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EPRI

May 21, 1998

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

Subject: Request for Withholding of Proprietary Document; 10CFR2.790(a)(4) NP-7480-L Addendum 2 "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates for Alternate Repair Limits" 1998 Database Update to the NRC

Gentlemen:

This a request under 10CFR2.790(a)(4) that the NRC withhold from public disclosure the proprietary document and database identified above (the "Report"). Five copies of the Report and the affidavit in support of this request are enclosed.

EPRI desires to disclose the Report to the NRC as a means of exchanging information with the NRC for the purpose of supporting generic regulatory improvements related to the repair of the subject reactor components. EPRI would welcome any discussions between EPRI and the NRC related to the Report that the NRC desires to conduct.

The Report is for the NRC's internal use and may be used only for the purpose for which it is disclosed by EPRI. The Report should not be otherwise used or disclosed to any person outside the NRC without prior written permission from EPRI.

If you have any questions about the legal aspects of this request for withholding, please do not hesitate to contact me at (650) 855-8957. Questions on the contents of the Report should be directed to Govinda Srikantiah of EPRI at (650) 855-2109.

Sincerely,

Mark D. Fox
Intellectual Property Attorney
Intellectual Property Department

Enclosures

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RE: Request for Withholding of Proprietary Document; 10CFR2.790(a)(4) NP-7480-L Addendum 2 "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates for Alternate Repair Limits" 1998 Database Update to the NRC

I. MARK D. FOX, being duly sworn, depose and state as follows:

I am an attorney at the Electric Power Research Institute ("EPRI") and I have been specifically delegated responsibility for reviewing the report listed above that is sought under this affidavit to be withheld (the "Report") and authorized to apply for its withholding on behalf of EPRI. This affidavit is submitted to the Nuclear Regulatory Commission ("NRC") pursuant to 10 CFR 2.790(a)(4) based on the fact that the Report consists of trade secrets of EPRI and that the NRC will receive the Report from EPRI under privilege and in confidence.

The basis for which the Report should be withheld from the public is set forth below:

(i) The Report has been held in confidence by EPRI, its owner. All those accepting the Report must agree to preserve the confidentiality of the Report.

(ii) The Report is of a type customarily held in confidence by EPRI and there is a rational basis therefor. The Report is trade secrets and is held in confidence by EPRI because to disclose it would prevent EPRI from licensing the Report at fees which would allow EPRI to recover its investment. If consultants and other businesses providing services in the nuclear power industry were able to publicly obtain the Report, they would be able to use it commercially for profit and avoid spending the large amount of money that EPRI was required to spend to prepare the Report. The rational basis that EPRI has for classifying the Report as trade secrets is the Uniform Trade Secrets Act which California adopted in 1984 and which has been adopted by

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over twenty states. The Uniform Trade Secrets Act defines a "trade secret" as follows:

> "Trade secret" means information, including a formula, pattern, compilation, program, device, method, technique, or process, that:
>
> (1) Derives independent economic value, actual or potential, from not being generally known to the public or to other persons who can obtain economic value from its disclosure or use; and
>
> (2) Is the subject of efforts that are reasonable under the circumstances to maintain its secrecy.

(iii) The Report will be transmitted to the NRC in confidence.

(iv) The Report is not available in public sources. EPRI developed the Report only after making a determination that the Report was not available from public sources. It required a large expenditure of dollars for EPRI to develop the Report. In addition, EPRI was required to use a large amount of time of EPRI employees. The money spent, plus the value of EPRI's staff time in preparing the Report, show that the Report is highly valuable to EPRI. Finally, the Report was developed only after a long period of effort of at least several months.

(v) A public disclosure of the Report would cause substantial harm to EPRI's competitive position and the ability of EPRI to license the Report both domestically and internationally. The Report can be properly acquired or duplicated by others only with an equivalent investment of time and effort.

I have read the foregoing and the matters stated therein are true and correct to the best of my knowledge, information and belief. I make this affidavit under penalty of perjury under the laws of the United States of America and under the laws of the State of California.

Executed at 3412 Hillview Avenue, Palo Alto, being the premises and place of business of the Electric Power Research Institute:

May 21, 1998

Mark D. Fox

Subscribed and sworn before me this day: May 21, 1998

Tamsen Helen Gagnon, Notary Public

Tamsen Helen Gagnon, Notary Public

TAMSEN HELEN GAGNON
Commission # 1172409
Notary Public - California
Santa Clara County
My Comm. Expires Feb 5, 2002

ENCLOSURE 2

Response to NRC RAI Question 9, Part 2
Review of EPRI Report NP 7480-L, Addendum 1, 1996 Database Update

Question 9, Part 2 Staff Comment

(2) Provide an assessment of the POPCD approach at conservatively projecting the EOC voltage distribution. Perform this assessment for at least 20 steam generators. The steam generators should be chosen arbitrarily from the entire population of plants which implement (or have implemented) the GL 95-05 repair criteria. The assessment should include data from steam generators where the results from the inspection were not included in the POPCD determination. It is intended that this assessment will determine whether or not the POPCD should be plant-specific, generator-specific, and/or cycle-specific and/or a more conservative POPCD adjustment procedure should be used.

In performing the above assessment, take into consideration that calculations of the EOC voltage distribution may be generated in a variety of ways (e.g., using a steam generator specific growth rate distribution and/or a bounding growth rate distribution), and use the most limiting assumptions in demonstrating the conservatism of the proposed approach.

Provide the criteria used in assessing the conservatism of the projected EOC voltage distribution (e.g., by comparing the projected probability of burst and leakage under postulated accident conditions using the POPCD approach to the results from the as-found condition).

Response

1.0 Summary and Conclusions

An evaluation was carried out to demonstrate conservatism in projections for EOC conditions using POPCD. The POPCD distribution (POD as a function of voltage) used in the evaluation is presented in Addendum 1 of the EPRI database report, Table 7-2 of Reference 2. This report has been updated as Addendum 2 (Reference 6) which includes an update to the POPCD evaluation. However, the differences in POPCD between Addenda 1 and 2 are small and would not influence the conclusions of this RAI response. A series of Monte Carlo analyses were carried out to compare leak rates and burst probabilities based on projected EOC voltages with those calculated using the actual measured EOC voltages. Both plants with _" diameter SG tubes as well as those with 7/8" diameter tubes were considered. The specific SGs selected for this assessment are representative of the plant population which has implemented GL 95-05. The 32 reference SG cases are composed of 18 SGs with 7/8" tubes and 14 SGs with _" tubes. In addition, 17 sensitivity cases were also considered to examine the effect of the following parameters and assumptions on the calculated leak rates and burst probabilities: growth rates used for projections, use of a leak rate correlation for 7/8" tubes, use of a POD of 0.6 per GL 95-05 and "locked" tube support plates for _" tubes. The analyses al o include updates to the ARC methods, as developed in Reference 6, for cross calibration of ASME standards used for voltage normalizations, voltage dependent growth rates and growth rates of deplugged tubes returned to service.

