UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO HYDRAULIC EQUIVALENCY

LASER WELDED STEAM GENERATOR TUBE REPAIRS

TXU ELECTRIC

COMANCHE PEAK STEAM ELECTRIC STATION, UNITS 1 AND 2

DOCKET NOS. 50-445 AND 50-446

1.0 INTRODUCTION

By letter dated September 6, 2000, TXU Electric, the licensee for the Comanche Peak Steam Electric Station (CPSES), Units 1 and 2, requested an amendment to its operating licenses to allow installation of laser-welded tube sleeves as an alternative to plugging defective steam generator (SG) tubes (Reference 1) for CPSES, Unit 1, as supplemented by letter dated December 14, 2000. By supplemental letter dated January 25, 2001, the licensee modified its request to include a clearly conservative hydraulic equivalency of sleeved to plugged tubes (Reference 2). The U.S. Nuclear Regulatory Commission (NRC) issued Amendment Nos. 83 and 83 for CPSES, Units 1 and 2, respectively, by letter dated February 20, 2001 (Reference 3), approving the modified request with an understanding that the NRC staff would continue to review the hydraulic equivalency proposed in the original request. The licensee submitted a generic topical report (Reference 4) and a topical report specific to CPSES (Reference 5), as part of its Reference 1 request.

2.0 BACKGROUND

SG tubes with indications of degradation in excess of allowable limits must be removed from service or repaired. Plugging SG tubes decreases the SG primary side flow and heat transfer areas and, consequently, increases both the resistance to primary side flow and the primary to secondary resistance to heat transfer. This, in turn, causes a decrease in reactor coolant system (RCS) flow rate and an increase in the RCS-to-SG secondary side temperature difference for the same core thermal power level. These changes affect CPSES operational characteristics, its design basis analyses, and its licensing basis. Licensees typically address potential impact by assuming some fraction of the SG tubes is plugged in each of the SGs and then re-establish the licensing (and accident analysis) bases via new analyses to establish that a stated "plugging limit" is bounding with respect to the analyzed configurations. Once a plugging limit is established, a licensee may operate with any fraction of tubes plugged subject to not exceeding the established limit.

Operationally, plugged SG tubes may restrict operational flexibility and, if enough SG tubes are plugged, will limit core thermal power. Thus, even if there is no regulatory concern, licensees may prefer to limit the number of plugged SG tubes.

Often, SG tubes may be repaired by inserting one or more smaller diameter tubes inside the original SG tube, a process termed "sleeving." Sleeving allows the original SG tube to remain in service and, although there is an impact on resistance to primary side flow and to heat transfer, the impact is less than would result from plugging the original SG tube. Licensees typically propose to address the effect of sleeving by establishing an equivalence between the impact of sleeving and of plugging. For example, assume one determines that a certain number of sleeved SG tubes is equivalent to one plugged SG tube under certain conditions. Since the equivalent number of SG tubes varies with the number, location, type, and size of the sleeves; with the location of the sleeve in the SG tube; with plant operational characteristics; and with postulated accident conditions, a different equivalency may result for different conditions. Consequently, a bounding value must be established for purposes of meeting an SG plugging limit due to a combination of plugged and sleeved SG tubes.

As stated in Reference 3, the NRC staff approved a clearly conservative hydraulic equivalency of sleeves-to-plugged SG tubes with an understanding that the NRC staff would continue to review the hydraulic equivalency proposed in the original request. In this evaluation, the NRC staff completes its evaluation of the licensee's original Reference 1 request, as supplemented, regarding the equivalency between sleeved and plugged SG tubes.

3.0 EVALUATION

3.1 Historic Staff Review of Equivalence Between Sleeved and Plugged SG Tubes

The licensee approaches the effect of sleeving SG tubes by establishing an equivalence between sleeved tubes and plugged tubes. This is not new. Reference 6 reported that the Maine Yankee Atomic Power Company (MYAPC) stated that 28 sleeved SG tubes met the hydraulic equivalence of one plugged SG tube; apparently other licensees had reported sleeved-to-plugged ratios of 10:1 to 15:1, and Westinghouse Electric Company (W) had reported 14:1. Some differences were attributed to assumed conservatisms in the calculations, with the MYAPC's 28:1 ratio being a best estimate value. Reference 6 additionally reported that later MYAPC estimates yielded a ratio of 26.7:1 and that, when MYAPC used the stated W conservatisms, it calculated a ratio of 14.9:1. Reference 6 also reported that a change from average sleeve length of 30 inches to 36 inches changed the ratio from about 28:1 to about 20:1.

