of 15 to 16 mils. Such welds would likely be rejected as a result of the UT examination. The opposite is also implied, i.e., welds that are not rejected by the UT examination likely have average widths on the order of 20 to 21 mils. The probability of a 15 mil-wide weld being made and accepted is the product of the probability of making the weld and the probability of passing the UT examination. The qualification data from the UT process indicate a 100% success rate for 114 specimens with weld widths less than 15 mils, Reference 13. Thus, the overall probability of a field weld having an average width less than the design-by-analysis requirement of the Code is reduced by about two orders of magnitude.

4.2.2 Range of the Weld Widths

The mean of the difference between the average weld width to the minimum weld width for the eleven specimens is 5.32 mils. This is not unexpected given the standard deviation from the previous section. The average difference between the average and minimum width is about 2.0 standard deviations, which is not unusual considering that 24 measurements of each weld were made. These data suggest that a weld that is accepted with a minimum width of 15 mils has an average width on the order of 20 to 21 mils. This supports the conclusion of the previous paragraph regarding the effect of the variation of the width within a weld on the probability of making and accepting a weld with an average width less than the design-by-analysis requirement of the Code. Of course, the likelihood of making a weld with an average width less than 19 mils is significantly less than that for a 21 mil weld.

5.0 Consideration of Material Properties

The weld between the sleeve and the tube is characterized as autogenous because no filler material is used. The joint is made by fusing molten sleeve metal with molten tube metal. Chemical analysis of the solidified weld metal has confirmed that it conforms to the requirements for nickel-chromium-iron Alloy 690. This is the basis for the superior corrosion resistance exhibited by both the sleeve and the weld of laser welded test specimens. In performing the analysis of the weld, the allowable minimum width is calculated using Code minimum material properties. In practice the material properties are usually significantly greater than required by the Code, thus the strength of the installed welds would be expected to be greater than estimates based on using Code minimum properties.

6.0 Conclusions/Recommendations

The deterministic estimate of the likelihood of making a weld with an average width of less than 21 mils is expected to be less than 0.1%. In addition, the deterministic estimate of the likelihood of making a weld with an average width of less than 19 mils is calculated to be less than 0.01%. Conservative tolerance bound estimates confirm the predicted values. Monte Carlo simulations which include uncertainties associated with the parameters of the population from which the test data were drawn indicate even lower probabilities of making welds narrower than 21 and 19 mils. Hence, the following conclusions are appropriate:

1. There is a low probability that any of the existing welds were made with an average width less than the Code design-by-analysis value of 21 mils.
2. There is an even lower probability that any of the existing welds were made with an average width (less than 19 mils) that would result in failure of the weld at a pressure lower than the burst pressure of an intact sleeve. Since the sleeve itself meets the design requirements of the Code, compliance of the weld strength with the Code requirements is implied.
3. The use of optically measured weld widths instead of metallographic examination results leads to underestimates of the actual weld widths in the range of 4 to 5 mils. This is on the order of two additional standard deviations from the mean of the data and would significantly reduce the above probability estimates if accounted for in the analyses.
4. The variation of width over the circumferential length of the individual welds is on the order of the difference between the minimum width criterion of 15 mils and the Code design-by-analysis requirement of an average width of 21 mils. This means that welds deemed sufficient from the UT inspection likely have average widths that meet the Code requirements.

In summary, in spite of the inspection criterion limit of a minimum width of 15 mils, the use of conservative measurement data leads to the conclusion that it is unlikely that welds were made with average widths less than that needed to meet the design-by-analysis requirements of the ASME Code. In addition, it is quite likely that all of the fabricated welds have a failure pressure greater than that of the installed sleeves. Therefore, no special inspection provisions need to be developed for existing welds and no further action is necessary regarding installed welds.

Per the discussion of Section 1.1, future LWS weld inspections will be performed to verify the acceptability of the average weld widths. Any welds determined to have an average width of less than 21 mils will be subjected to an engineering disposition process. Special considerations may then be made and documented that result in infrequently accepting welds with average widths as small as, but not less than, 19 mils (the width required for the joint to be stronger than the sleeve).

7.0 References

1. WCAP-13088, Revision 4, "Westinghouse Series 44 and 51 Steam Generator Generic Sleeving Report, Laser Welded Sleeves," Westinghouse Electric Corporation, Pittsburgh, PA (January 1997).

2. WCAP-13698, Revision 1, "Laser Welded Sleeves for 3/4 Inch Diameter Tube Feedring-Type and Westinghouse Preheater Steam Generators," Westinghouse Electric Corporation, Pittsburgh, PA (May 1993).