The results show that projected EOC leak rates overpredict the leak rates obtained from the as-measured or actual voltage distributions for 23 of the 32 SGs analyzed. With a negligible difference between projections and that obtained from the actual voltages defined as 0.25 gpm (typically <5% of allowable limits), the projections are in agreement with the actuals for 26 of the 32 SGs. When the recommended methods updates of Reference 6 are applied to the analyses, the projections are in agreement with the actuals for 31 of the 32 SGs. The only exception is an isolated occurrence of a large voltage indication (13.7 volts) which could not have been predicted based on plant history and for which the indication voltage was influenced by an application of pressure pulse cleaning prior to the inspection.

For tube burst probabilities, the projected values exceed those obtained from the actual voltage distributions for 23 of the 32 SGs analyzed. With a negligible difference between projections and that obtained from the actual voltages defined as 5×10^{-4} (5% of reporting guideline of 10^{-2}), the projections are in agreement with the actuals for 30 of the 32 SGs. When the recommended methods updates of Reference 6 are applied to the analyses, the projections are in agreement with the actuals for 31 of the 32 SGs. The only exception is the isolated occurrence of the 13.7 volt indication described above.

Overall, it is concluded that the 32 comparisons between projected results and results calculated from actual voltage distributions strongly support the use of POPCD. The projections, incorporating the methods recommendations of Reference 6, either overpredict leak rates and burst probabilities or agree within negligibly small differences except for one isolated occurrence of a single large voltage indication. The conservatism of applying the GL 95-05 POD of 0.6 tends to make the conservative POPCD results even more conservative but does not compensate for significant methods limitations particularly in growth rate determinations. The conservatisms of a 0.6 POD can mask small methods problems until they become bigger problems. The proposed POPCD distribution adequately accounts for missed indications and new indications occurring during a cycle. It is recommended that POPCD be used in place of a constant POD value of 0.6.

2.0 Methods and Data Used for RAI Response Analyses

2.1 Selection of Cases for Analysis

To demonstrate conservatism in applying POPCD to project EOC voltage distributions, leak rates and tube burst probabilities, a series of Monte Carlo analyses were carried out to compare leak and burst results based on projected EOC voltages with those based on actual measured EOC voltages. Both plants with _" diameter steam generator tubes as well as those with 7/8" diameter tubes were considered. The plants and specific SGs selected for this assessment are representative of the plant population which has already implemented or likely to implement GL 95-05. The following guidelines were used to select the specific steam generator analyzed.

- Selected steam generators should have significant leak rates. Comparing projected and actual leak rates of 0.01 gpm magnitudes has minimal value.
- A minimum of 10 steam generators with _" tubing and 10 steam generators with 7/8" tubing should be analyzed.
- Analyses should include cases with at least two steam generators per plant per cycle to compare differences between SGs as well as between plants.
- A minimum of 2 plants for two cycles per tube size should be analyzed.
- Data from several inspections not included in the POPCD determination should be analyzed.

A total of 32 reference cases representing EOC conditions for 18 different steam generators from 10 plants were considered in this evaluation. The EOC conditions analyzed included the first IPC/APC application cycle as well as those applying IPC/APC on a continuing basis. In addition to the 32 reference cases, 17 sensitivity cases were also analyzed to examine the effect of the following variables: sensitivity to growth rates assumed for EOC projections, application of voltage dependent leak rates for plants with 7/8" tubing, utilization of a constant POD of 0.6 and "locked" tube support plates in plants with _"inch tubing. Since a voltage dependent leak rate correlation has been obtained for 7/8" tubing after many of the original plant analyses were performed without a leak rate correlation, the results for the correlation become the reference case for assessing the influence of a voltage dependent POD. Of the 32 reference cases, only 4 of the cycles were used in the development of the Reference 2 POPCD distribution applied in the current analyses. However, inclusion of data from 10 more of these cycles in the POPCD update of Reference 6 did not lead to a significant change in the POPCD distribution. Thus, the conclusions are essentially independent of whether or not the reference cases were included in the POPCD distribution.

Additional cases were run to incorporate updated analysis methods of Reference 6 for voltage dependent growth rates (6 cases) and deplugged tube growth rates (3 cases).

2.2 Method of Analysis

The Monte Carlo analysis methodology used in the present assessment has been applied to over 20 IPC/APC evaluations performed in the past two years; it is documented in WCAP-14277 (Reference 1). It takes into account uncertainty in measured bobbin voltages due to probe wear and analyst variability. The probe wear uncertainty has a standard deviation of 7.0 % about a mean of zero and is truncated at 15% based on implementation of the probe wear standard. The analyst variability uncertainty has a standard deviation of 10.3% about a mean of zero with no cutoff. GL 95-05 requires that NDE uncertainties be included in the leak rate and burst probability analyses for the actual or measured distribution (condition monitoring analyses). Since NDE uncertainties are already included in the measured distribution, inclusion in the condition monitoring analyses amounts to a second application of NDE uncertainties. It has been shown in Reference 7 that the "true" distribution of indications is significantly narrower than the measured distribution. NDE uncertainties should be considered only for the high voltage tail of the distribution for which the number of indications is too small to draw a statistical conclusion on the "true" shape of the tail. The analyst variability uncertainty of 10.3% was developed from voltage indications dominantly less than about 1.5 volts. At higher voltages, the bobbin flaw response is clearer which results in reduced analyst variability. Although data have not been statistically analyzed, it is judged that the analyst variability for indications above about 2 volts would be about 5% or less. This value is applied when large voltage indications are found in the measured distribution and use of the larger NDE uncertainty would significantly overestimate the potential leak rate and burst probability for the measured distribution.

In accordance with GL 95-05, the larger of the growth rates from the past two inspections were used to project EOC voltages for the next cycle. For projections of a specific SG, the more conservative growth between the distributions for the specific SG and for all SGs collectively was used. This approach is consistent with the approved methods of Reference 1.

Leak rate estimates for SGs with _" tubes were obtained using a voltage dependent leak rate correlation. Leak rate estimates for SGs with 7/8" tube were obtained using a constant leak rate for most analyses since approval for the use of a voltage dependent leak rate had not been obtained at the time of the original analyses. For a few selected SGs with 7/8" tubing, leak rates were also estimated using a voltage-dependent leak rate correlation. The databases from which the various correlations used in this assessment for burst probability, leakage probability and leak rates are described in the following section.

2.3 Database Applied

The databases used for the ARC correlations applied in this assessment for _" and 7/8" tubes are documented in References 2 and 3, respectively, and they are consistent with GL 95-05. These databases are updated versions of the original ARC databases documented in References 4 and 5 with revisions to implement exclusion criteria and to include additional pulled tube data from domestic plants available by September 1996.
The database used for the leak correlation for _" tubes includes Model Boiler specimen 598-3 data and the leak rate from the R28C4., TSP1, tube section from Plant S at a SLB leak rate of 2496 lph consistent with NRC recommendations. Correlations for burst pressure, probability of leakage and leak rate used in the present assessment for _" tubes are shown in Tables 6-1, 6-2 and 6-4, respectively, of Reference 2.