3.2 Licensee and W Approach to Equivalency

The variability in equivalence ratio is addressed by the CPSES licensee via a bounding approach with an illustrative sensitivity evaluation. The equivalence is stated to consist of two parts: a hydraulic equivalence and a thermal equivalence. On the basis of normal operational conditions, the hydraulic equivalence is stated to be more limiting than the thermal equivalence. With respect to off-normal conditions, Reference 4 states that a hydraulic equivalence "... is established using flow rates consistent with the reflood phase of a post-LOCA [loss-of-coolant accident] when peak clad temperatures exist." Reference 4 also states "The specific LOCA conditions used to evaluate the effect of sleeving on the ECCS [emergency core cooling system] analysis occur during a portion of the postulated accident when the analysis predicts that the fluid in the secondary side of the steam generator is warmer than the primary side fluid. For this situation, the reduction in heat transfer capability of sleeved tubes would have a beneficial reduction on the heat transferred from secondary to primary fluids." It then reports

that the thermal equivalence may be ignored when determining the number of sleeved tubes that are equivalent to one plugged tube. Reference 4 concludes that "In all cases, the hydraulic equivalency number for normal operation is more limiting than for postulated LOCA conditions."

Reference 4 continues with a statement that the location of the sleeve in the cold leg at the highest tube support plate (TSP) elevation gives the most conservative equivalence results. It then briefly describes calculated results for 36-inch sleeve lengths at several locations in three W SG models and provides limited sensitivity study results. Equivalency variation with TSP sleeve length and location, and a smaller variation with temperature and operating conditions, are mentioned, and the results are stated to be correlated in Reference 4, Figures 3-20, 3-21, and 3-22[1]. The sensitivity results are stated to establish that the selected sleeve configurations are the most conservative.

Reference 5 states that the CPSES sleeves are much shorter than the 36-inch sleeves, which will make the Figure 3-20 correlation conservative for CPSES. It identifies results from the SLEEVE code as conservative when compared to test data by a factor of two to four for hot leg sleeves, and by 25% to 60% for cold leg sleeves.

Reference 5 continues with a conclusion that, for moderate numbers of sleeved tubes, use of the conservative approach will not add significantly to the total equivalent plugging. On this basis, it implies that the conservative approach may be used; however, it also states that best estimate values for hydraulic equivalency should be used if the amount of sleeving results in sleeving dominating the behavior.

3.3 Evaluation of Equivalence between Sleeved and Plugged SG Tubes

To evaluate the hydraulic equivalency issue raised in Reference 1, the NRC staff considered the licensee's (and the W) claimed conservatisms, the influence of sleeving in comparison with plugging, historic information, SLEEVE code information, and test data. The NRC staff found the Reference 1, 4, 5, and 7 information to be generally consistent with Reference 6, but were unable to substantiate some of the licensee's claimed conservatisms. The NRC staff also found reference to variation with such parameters as sleeve length, position of the sleeve in the SG tube, number of sleeves in a tube, and variation with RCS flow rate and temperature, but limited detail was provided. The behavior for such conditions as transients, medium or small break LOCAs, sleeving asymmetry, and variation of behavior with break location was not discussed. The licensee also did not discuss the potential effect of changes in the early LOCA blowdown and refill response, and the corresponding influence on reflood behavior.

The licensee supplemented the above information by Reference 8, and by additional information available for review in the W, Rockville, Maryland office (see Reference 9).

3.3.1 The SLEEVE Code

Reference 8 describes the SLEEVE code as a methodology for computing "... hydraulic loss coefficients for sleeved and unsleeved tubes, which are used to estimate a hydraulic equivalency for the sleeve. The hydraulic coefficients are calculated using standard

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[1]Figure 3-20 applies to the CPSES SG designs.

correlations for losses due to contractions, expansions and wall friction." This description is consistent with the loss equations provided by Reference 8 for flow-through SG tubes from the hot leg SG inlet plenum to the SG outlet plenum, when several assumptions are applied. Some of these assumptions, and an assessment of each, include:

1. <u>There is no influence of one tube on another in the tube entrance and exit regions.</u> This assumption is accurate for widely scattered sleeved tubes. An unanalyzed perturbation will occur with tubes in close proximity. We judge the overall perturbation will be small.