3. WCAP-14596, "Laser Welded Elevated Tubesheet Sleeves for Westinghouse Model F Steam Generators," Westinghouse Electric Corporation, Pittsburgh, PA (March 1996).

4. ASME Boiler and Pressure Vessel Code, Section III, "Rules for the Construction of Nuclear Power Plant Components," American Society of Mechanical Engineers, New York, NY (1989 Edition).

5. ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," American Society of Mechanical Engineers, New York, NY (1989 Edition).

6. ASME Boiler and Pressure Vessel Code, Section IX, "Welding and Brazing Qualifications," American Society of Mechanical Engineers, New York, NY (1989 Edition).

7. WCAP-13088, Revision 4, Addendum 1, "Westinghouse Series 44 and 51 Steam Generators Generic Sleeving Report, Laser Welded Sleeves," Westinghouse Electric Corporation, Pittsburgh, PA (June 1998).

8. WCAP-13698, Revision 2, Addendum 1, "Laser Welded Sleeves for 3/4 Inch Diameter Tube Feedring-Type and Westinghouse Preheater Steam Generators Generic Sleeving Report", Westinghouse Electric Corporation, Pittsburgh, PA (June 1998).

9. WCAP-14596, Revision 0, Addendum 1, "Laser Welded Elevated Tubesheet Sleeves for Westinghouse Model F Steam Generators Generic Sleeving Report", Westinghouse Electric Corporation, Pittsburgh, PA (June 1998).

10. Regulatory Guide 1.121 (draft), "Bases for Plugging Degraded PWR Steam Generator Tubes," United States Nuclear Regulatory Commission, Rockville, MD (August 1976).

11. NEI 97-06, Revision 1, Draft 4, "Steam Generator Program Guidelines," Nuclear Energy Institute, Washington, DC (November 1999).

12. Hahn, G. J., and Meeker, W. Q., "Statistical Intervals," John Wiley & Sons, New York, NY (1991).

13. SGIP-DA-98-051, "Weld Width Measurements," D. C. Adamonis, S/G NDE Applications & Tooling, Westinghouse Electric Company (May 15, 1998).