SLB leak rate database applied for 7/8" tubes include Model Boiler specimen 542-4 and Plant J-1 pulled tube R8C74, TSP1 per NRC recommendation. Also included are the two

EdF datapoints recommended by the NRC. At the time of the original plant ARC analyses, the SLB leak rate data did not satisfy the guidelines for a voltage dependent correlation. Therefore, SLB leak rates for plants with 7/8" tubes were calculated using the mean of the leak rate data in the database, as described in Reference 1. Correlations for burst pressure, probability of leakage and leak rate used in the present assessment for 7/8" tubes are shown in Tables 3-8, 3-9 and 3-11, respectively, of Reference 3. With a recent clarification of the requirements for a statistical correlation, a correlation between leak rate and bobbin voltage is obtained for 7/8" tubing, and such a leak rate correlation is presented in Table 6-8 of Reference 2. Although the leak rate correlation has changed over the last few years, the results of this study are not particularly sensitive to the database as long as the same database is used for both the projections and analyses of the actual voltage distributions.

3.0 Reference Analysis Results

Leak and burst results for projected and as-found conditions for all the cases examined are presented in Tables 1 and 2. Tables 1 and 2 show the EOC voltage data, SLB leak rates and tube burst probabilities for SGs with 7/8" tubes and _" tubes, respectively. A total of 18 SGs were analyzed for 7/8 inch tubing and 14 for _ inch tubing. The results for the 17 sensitivity cases, also included in Tables 1 and 2, are discussed in the next section.

The following data are presented in Tables 1 and 2 to compare projected EOC voltage distributions with actual measured distributions: total number of indications in the distribution, mean voltage and maximum voltage. The number of indications is overpredicted for 10 of the 18 SGs with 7/8 inch tubing and 7 of the 14 SGs with _ inch tubing. The differences between the predicted and actual number of indications are generally small with negligible influence on the comparisons of leak rates and burst probabilities. The more significant difference is the underprediction of maximum voltages for 4 SGs for 7/8 inch tubing and 5 SGs for _ inch tubing. The underprediction is meaningful for Table 1 Cases 11, 13 and 16 and Table 2 Cases 10, 12, 14 and 18. When the maximum voltage is significantly underpredicted, the leak rates and burst probabilities tend to be underestimated. As discussed later in this response (see new methods identified in Sections 5 and 6), these underpredictions of maximum voltage are due to underprediction of the growth rates and are not due to the POD applied. The mean voltage reflects both the number and the size of the indications and thus provides an average representation of EOC voltage distributions. Among the SGs analyzed for mean voltage, the trend of the analyses is to overestimate the mean voltage. This result indicates an underestimate of the number of small voltage indications since the maximum voltage indications are not significantly overestimated and the mean voltage overestimates occur even when the number of indications is slightly underestimated. Overall, it is concluded that the POPCD distribution provides a conservative prediction of EOC voltages.

The SLB leak rate predictions based on POPCD conservatively bound the results for as-found conditions in most of the cases analyzed. For the minority of the SGs (9 out of 32 reference cases) where leak rate is underpredicted, the differences between the predictions and actuals are small in comparison to their acceptance limit. Of the 18 SGs analyzed for plants with 7/8" tubes, SLB leak rates are overpredicted for 15 SGs. For the SGs with underpredicted leak rates (Cases 4, 13 and 16 in Table 1), the difference between the predicted and actual leak rates is small (about 0.03 to 0.34 gpm using voltage dependent leak rate correlation) and amount to only about 3% of the allowable SLB leak rate limit. The actual growth rates for these SGs are higher than those used for the projections. Sensitivity analyses for these SGs using their actual growth rates for the cycle analyzed yielded leak rates equal to that for the as-found condition except for Case 16 which is discussed in Section 6. Reference 6 includes a recommendation for cross calibration of ASME standards used for voltage normalization to improve consistency in voltage normalizations. This effect is shown in the comparison between Cases 4 and 8 in Table 1. It was found that the voltage cross calibration for EOC-11 resulted in voltages normalized about 12% higher than at EOC-10. When the EOC-11 voltages are reduced for this adjustment (Case 8), the leak rates from the projection become an overprediction instead of an underprediction relative to that obtained from the actual voltages. Case 8 can be considered to be the reference projection results. Implementation of the Reference 6 recommendations on voltage normalization should eliminate this effect in the future. For the _ inch tubing results in Table 2, leak rates are underestimated for Cases 1, 10, 12, 14, 18 and 20. Case 1 has a negligible underestimate of 0.09 gpm. The remaining 5 cases were found to require use of voltage dependent growth rates as discussed in Section 5. Thus, underprediction of leak rate is attributable to actual growth being higher than assumed for the projections and not due to application of a voltage dependent POD.

The burst probability projections for 7/8" tubes based on POPCD are also generally conservative or within a negligible difference ($5x10^{-4}$). Eleven out of 18 SGs analyzed for plants with 7/8" tubes have predicted burst probabilities higher than those for the as-found conditions. Burst probability for 4 of the remaining 6 cases are underpredicted by 3×10^{-6} to $<5\times10^{-4}$, but differences of this magnitude are not significant. Case 16 with an underprediction of 6×10^{-4} is attributable to high deplugged tube growth rates as addressed in Section 6 and the $4.7x10^{-3}$ underprediction for Case 14 is due to an underprediction of the single large maximum voltage indication. For _ inch tubing, burst probabilities are overpredicted for 12 of the 14 cases and the remaining two cases are underpredicted by a negligible $< 5x10^{-4}$. It can be noted, however, that the burst probabilities for Cases 10, 12, 14 and 18 in Table 2 would likely have been underpredicted if burst had not been eliminated by "locking" of the hot leg TSPs. These cases require application of voltage dependent growth rates as discussed in Section 5.

In summary, based on comparisons of projected EOC voltages, SLB leak rates and tube burst probabilities predicted using POPCD with results for the as-found conditions in the 32 reference cases, it is concluded that adequate conservatism can be maintained in the projections using voltage dependent POPCD in place of the GL 95-05 mandated constant POD of 0.6. The POPCD distribution, shown in Table 7-4 of Reference 2, can be applied to both SGs with 7/8" tubes and _" tubes. When leak rates and/or burst probabilities are underestimated, growth rates for the projected cycle were underestimated based on prior cycle results. Methods have been developed to improve the projections for the most significant underpredictions as described in Sections 5 and 6. Use of the very conservative POD of 0.6 would not have significantly reduced the larger underpredictions for which the new methods have been developed.

4.0 Sensitivity Analysis Results

In addition to 32 reference cases, sensitivity analyses were performed for 17 additional cases and their results are also included in Tables 1 and 2. For the nine reference cases where SLB leak rates were underpredicted, it was noted that the actual growth rates for the cycle analyzed were higher than those used for the projections. Hence, sensitivity analyses were performed to examine if the leak rate underprediction was caused by using growth rates lower than actual growth rates. The use of actual growth rates eliminated leak rate underprediction in three cases (compare Case 4 with 5 and Case 13 with 15 in Table 1 and Case 1 with 2 in Table 2). The differences in leak rates for these three cases between the reference case and that obtained from the measured distribution are modest (< 0.7 gpm) and attributable to an underestimate of the largest voltage indications. The remaining 6 cases are addressed by the methods changes in Sections 5 and 6.