2. <u>Reversed flow is not addressed and the losses may differ between forward and reverse flow</u>. This could affect equivalency predictions for hot leg breaks and for some transients. Although these effects have not been quantified, we believe they are unlikely to result in a significant equivalency change.

3. <u>Flow coefficients are assumed constant for all operational and accident conditions.</u> This is consistent with typical thermal-hydraulic codes applied to licensing basis analyses and is not of general concern.

4. <u>Choked flow is not considered.</u> With the exception of SG tube rupture, choked flow in SG tubes is unlikely. SG tube rupture is not of concern in many analyses because the break is not simulated by actually modeling flow from a tube.

5. <u>The flow distribution within each tube is fully developed.</u> In some cases, flow area changes occur in close proximity to each other, in violation of the assumption that individual flow coefficients are unaffected by their neighbors. We judge this to over-predict the total loss coefficient, a conservatism in comparing sleeved-to-unsleeved tubes for most situations.

The SLEEVE code models a single SG tube with contained sleeves. Apparently, an average tube length is assumed when determining an equivalency. This is consistent with typical analysis code treatment, although there may be instances where it is insufficient from the standpoint of code instability or modeling for specific analysis purposes.

3.3.2 Comparison with Test Data

Reference 8 describes full scale tests that were conducted with an unsleeved tube and with 30- and 36-inch long sleeves similar in design to sleeves that would be used in SGs. Flow rates were varied . The licensee stated that this produced Reynolds Numbers (Re) from 1×10^5 to 7×10^5, whereas a typical Re for normal operation is about 9×10^5 and Re's during an accident can be a factor of 10 larger. For the 30-inch hot leg sleeve, the licensee concluded that "... the hydraulic equivalency determined from the test data was found to be on average 3.38 times greater than the hydraulic equivalency calculated using the SLEEVE code. For the 36[-inch] hot leg sleeve, the hydraulic equivalency was found to be on average 2.35 times greater than the hydraulic equivalency calculated using the SLEEVE code. The test data suggests that as the Re increased, the ratio of hydraulic equivalency for test to calculated conditions indicates a slightly increasing ratio."

The licensee summarized the test data in Reference 8, Figure 1. The difference between the loss coefficient data for 36-inch sleeves and the data for 30-inch sleeves is about the same as

the difference between the 30-inch sleeves and no sleeves. This suggests a diminishing difference with decreasing sleeve length and implies that 12-inch sleeve loss coefficients may not differ substantially from 30-inch sleeve loss coefficients, an apparent contradiction to the licensee's implied conclusion that there is substantial conservatism introduced by the use of 12-inch sleeves. The 12-inch sleeves were not tested. The licensee's no-sleeve data also appear to be non-linear, with the effect of changes in Re becoming smaller as Re becomes larger. The lines fitted to the data do not reflect this behavior. The effect is not as evident in the sleeved data. The NRC staff notes the diminishing effect with decreasing length and the observed non-linearity with Re are consistent with theory in that frictional flow due to length becomes a smaller contributor in comparison to change of flow area contributions as length decreases. The Re to a fractional power appears in the denominator of friction equation. Not modeled is the behavior due to failure to fully develop the flow pattern from one flow area perturbation to the next. The NRC staff also notes that there was no evaluation of differences between the tested configurations and actual SG sleeves.

To obtain additional understanding of the test data, the NRC staff examined a report that was identified as proprietary and that was not submitted to or retained by the NRC staff[2]. This report described that unsleeved SG tube sections were used to obtain unsleeved tube loss coefficients in a test section. More than 40 test values were obtained, and a curve was fit to the values that, with one exception, underpredicted all values. Underprediction of friction in unsleeved tubes is conservative when comparing to the effect of sleeving. This is not completely consistent with Reference 8, Figure 1, where 20 test values are shown for unsleeved tubes and the curve fits appear to be best-estimate; however, the NRC staff found no significant impact regarding conclusions.