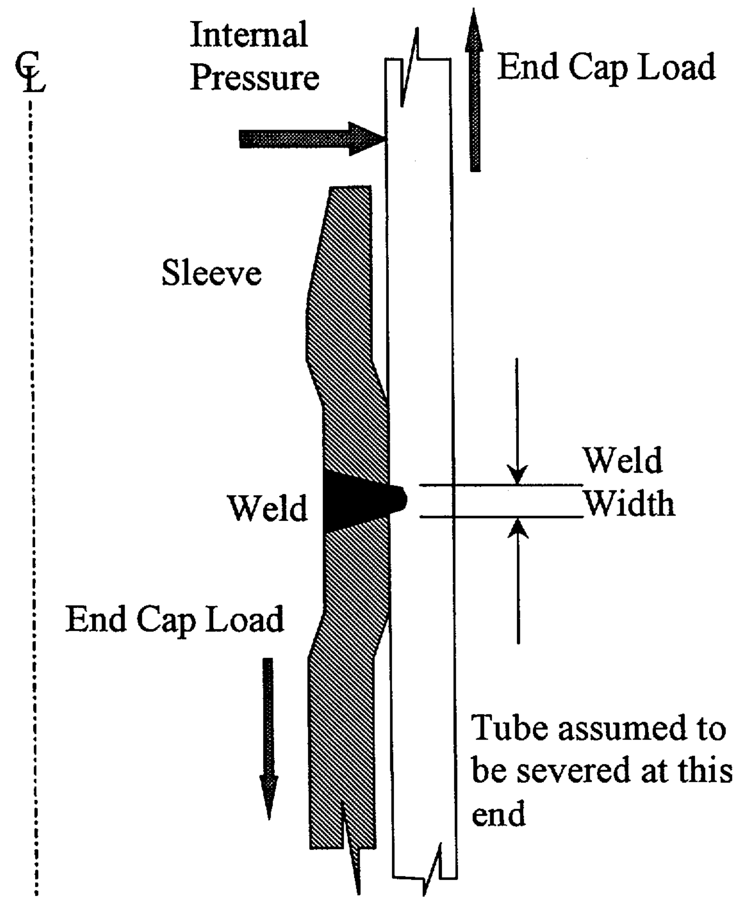

Figure 1: Schematic of the LWS Sleeve-to-Tube Weld

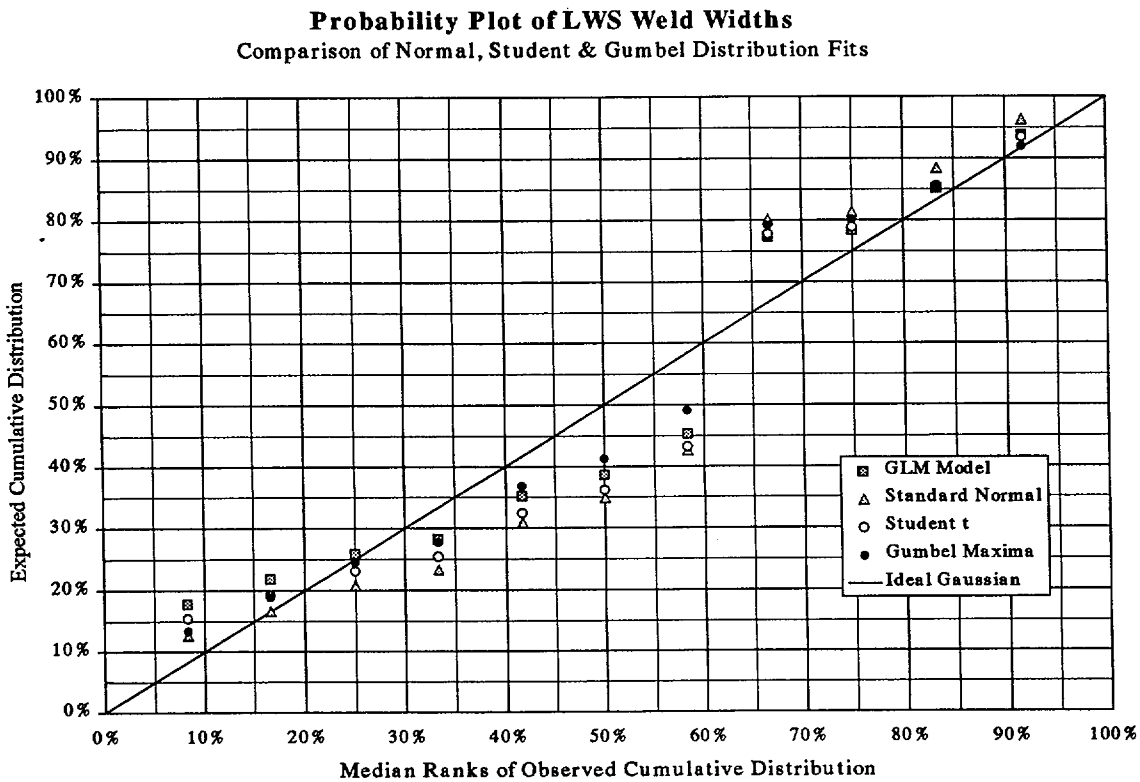

Figure 2: Correlation of Characterizing Distributions