Another sensitivity analysis examined the effect of applying leak and burst correlations for 7/8" tubes. Correlations for burst pressure, probability of leak and leak rates for 7/8" tubes are shown respectively in Tables 6-5, 6-6 and 6-8 of Reference 2. The analysis carried out for 3 cases (Cases 6, 14 and 26 in Table 1) using the leak and burst correlations show that the ratios of projected to actual leak rates are not significantly different between no correlation and a correlation for the leak rate. Consequently, either method may be used to assess the POPCD and the effectiveness of the projection methods. When the leak rate correlation is applied, the underpredictions of the leak rates for Cases 6 and 14 are reduced to negligible differences (0.01 and 0.28 gpm).

A third sensitivity analysis examined the effect of restraining indications from bursting for SGs with _" tubes by minimizing TSP displacement during SLB by tube expansion. Supplemental calculations (Cases 7 and 9 in Table 2) were run by analyzing the hot leg indications as free span indications rather than indications prevented from burst. These results follow the general trend that when the largest voltages are adequately predicted, the burst probability is also acceptable.

The fourth sensitivity parameter evaluated was the use of a constant POD of 0.6 as required by GL 95-05. The difference between Cases 4 and 7 in Table 1 is a case where the use of POD = 0.6 moved the leak rate from an underprediction to an overprediction. However, as shown by Case 8, the original underprediction resulted from a change in voltage cross calibration methods and is not due to an analysis issue. The use of POD = 0.6 thus leads to a more substantial overestimate when compared with the corrected Case 8 results and masks the real issue associated with calibration standards. The use of the constant POD had a negligible reduction in the underestimates between Cases 16 and 18. The source of the underpredictions for this cycle is addressed in Section 6. The influence of POD = 0.6 leading to a substantial overestimate of the leak rate is shown by Cases 20 and 21 where voltage dependent POD resulted in an overestimate which was substantially increased with the use of a constant POD. These results indicate that a constant POD leads to overestimates of leak rates and burst probabilities when the methods are adequate, can mask a small methods issue and does not significantly reduce underestimates when methods adjustments are required. The more general result of applying a POD of 0.6 is excessive conservatism.

These sensitivity results support the conclusion that the principal contributor to underpredictions of leak rates and burst probabilities is an underestimate of the growth rates for the projected cycle based on historical (prior two cycle values) growth data. To address this issue, methods were developed (Reference 6) to utilize voltage dependent growth rates when necessary and to utilize larger growth rates for the first cycle of operation following deplugging of tubes and returning the indications to service. The analyses using these methods are described in Sections 5 and 6. As shown in these sections, the revised analysis methods eliminate the more significant underpredictions of leak rates in Tables 1 and 2.

5.0 Evaluations with Voltage Dependent Growth

As seen in Table 2, the leak rates for Plant AA-1 at EOC-6 are significantly underestimated. To a lesser extent, the same is found for Plant AB-1 at EOC-7B. These plants had implemented a 3 volt ARC with limited TSP displacement in a SLB event at the beginning of these cycles. Evaluation of the cause for these underestimates led to the need to include voltage dependent growth rates in the EOC projections. The methods for applying voltage dependent growth are described in Reference 6. The EOC-6 projections for Plant AA-1 and the EOC-7B analyses for Plant AB-1 were reanalyzed using the Reference 6 voltage dependent growth rate methodology to obtain the results given in Table 3. These analyses use growth rates found for the actual cycles being analyzed as only these cycles show the voltage dependent growth.

In Table 3, it is seen that the SLB leak rates for Plant AA-1 SGs A, C and D using voltage dependent growth rates are in very good agreement with the leak rates obtained from the actual voltage distribution. It is seen from Cases 11, 13 and 15 in Table 2 that use of growth rates for the actual cycle being evaluated but without application of voltage dependence does not lead to good agreement with leak rates from the actual distribution. For SG C, leak rates for the actual distribution are calculated using NDE analyst variability for the GL 95-05 required 10.3% standard deviation and for a standard deviation of 5%. The 10.3% standard deviation was developed from a population of indications that were dominantly less than about 1.5 volt. At higher voltages, the indications are large enough to have a well-defined voltage signal and the differences between analysts on a percentage basis is much smaller than at lower voltages although a statistical evaluation has not been performed. It is judged that the analyst variability for voltages above about 2 volts would be about 5% or less. It is seen in Table 3 that the difference between the analyst variability uncertainty of 10.3% and 5% leads to a reduction in the leak rate for the actual voltage distribution from 11.5 tc 9.8 gpm. The 9.8 gpm leak rate is a much more realistic value and is the basis for evaluating methods improvements such as application of voltage dependent growth rates. This leak rate for the actual distribution is in very good agreement with the projected value for SG C.

The results in Table 3 for Plant AB-1 SGs B and C using voltage dependent growth rates are also in very good agreement with the results obtained for the actual distribution.

The need for voltage dependent growth rates was also evaluated for Plant A-1 EOC-14 with the results given in Table 3. Comparing Case 7 with voltage dependent growth to Case 9 without voltage dependence shows that voltage dependent growth is not required for Plant A-1. As noted in Reference 6, it appears that voltage dependent growth rates are required only for plants with greater than 2 volt repair limits although growth results should be evaluated for voltage dependence at each outage.

The resul:s of Table 3 support the application of the EPRI voltage dependent POD.

6.0 Evaluations with Deplugged Tubes Returned to Service

The results for Plant A-2 EOC-11 (Cases 16 and 17 in Table 1) show a moderate underestimate of the SLB leak rate and burst probability even when the Cycle 11 growth rates are used for the analysis. Evaluation of this underestimate led to the identification of significant differences between the growth rates for previously active tubes and deplugged tubes returned to service at the BOC. A method is described in Reference 6 for applying different growth rates for active and deplugged tubes. The methodology of Reference 6 provides for a weighted combination of active and deplugged tube growth rates to obtain a single distribution for the EOC projections. This methodology is applied for Plant A-2 EOC-11 and Plant P-1 EOC-12 in Table 4.

It is seen from a comparison of Case 2 of Table 4 with Case 16 of Table 1 that the use of the Reference 6 recommended method including deplugged tube growth rates leads to a significant improvement between projected and actual leak rates and burst probabilities. The Table 2 leak rates are based on a voltage dependent leak rate correlation while the Table 3 results use a voltage independent correlation which tends to yield larger gpm differences between analysis results and that obtained from the actual voltage distribution.

Case 4 of Table 4 shows the comparisons for Plant A-2 at EOC-12 as obtained from Table 1. This case shows an overprediction of leak rates in the second cycle following deplugging and return to service of the tubes. The large growth rates found in the first cycle following deplugging is not found in the second cycle. Consequently, inclusion of the deplugged tube growth rates in the EOC-12 projections results in the overestimates at EOC-12. As noted in Reference 6, the allowance for increased growth rates of deplugged tubes returned to service is only required for the 1st cycle following return to service of the deplugged tubes.

Calculations using the Reference 6 method for deplugged tube growth rates are also shown in Table 4 for Plant P-1 EOC-12. The deplugged tube growth rate found for Plant P-1 was considerably smaller than that found for Plant A-2. The leak rates for Plant P-1 are overpredicted with or without deplugged tube growth rates as shown by a comparison of Case 9 (voltage dependent leak rate correlation) in Table 1 with Case 5 (leakage independent of voltage) of Table 4. In this case, the inclusion of deplugged tube growth rates is not required and increases the conservatism of the projections. In part, the overpredictions at EOC-12 are due to the difference in cross calibration methods applied at EOC-11 as discussed in Section 3 and reflected in Case 8 of Table 1.