For the hot leg sleeves, the data support a hydraulic equivalency of a factor of 2 to 4 larger for the tests when compared to SLEEVE calculations, roughly consistent with References 5 and 8. Comparisons for cold leg sleeves were also approximately consistent with Reference 5, but the cold leg sleeve data reflected a conservative factor of 1.25 to 1.55 (Reference 9). This difference in conservatism between the hot and cold leg sides has not been satisfactorily explained. Also unexplained is the test-to-code multiplier behavior; for hot leg sleeves, it is larger for the 30-inch sleeves than for the 36-inch sleeves, but the reverse occurs for cold leg sleeves. Such unexplained differences indicate the need for caution when extrapolating conclusions regarding a quantitative conservatism for 12-inch sleeves.

The unsleeved test section included a Swagelok union. The licensee indicated that a Swagelok union was also used in the sleeved test section and pointed out that there should be no effect on hydraulic equivalency. The NRC staff has no information regarding whether such perturbations were modeled in SLEEVE nor has the NRC staff seen a quantitative assessment of the effect; however, the NRC staff notes that anything that increases flow resistance in the unsleeved tests is non-conservative when used to obtain sleeve to non-sleeve flow coefficients. The NRC staff further notes that a perturbation in a non-sleeve test will have more relative impact than the same perturbation in a sleeve test because the latter introduces additional perturbations. Overall, the NRC staff concludes that the impact is likely small because the NRC

[2]Page 1 of 69 was identified as "Sleeve Code Multiplier for Excess Conservatism," Calculation Note Cover Sheet, Calc. No. TH-97-08, Rev 0, (Westinghouse), September 2, 1997.

staff expects that pressure drop within the Swagelok union is small in comparison to the total pressure drop for long test sections, and that the potential impact would be larger with decreasing test section length.

The NRC staff concludes that the test data support the pre-test assumption that the SLEEVE code calculates a loss coefficient that is higher than actual for 30- and 36-inch long sleeves; however, there are sufficient anomalies in the test results that caution is required when extrapolating the test results to shorter sleeves. These anomalies, in combination with other assumptions in applying the SLEEVE code and in assessing operational and accident response, lead the NRC staff to conclude that loss coefficients smaller than predicted for 30- or 36-inch long sleeves are not justified for situations where smaller coefficients are associated with a reduced conservatism.

4.0 CONCLUSION

The following statement is contained in Reference 5:

> "For moderate sleeving programs, the generic report (Reference 4) equivalency values can be used without significantly affecting the steam generator total equivalent plugging. When large scale sleeving programs are anticipated, the expected sleeve configurations should be calculated on a best estimate basis to determine the total equivalent plugging which will result."

The equivalent number of tubes varies with the number, location, type, and size of the sleeves; with the location of sleeves in a tube; with plant operational characteristics; and with postulated accident conditions. A bounding value, therefore, must be established for purposes of meeting a plugging limit due to a combination of plugged and sleeved tubes. Although the licensee presents some information in support of establishing a bound, the information is incomplete. The NRC staff concludes that there is sufficient conservatism in the 30- and 36-inch generic determinations to compensate for this and other approximations; however, since there are no test data for sleeves shorter than 30 inches, and there are some test anomalies that have not been explained, the NRC staff cannot make any conclusions regarding extrapolation to shorter sleeve lengths via a calculational methodology. Therefore, since it is reasonable to assume shorter sleeves will have a smaller loss coefficient, the NRC staff concludes that equivalency values for sleeves of less than 30 inches in length are acceptable, with the stipulation that such sleeves shall be assumed to be at least 30 inches long when calculating equivalency.

The licensee has not clearly defined "best estimate." Further, the above-identified issues would have to be fully addressed before the NRC staff could undertake an evaluation of a best estimate methodology. Consequently, the NRC staff concludes that a "best estimate basis" has not been sufficiently justified and would require additional clarification and validation to be acceptable.

The NRC staff concludes that, the Reference 5 Table 3-8 values for the 36-inch hot leg, 30-inch hot leg, and 30-inch hot leg and cold leg (combined) are acceptable. These values are also acceptable for sleeves shorter than 30 inches. The remaining Table 3-8 values are not acceptable.