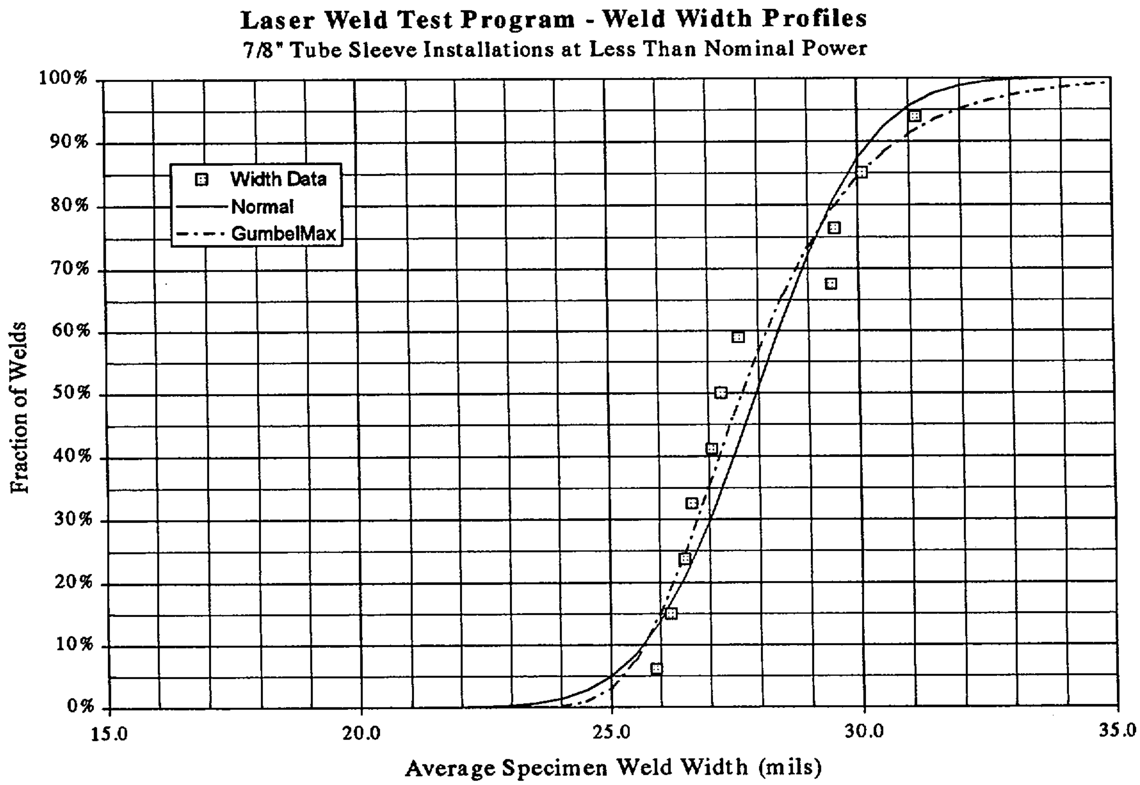

Figure 3: CDFs of Characterizing Distributions

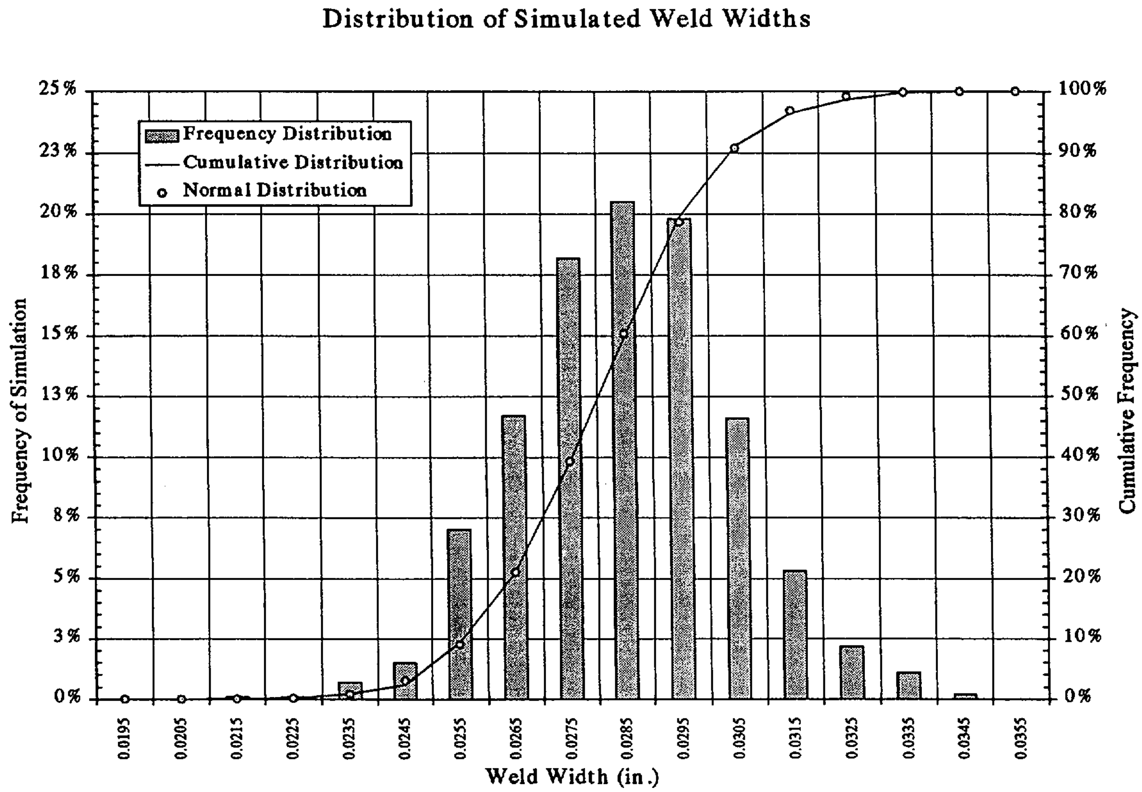

Figure 4: Results of the Monte Carlo Simulation