7.0 Conclusions

Table 5 provides a summary of comparison between the predictions based on POPCD with those based on actual measured voltages. Separate summaries are provided for the 7/8 and _ inch tubing results. Columns labeled "Direct Comparisons" are based on results for the 32 reference cases analyzed in accordance with the methodology used for their APC application. The columns labeled "Within Negligible Differences" include results with small differences between projections and values calculated from the actual distributions as acceptable results. For this table, negligible differences are defined to be maximum voltages within a 1.0 volt difference, leak rates within 0.25 gpm and burst probabilities within $5x10^{-4}$. These leak rate and burst probability differences are about 5% of typical allowable limits such that agreement within these limits represents a negligible underprediction. For 7/8" tubing, the calculations using the leak rate versus voltage correlation, as currently applicable to ARC analyses, are used to prepare Table 5. The columns labeled "With Recommended Methods" incorporate the updated methods from Reference 6 with analysis results given in Sections 5 and 6. Results for this column also apply the negligible differences to define acceptable results. For leak rate analyses, it is seen that only 3 cases for 7/8" tubing and 3 cases for _" tubing have significant differences between projected results and results calculated from the actual distributions. For the recommended methods, only one case has a leak rate and burst probability with a significant difference. This difference is totally dependent upon the occurrence of a single 13.7 volt indication found in the inspection and is further addressed below. These results strongly support the application of POPCD for the ARC projection analyses and demonstrate the importance of identifying and correcting causative factors for underprediction of growth rates from historical data. When the growth methods are adequate, POPCD results yield good agreement between projections and actuals.

Table 6 identifies the more significant underpredictions of leakage or burst probability from the results of Tables 1 and 2. The cause of the underprediction is discussed and the recommended methodology update from Reference 6 to correct the underprediction is also described in Table 6. The methodology updates correct all significant underpredictions except for the Plant A-1 leak rate and burst probability predictions for EOC-14. The underpredictions for this case are due to a single 13.7 volt indication found in the inspection. The destructive examination for this indication found fatigue propagation at cellular corrosion patches in this indication. This effect, which is similar to tube pulling operations that open cellular patches with identified increases in bobbin voltage, is expected to have increased the voltage response although the increase cannot be quantified. In either case, this is a single, isolated large indication that could not possibly be predicted based on historical data for this unit. The underprediction is approximately independent of the use of POPCD or a POD of 0.6.

Overall, it is concluded that the 32 comparisons between projected results and results calculated from actual voltage distributions strongly support the use of POPCD. The projections, incorporating the methods recommendations of Reference 6, either overpredict leak rates and burst probabilities or agree within negligibly small differences except for one isolated occurrence of a single large voltage indication. The conservatism of applying the GL 95-05 POD of 0.6 tends to make the conservative POPCD results even more conservative but does not compensate for significant methods limitations particularly in growth rate determinations. The conservatisms of a 0.6 POD can mask small methods problems until they become bigger problems.

References

1. WCAP-14277, "SLB Leak Rate and Tube Burst Probability Analysis Methods for ODSCC at TSP Intersections," Westinghouse Nuclear Services Division, Revision 1, December 1996.

2. Addendum-1 to EPRI Report NP-7480-L, "Steam Generator Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Criteria," October 1996.

3. SG-96-01-003, "Farley Unit-1, 1995 Interim Plugging Criteria 90 Day Report," Westinghouse Electric Corporation, January 1996.

4. EPRI Report NP-7480-L, "Steam Generator Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Criteria, Volume 2: _ Inch Diameter Tubing," Revision 0, October 1993.

5. EPRI Report NP-7480-L, "Steam Generator Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Criteria, Volume 1: 7/8Inch Diameter Tubing," Revision 1, December 1993.

6. Addendum-2 to EPRI Report NP-7480-L, "Steam Generator Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Criteria," April 1998.

7. EPRI Report TR-107197-P1, "Depth Based Structural Analysis Methods for Steam Generator Circumferential Indications", Interim Report, November 1997 (Section 9).

Table 1. Comparison of Leak and Burst Results Based on Projected EOC Voltages Using POPCD with those Based on Actual Measured Voltages – Steam Generators with 7/8" dia. Tubes

				EOC Voltage												
				Projected			Actual									
				No. of Inds.	Mean	Max.	No. of Inds.	Mean	Max.	Projected	Actual	Ratio (1)	Projected	Actual	Difference (2)	
1			A	648	0.92	3.7	484	0.71	2.6	2.30	1.06	2.2	1.3×10⁻⁴	3.7×10⁻⁵	9.3×10⁻⁵	4
2			B	437	0.80	2.7	400	0.65	1.8	0.98	0.62	1.6	3.0×10⁻⁵	4.2×10⁻⁵	-1.2×10⁻⁵	4
3			A	759	0.78	2.7	849	0.77	2.2	1.89	1.50	1.3	6.8×10⁻⁵	6.1×10⁻⁵	7.0×10⁻⁶	4
4			B	676	0.69	3.0	698	0.76	3.7	1.24	1.50	0.8	4.2×10⁻⁵	6.5×10⁻⁵	-2.3×10⁻⁵	4
5										1.51		1.0				5
6										0.14	0.15	0.9				5, 6
7				737		3.1				1.76	1.50	1.2	5.4×10⁻⁵		-0.9 ×10⁻⁵	4, 8
8				676	0.69	3.0	698	0.62	3.3	1.24	1.10	1.1	4.2×10⁻⁵	3.1×10⁻⁵	1.1×10⁻⁵	3, 4
9		EOC-12	B	1091		2.9	914	0.54	1.8	0.40	0.09	4.4	1.3×10⁻⁴	1.9×10⁻⁵	1.1×10⁻⁴	4, 7
10			A	641	1.23	3.6	796	0.97	2.7	3.95	3.51	1.1	1.8×10⁻⁴	1.7×10⁻⁴	1.0×10⁻⁵	4
11			C	851	1.33	3.7	973	1.06	7.0	6.20	5.34	1.2	3.2×10⁻⁴	8.1×10⁻⁴	-4.9×10⁻⁴	4
12			B	1021	1.03	5.9	1014	0.95	3.1	4.28	4.20	1.0	2.3×10⁻⁴	1.9×10⁻⁴	4.0×10⁻⁵	4
13										6.92	7.60	0.9	5.2×10⁻⁴		-4.7×10⁻³	4
14										0.98	1.26	0.8	4.7×10⁻⁴		-4.7×10⁻³	4, 6
15				1118	1.29	13.8				7.8	7.6	1.0	3.9×10⁻³		-1.3×10⁻³	5
16				221	1.20	3.8				0.21		0.4	1.0×10⁻⁴		-6.2×10⁻⁴	4, 7
17				221	1.38	6.2				0.37		0.7	4.1×10⁻⁴		-3.1×10⁻⁴	5, 7
18				252	1.23	3.9				0.26		0.5	1.6×10⁻⁴		-5.6×10⁻⁴	4, 8
19		EOC-12	B	142	1.20	5.4	151	0.97	3.1	1.0	0.7	1.4	1.9×10⁻⁴	8.3×10⁻⁵	1.1×10⁻⁴	4
20			C	244	1.44	6.2	275	1.10	3.3	2.6	1.9	1.4	3.6×10⁻⁴	2.1×10⁻⁴	1.5×10⁻⁴	4
21				346	1.62	7.6				5.1		2.7	1.2×10⁻³		1.0×10⁻³	4, 8