The distribution of equivalent plugged tubes between SGs (and, in some cases within SGs) must remain bounded by the assumed distribution used in the analyses of record. For example, if a licensee assumed 10% of the tubes in each SG were plugged in its bounding analyses of record in establishing a total plugging limit of 10%, then the equivalent number of plugged tubes in any one SG may be no more than 10% of that SG's tubes. Similarly, if the analyses of record depend upon an effective distribution of affected tubes within one SG or between SGs, then the effective combination of plugged and sleeved tubes must remain within the established bounds.

Finally, the NRC staff assessed the potential impact of the NRC staff's conservative approach on plant operation. Typically, a SG has approximately 4,000 tubes. Assume 1,000 tubes are sleeved. If the equivalency ratio is 20 sleeved tubes to one plugged tube[3], the equivalent number of plugged tubes is 1,000/20 = 50, and the equivalent percent of plugged tubes is 50/4,000X100 = 1.25%. The NRC staff concludes that assuming a conservative equivalency value consistent with the NRC staff's conclusions is unlikely to cause a significant impact upon plant operation.

7.0 REFERENCES

1. Letter from C. Lance Terry, TXU Electric, to the U.S. Nuclear Regulatory Commission, "Comanche Peak Steam Electric Station (CPSES), Docket Nos. 50-445 and 50-446, License Amendment Request (LAR) 00-04, Steam Generator Tube Repair Using Laser Welded Sleeves," September 6, 2000.

2. Letter from C. Lance Terry, TXU Electric, to the U.S. Nuclear Regulatory Commission, "Comanche Peak Steam Electric Station (CPSES), Docket No. 50-445, Supplement for License Amendment Request (LAR) 00-04, Steam Generator Tube Repair Using Laser Welded Sleeves (TAC Nos. MA9950 and MA9951)," January 25, 2001.

3. Letter from David H. Jaffe, U.S. Nuclear Regulatory Commission, to C. Lance Terry, TXU Electric, "Comanche Peak Steam Electric Station (CPSES), Units 1 and 2 - Issuance of Amendments Re: Installation of Laser Welded Sleeves as an Alternative to Plugging Defective Steam Generator Tubes (TAC Nos. MA9950 and MA9951)," February 20, 2001.

4. Westinghouse Electric Company Topical Report, "Laser Welded Sleeves for 3/4 Inch Diameter Tube Feedring-Type and Westinghouse Preheater Steam Generators, Generic Sleeving Report," WCAP-13698 Rev. 3 (Proprietary), July, 1998.

5. Westinghouse Electric Company Topical Report, "Specific Application of Laser Welded Sleeves for the Comanche Peak Units 1 and 2 Steam Generators," WCAP-15090 Rev. 1 (Proprietary), March, 1999.

6. U. S. Nuclear Regulatory Commission Memorandum from Brian W. Sheron, Director, Division of Engineering, to Ashok C. Thadani, Associate Director for Technical

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[3]The licensee considers actual values to be proprietary. This value is within the range identified in Reference 6.

Assessment, NRR, "Equivalence Between Plugs and Sleeves in Steam Generators," June 27, 1995.

7. Letter from C. Lance Terry, TXU Electric, to the U.S. Nuclear Regulatory Commission, "Comanche Peak Steam Electric Station (CPSES), Docket Nos. 50-445 and 50-446, License Amendment Request (LAR) 00-04, Request for Additional Information Regarding Steam Generator Tube Repair Using Laser Welded Sleeves," December 14, 2000.

8. Letter from C. Lance Terry, TXU Electric, to the U.S. Nuclear Regulatory Commission, "Comanche Peak Steam Electric Station (CPSES), Docket Nos. 50-445, Request for Additional Information Regarding Steam Generator Tube Repair Using Laser Welded Sleeves," May 4, 2001.

9. Letter from C. Lance Terry, TXU Electric, to the U.S. Nuclear Regulatory Commission, "Comanche Peak Steam Electric Station (CPSES), Docket Nos. 50-445 and 50-446, Request for Additional Information Regarding Steam Generator Tube Repair Using Laser Welded Sleeves," September 12, 2001.

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