Table 1. Comparison of Leak and Burst Results Based on Projected EOC Voltages Using POPCD with those Based on Actual Measured Voltages – Steam Generators with 7/8" dia. Tubes

				EOC Voltage												
				Projected			Actual									
				No. of Inds.	Mean	Max.	No. of Inds.	Mean	Max.	Projected	Actual	Ratio (1)	Projected	Actual	Difference (2)	
22			A	263	0.52	2.1	205	0.44	1.8	0.19	0.15	1.3	1.6×10^{-5}	1.9×10^{-5}	-3.0×10^{-6}	4
23			B	656	0.67	3.0	561	0.60	2.8	1.16	1.01	1.1	4.9×10^{-5}	8.3×10^{-5}	-3.4×10^{-5}	4
24			A	419	0.59	2.7	257	0.52	1.8	0.53	0.26	2.0	3.0×10^{-5}	1.9×10^{-5}	1.1×10^{-5}	4
25			B	979	0.71	3.2	710	0.62	2.2	2.04	1.20	1.7	7.5×10^{-5}	3.1×10^{-5}	4.4×10^{-5}	4
26										0.22	0.12	1.8	5.5×10^{-5}	5.3×10^{-5}	2.0×10^{-6}	6
27	D-1	EOC-14	11	226	0.72	1.9	199	0.69	1.8	0.31	0.27	1.1	1.9×10^{-5}	$<4\times10^{-6}$	1.5×10^{-5}	4
28	W-2	EOC-8	4	314	0.64	1.8	282	0.50	1.5	0.34	0.25	1.4	$<1.9\times10^{-5}$	$<1.9\times10^{-5}$	$< 10^{-5}$	4

Notes:

(1) Ratio of projected to actual leak rates.

(2) Difference between projected and actual burst probabilities.

(3) Actual EOC voltages adjusted by about 12% decrease to correct cross calibration of ASME standards.

(4) Reference case - Projection methodology consistent with APC application.

(5) Sensitivity case - SG-specific, actual growth for the cycle being analyzed used for projection analysis.

(6) Sensitivity case - Leak rate correlation for 7/8 tubes shown in Table 6-8 of Reference 2 applied (French pulled tube data excluded

(7) Reference case includes use of leak rate correlation. Analyses completed after leak rate correlation with voltage was established.

(8) Calculations based on constant POD = 0.6 rather than POPCD

Table 2. Comparison of Leak and Burst Results Based on Projected EOC Voltages Using POPCD with those Based on Actual Measured Voltages – Steam Generators with _" dia. Tubes

				EOC Voltage												
				Projected			Actual									
				No. of Inds.	Mean	Max.	No. of Inds.	Mean	Max.	Projected	Actual	Ratio (1)	Projected	Actual	Difference (2)	
1				3450	0.94	4.1				0.24		0.7	2.3×10^{-5}		-1.1×10^{-5}	4
2				3450	0.98	6.0				0.72		2.2	7.0×10^{-5}		3.4×10^{-5}	5
3			D	3280	1.05	4.3	1214	0.57	2.9	0.40	0.03	133	4.5×10^{-3}	3.8×10^{-4}	4.1×10^{-5}	4
4			A	791	0.91	5.2	1065	0.84	4.0	0.33	0.27	1.2	3.2×10^{-3}	2.8×10^{-3}	4.0×10^{-4}	4
5			C	1397	0.85	7.3	1526	0.86	5.1	0.81	0.38	2.1	8.3×10^{-3}	4.0×10^{-3}	4.3×10^{-3}	4
6				1109	0.82	3.2	1031	0.72	3.2	0.07	0.05	1.4	2.9×10^{-5}	1.9×10^{-5}	1.0×10^{-5}	4, 6
7				1109	0.82	3.2	1031	0.72	3.2	0.07	0.05	2.1	8.0×10^{-4}	5.5×10^{-4}	3.5×10^{-4}	7
8				1572	0.85	3.8	1480	0.77	2.9	0.12	0.07	1.7	$<2\times10^{-5}$	$<2\times10^{-5}$	$< 10^{-5}$	4, 6
9				1572	0.85	3.8	1480	0.77	2.9	0.11	0.07	1.6	1.1×10^{-3}	8.0×10^{-4}	3.1×10^{-4}	7
10					1.15	7.0				1.64		0.26	$<2\times10^{-5}$	$<2\times10^{-5}$	$< 10^{-5}$	4, 6
11					1.06	7.9				1.79		0.28	$<2\times10^{-5}$	$<2\times10^{-5}$	$< 10^{-5}$	5, 6
12					1.20	7.1				2.70		0.23	$<2\times10^{-5}$	$<2\times10^{-5}$	$< 10^{-5}$	4, 6
13					1.11	8.8				6.33		0.55	$<2\times10^{-5}$	$<2\times10^{-5}$	$< 10^{-5}$	5, 6
14					1.18	7.0				1.67		0.24	$<2\times10^{-5}$	$<2\times10^{-5}$	$< 10^{-5}$	4, 6
15					1.03	6.6				1.74		0.25	$<2\times10^{-5}$	$<2\times10^{-5}$	$< 10^{-5}$	5, 6
16			B	1006	0.95	7.1	1602	0.71	3.0	0.33	0.09	3.7	3.5×10^{-3}	1.0×10^{-3}	2.5×10^{-3}	4
17			C	925	1.03	7.7	1595	0.76	2.7	0.64	0.06	10.7	6.5×10^{-3}	7.3×10^{-4}	5.8×10^{-3}	4
18		EOC-7B	B	2212	0.75	3.5	1791	0.71	4.5	0.10	0.27	0.4	9.5×10^{-6}	$<6\times10^{-6}$	3.5×10^{-6}	4, 6
19				2212	0.81	3.6				0.14		0.5	1.1×10^{-5}		5.0×10^{-6}	5, 6
20			C	2278	0.78	3.3	2040	0.70	2.7	0.08	0.13	0.6	6.0×10^{-6}	9.5×10^{-6}	-3.5×10^{-6}	4, 6
21				2278	0.82	3.4				0.11		0.8	6.0×10^{-6}		-3.5×10^{-6}	5, 6

Table 2. Comparison of Leak and Burst Results Based on Projected EOC Voltages Using POPCD with those Based on Actual Measured Voltages – Steam Generators with _" dia. Tubes

				EOC Voltage												
				Projected			Actual									
				No. of Inds.	Mean	Max.	No. of Inds.	Mean	Max.	Projected	Actual	Ratio (1)	Projected	Actual	Difference (2)	
22	AC-1	EOC-7	C	921	0.51	2.1	488	0.36	1.6	0.0035	0.00097	3.6	7.8×10^{-5}	3.1×10^{-5}	4.7×10^{-5}	4

Notes:

(1) Ratio of projected to actual leak rates.
(2) Difference between projected and actual burst probabilities.
(3) Difference between projected and actual leak rates as a percent of the allowable SLB leakage limit.
(4) Reference case - Projection methodology consistent with APC application.
(5) Sensitivity case - SG-specific, actual growth for the cycle analyzed used for projection analysis.
(6) Indications restrained from burst (IRB, by TSP expansion).
(7) Sensitivity case - TSP expansion for IRB NOT considered

Table 3. Application of Recommended Methods for Voltage Dependent Growth Rates
Comparisons of Projected Leak and Burst Probability Results with Results Based on Actual Measured Voltages

No.	Plant	Cycle	SG	EOC Voltages				SLB Leak Rates - gpm			Burst Probability			Notes
				Projected		Actual								
				No. Ind.	Max. Volts	No. Ind.	Max. Volts	Projected	Actual	Ratio(1)	Projected	Actual	Difference(2)	
1	AA-1	EOC-6	A	1450	9.7	1754	8.9	6.6	6.4	1.03	Burst probability not applicable for these SGs as indications restrained from burst by tube expansion at TSP intersections.			
2			C	1973	10.6	2098	10.5	9.8	11.5	0.85				
3									9.8	1.0				3
4			D	1492	9.7	2099	8.8	7.4	7.0	1.06				
5	AB-1	EOC-7B	B	2208	4.2	1791	4.5	0.29	0.27	1.07				
6			C	2276	3.7	2040	2.7	0.16	0.13	1.23				
7	A-1	EOC-14	C	1118	14.4	1140	13.7	8.12	7.60	1.07	4.6×10^{-3}	5.2×10^{-3}	-0.6×10^{-3}	
8					14.2			1.71	1.28	1.34	4.5×10^{-3}	4.9×10^{-3}	-0.4×10^{-3}	4
9					13.8			7.8	7.6	1.03	3.9×10^{-3}	5.2×10^{-3}	-1.3×10^{-3}	5

Notes:

(1) Ratio of projected to actual leak rates.
(2) Difference between projected and actual burst probabilities.
(3) Results for actual distribution calculated using 5% for NDE analyst variability uncertainty.
(4) Leak rate versus voltage correlation applied for 7/8" tubing
(5) Calculations without applying voltage dependent growth rates.

Table 4. Application of Recommended Methods for Deplugged Tube Growth Rates
Comparisons of Projected Leak and Burst Probability Results with Results Based on Actual Measured Voltages

No.	Plant	Cycle	SG	EOC Voltages				SLB Leak Rates – gpm[7]			Burst Probability			Notes
				Projected		Actual								
				No. Ind.	Max. Volts	No. Ind.	Max. Volts	Projected	Actual	Ratio[1]	Projected	Actual	Difference[2]	
1	A-2	EOC-11	C	239	6.3	232	6.7	2.5	2.8	0.89	$4.2x10^{-4}$	$8.4x10^{-4}$	$-4.2x10^{-4}$	
2									2.6	0.96		$5.8x10^{-4}$	$-1.6 x 10^{-4}$	3
3					6.7			2.5		0.96	$5.3 x 10^{-4}$		$-0.5 x 10^{-4}$	4
4		EOC-12		244	6.2	275	3.3	2.6	1.9	1.4	$3.6x10^{-4}$	$2.1x10^{-4}$	$1.5x10^{-4}$	
5	P-1	EOC-12	A	1384	2.9	1241	2.5	4.0	2.4	1.67	$1.3x10^{-4}$	$0.97x10^{-4}$	$0.3x10^{-4}$	6
6			B	1123	3.0	914	1.8	4.8	1.3	3.69	$1.9x10^{-4}$	$0.37x10^{-4}$	$1.5x10^{-4}$	6

Notes:

(1) Ratio of projected to actual leak rates.

(2) Difference between projected and actual burst probabilities.

(3) Results for actual distribution calculated using 5% (versus reference 10.3% for other cases) for NDE analyst variability uncertainty.

(4) Calculated applying voltage dependent growth rates for deplugged tubes.

(5) Calculations apply generic growth rates, which were derived from Plant A-2 data, for deplugged tubes.

(6) Calculations apply Plant P-1 specific growth rates for deplugged tubes returned to service.

(7) All leak rate calculations based on leak rate independent of voltage for 7/8 inch diameter tubing.

Table 5. Comparison of Projected Leak and Burst Results Based on POPCD with Actuals
Overall Summary of the Results for the Reference Cases

PARAMETER	7/8" Tubes			3/4" Tubes		
	Direct Comparison	Within Negligible Differences[1]	With Recommended Methods[2]	Direct Comparison	Within Negligible Differences[1]	With Recommended Methods[2]
Number of SG Operating Cycles Analyzed	18	18	18	14	14	14
EOC Voltage Predictions						
No.of SGs with Total Ind. Overpredicted	10			7		
No. of SGs with Mean Voltage Overpredicted	16	17	18	13	14	14
No. of SGs with Max. Voltage Overpredicted	14	15	16	9	10	13
SLB Leak Rate Predictions						
No. of SGs with Leak Rate Overpredicted	15	16	17	8	11	14
Overpredicted Prediction-to-Actual Ratios	1.0 to 4.4			1.2 to 133		
No. of SGs with Leak Rate Underpredicted	3	3	1	6	3	
Underpredicted Prediction-to-Actual Ratios	0.4 to 0.8	0.4 to 0.8	0.8	0.23 to 0.7	0.23 to 0.26	
Underprediction Range in Leak Rate (gpm)	0.26 to 0.34	0.26 to 0.34	0.28	0.05 to 8.8	4.8 to 8.8	
Underprediction Range as a % of Allowable Limit	2% to 3%	2% to 3%	2%	0.4% to 33%	18% to 33%	
Burst Probability Predictions						
No. of SGs with Burst Prob. Overpredicted	11	16	17	12	14	14
Overprediction Range in Burst Probability	2×10^{-6} to 1.1×10^{-4}			3.5×10^{-6} to 5.8×10^{-3}		
No. SGs with Burst Prob. Underpredicted	7	2	1	2		
Underprediction Range in Burst Probability	3×10^{-6} to 4.7×10^{-3}	6.2×10^{-4} to 4.7×10^{-3}	4.7×10^{-3}	3.5×10^{-6} to 1.1×10^{-5}		
Underprediction Range as a % of Allowable Limit	< 0.1% to 47%			< 0.1% to 4.9%		

Notes:

(1)Negligible differences between projections and values calculated from actual voltage distributions defined as 1.0 volt on maximum volts, 0.1 volt on mean volts, 0.25 gpm on leak rate and 5×10^{-4} on burst probability.

(2) Recommended methods updates described in text and developed in EPRI Report NP 7480-L, Addendum 2, 1998. Counting of SGs overpredicted is based on analyses with revised methods having negligible differences (Note 1 above) between projections and values calculated from actual voltage distributions.

Table 6. Summary of More Significant Underpredictions and Methodology Updates to Improve Projections

Plant Cycle	Underpredictions	Cause of Underprediction	Recommended Methodology Update
A-1 EOC-14	Leakage underpredicted by 0.68 gpm (9% low) with no leak rate correlation and 0.28 gpm with leak rate correlation. Burst underpredicted by 4.5×10^{-3} (factor of 10).	Failure to predict 13.7 volt indication. All other indications bounded by predictions.	None recommended. Single indication near 15 volts was unprecedented in plant operation. Destructive exam shows an influence of pressure pulse cleaning, applied prior to inspection, on crack morphology but influence on voltage is unknown. Underprediction is independent of POD applied in anal
A-2 EOC-11	Leakage underpredicted by 0.34 gpm (60% low). Burst underpredicted by 6×10^{-4}.	Underestimate of Cycle 11 growth rates in prediction with inability to predict 7.4 volts indication. Growth evaluation indicates growth rates of deplugged tubes were underestimated in predictions.	Analysis methods recommended to define growth rate for deplugged tubes (EPRI Report NP 7480-L, Addendum 2, 1998 Database Update) and to use a bounding historical distribution if there is no plant specific data available on growth rates of deplugged tubes. Underprediction is independent of POD applied in analyses.
P-1 EOC-11	Leakage underprediction by 0.26 gpm (17% low). Negligible differences for burst.	Apparent underestimate of Cycle 11 growth rates. Review of data collection procedures following large negative growth at EOC-12 found EOC-11 voltages were high due to a change in methods for cross calibrating ASME standards at EOC-11 inspection.	NDE methods recommended for a consistent procedure for cross calibration of ASME standards to the reference laboratory standard (EPRI Report NP 7480-L, Addendum 2, 1998 Database Update). Leakage underprediction becomes a 0.14 gpm overprediction when voltages at EOC-11 are corrected for ASME standard cross calibration difference between inspections.
AA-1 EOC-6	Leakage underpredicted by 7.8 gpm. Burst probability not affected due to "locked" TSPs applied to SGs.	Large underprediction of growth rates for the larger indications (> 1.5-2.0 volts) left in service. Growth rates for Cycle 6 show significant dependence upon BOC voltages.	Analysis methods recommended for incorporating voltage dependent growth rates in the projection analyses (EPRI Report NP 7480-L, Addendum 2, 1998 Database Update). Underprediction is independent of POD applied in analyses.
AB-1 EOC-7B	Leakage underpredicted by 0.17 gpm. Burst probability not affected due to "locked" TSPs applied to SGs.	Underprediction of growth rates for the larger indications (> 1.5-2.0 volts) left in service. Growth rates for Cycle 7 show modest dependence upon BOC voltages.	Analysis methods recommended for incorporating voltage dependent growth rates in the projection analyses (EPRI Report NP 7480-L, Addendum 2, 1998 Database Update). Underprediction is independent of POD applied in analyses.

ENCLOSURE 3

Response to NRC RAI of February 26, 1998
Proposed Data Exclusion Criteria and Adjustment of Measured Leak Rate for Tube R28C41 (Plant S)

Question

1. Discuss whether the proposed exclusion criteria be applied to leak rate data for 7/8-inch tubing. In addition, specify what data, if any, would be affected.

Response

The proposed exclusion criteria can be applied to 7/8 inch tubing as documented in Appendix E of Reference 1. However, Criterion 3a does not lead to exclusion of any 7/8 inch data from the current database. Criterion 3b would exclude 7/8 inch datapoints but, based on NRC review comments, this criterion is not included in the updated data exclusion criteria documented in Reference 2. Criterion 3a has been revised to establish the statistical prediction intervals at a one-sided 99% prediction interval in order to provide a higher level of assurance that the outlying data are inconsistent with other leak rate data in the database. This 99% prediction interval is applied to the correlations for leak rate as a function of bobbin coil voltage and crack length. The application of the revised Criterion 3a to the _ inch tubing database is described in Section 3 of Reference 2. This application results in excluding Model Boiler specimens 598-3 and 604-2 from the leak rate correlation for _ inch tubing.

Question

2. Proposed Criterion 3a excludes data based, in part, on a calculated leak rate from a measured crack length. As demonstrated for tube R28C41, such calculations are highly sensitive to the input crack length. Describe the process and criteria established to determine the appropriate crack length for input into the leak rate calculations. Also discuss what crack length will be assumed in the situation where multiple flaws located at a tube support plate intersection leak at steam line break pressure.

Response

Criterion 3a, as documented in References 1 to 3, does not include a calculated leak rate from a measured crack length. The length based part of the criterion utilizes a correlation of the measured (rather than calculated) leak rate with measured throughwall crack length. As shown by Figure 3-6 of Reference 2, the correlation with throughwall length is well defined with a few very low leak rates that are evaluated against Criterion 3a. Consequently, the process and criteria established to determine the appropriate crack length for the leak rate calculations is straightforward. The crack length to be used is the throughwall crack length measured by destructive exam fractography of the associated indication. Since Criterion 3a does not apply if uncorroded ligaments are present within the throughwall length, the measured throughwall length can be directly applied for evaluating the indication against the criterion.

When multiple flaws leak at steam line break pressures, the secondary cracks are large enough to be readily identified during the destructive examination. It is the recommended and commonly applied practice in destructive examinations to open up large secondary cracks for fractography. The destructive exam would then identify the throughwall lengths of the secondary cracks as well as the primary burst crack. For each throughwall length, an 'expected' leak rate can be obtained from the mean regression line of the correlation of leak rates with throughwall length. An 'effective' throughwall length can then be obtained by summing the products of throughwall length and its associated 'expected' leak rates and dividing by the sum of the 'expected' leak rates. For evaluation against Criterion 3a, the measured leak rate would be plotted against its 'effective' throughwall length.

Question

3. It was indicated in the text that CRACKFLO accounts for crack tip tearing. Describe how the CRACKFLO code determines the extent of crack tearing for steam generator tube flaws. If the governing fracture parameter of CRACKFLO is the J-integral, describe any benchmarking done of the code since J-controlled crack growth is not applicable to steam generator tube flaws. For tube R28C41, provide the overall crack length that was calculated by CRACKFLO in order to determine the tube leak rate.

Response

The CRACKLO code utilizes crack opening area as determined from equations developed by Paris-Dugdale (Reference 4). Constants in the equations may be adjusted to improve agreement with measured crack opening areas for various throughwall crack lengths. The effect of yielding near the crack tip is incorporated by the method of plastic zone corrections. This method yields an effective length which, however, does not explicitly represent throughwall crack tearing. For example, the SLB analysis for R28C41 with a 0.60 inch throughwall length yields an effective crack length of 0.90 inch. This length encompasses potential tearing and plasticity at the crack tips. It should be emphasized that crack opening areas and leak rates are checked against measurements and not the sub-details of the crack opening model.

References

1. EPRI Report NP-7480-L, Volume 1, Revision 2, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates - Database for Alternate Repair Limits, Volume 1: 7/8 Inch Diameter Tubing", November 1997
2. EPRI Report NP-7480-L, Addendum 2: 1998 Database Update, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits", April 1998

3. EPRI Report NP-7480-L, Volume 2, Revision 1, "Steam Generator Tubing Outside Diameter Stress Corrosion Cracking at Tube Support Plates Database for Alternate Repair Limits - Database for Alternate Repair Limits, Volume 2: 3/4 Inch Diameter Tubing", November 1997
4. Tada, Paris and Irwin, "The Stress Analysis of Cracks Handbook", Paris Productions and Del Research Corp., 1985