ENCLOSURE 2 TO NL-14-045

LTR-SGMP-14-22 NP-ATTACHMENT, REVISION 0, "ACCEPTABLE VALUE OF THE LOCATION OF THE BOTTOM OF THE EXPANSION TRANSITION (BET) FOR IMPLEMENTATION OF H* AT INDIAN POINT UNIT 2", MARCH 2014 (NON-PROPRIETARY)

Acceptable Value of the Location of the Bottom of the Expansion Transition (BET) for Implementation of H* at Indian Point Unit 2

Revision 0

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Background

The alternate repair criterion, H* (H-star), replaces the tube end weld as the pressure boundary between the primary and secondary sides of the steam generator (SG) with the hydraulic expansion joint between the tube and the tubesheet. The technical justification of H* demonstrates that the hydraulic expansion joint between the tube and the tubesheet provides adequate capability to satisfy the applicable structural and leakage performance criteria specified in Reference 1. The technical justification of H* determines the required length of non-degraded tubing within the tubesheet expansion region to assure that the tube cannot be pulled from the tubesheet by the limiting axial (end-cap) loads for normal operating conditions and for the limiting design basis accident with appropriate safety factors as specified in Reference 1. It is also shown that the coolant leakage through the joint is less than the leakage assumed in the Final Safety Analysis Report (FSAR) for the limiting accident conditions.

It must be verified by regular in-service inspections in accordance with the requirements of Reference 2 that the tubing within the tubesheet expansion region is not degraded by stress corrosion cracking (SCC) over the required length defined as H*. To accomplish this, it is necessary to establish a unique, repeatable point of reference. The top-of-the-tubesheet (TTS) is a point of reference that is readily established by current eddy current (EC) techniques and instruments (such as the bobbin probe). Consequently, the TTS is the point of reference chosen for H*. The recommended H* distance is specified as being measured from the TTS.

H* depends on contact between the tube and the tubesheet due to pressure loads, thermal loads and tubesheet flexure during operation. As a minimum, the technical justification assumes that line-on-line contact exists between the tube and the tubesheet over the length of the hydraulic expansion at cold conditions due to the hydraulic expansion. The manufacturing process requires a tolerance of approximately [ ][a,c,e] inch from the TTS to assure that overexpansion above the TTS does not occur. Thus, by design, there is a short span from the TTS to the bottom of the expansion transition (BET) where the assumption of line-on-line contact is not valid. The hydraulic expansion process is designed to minimize the distance from the TTS to the BET; however, the exact position of the location of the BET relative to the TTS can vary due to manufacturing tolerances as discussed below.

During the original development of H* using the thick-shell equations, to address the potential variation of the location of the BET, the technical justification for H* included a constant value of [ ][a,c,e] inch below the TTS for the location of the BET. This value was added to the calculated H* distance required to meet the performance criteria because the underlying assumption of the H* calculation is that the initial condition is line-on-line tube-to-tubesheet contact. H*, as currently licensed at a number of plants, is now based on application of the "Square-Cell" model as described in Reference 1. Application of the Square-Cell model has rendered the position of the BET, relative to the TTS, unnecessary because of the predicted contact pressure profiles within the tubesheet expansion region as discussed below.

Potential Sources of BET Position Variability

As discussed in Reference 3, the hydraulic expansion tooling is likely the principal source of BET location variation but the tooling also provides an effective upper limit for the potential variation of the location of the BET. Hydraulic expansions are performed using a mandrel that seats on the bottom of the tubesheet (the primary, clad side of the tubesheet), with top and bottom seals that contain the pressurizing medium, water. The distance between the seals on

the mandrel is fixed by the nominal thickness of the tubesheet and cladding and the design criterion for locating the BET relative to the TTS. The design criteria for locating the BET is to minimize the crevice length and, also, to minimize the potential for overexpansions (BET located above the TTS). The nominal design position of the BET is [ ]^{a,c,e} inch below the TTS. Within these criteria, the distance between upper and lower mandrel seals is fixed for each model of SG. The lower seal is also fixed at [ ]^{a,c,e} inch above the seating surface on the mandrel. If the mandrel is not seated on the primary surface of the tubesheet, the maximum possible distance between the seating surface and the surface of the tubesheet is [ ]^{a,c,e} inch (less in practice) or the mandrel cannot be pressurized. Therefore, for all expanded tubes, the BET must be located within less than [ ]^{a,c,e} inch plus the initial design tolerance, [ ]^{a,c,e} inch, (=[ ]^{a,c,e} inch, total) of the TTS.

The tubesheet thickness can also vary above the minimum specified thickness and this variation is not necessarily the same across the entire surface of the tubesheet. There is also a design tolerance on the thickness of the cladding on the primary side of the tubesheet. Thus, tubesheet tolerances can create the appearance that the BET location is greater than expected from the nominal dimension. However, a variation of the tubesheet thickness does not reduce the contact length between the tube and the tubesheet; it is always controlled by the manufacturing tooling seated on the reference surface, the primary side of the tubesheet. For example, if a local condition exists where the combined tolerances on tubesheet thickness and cladding thickness are 0.1 inch greater than the design nominal dimension, the apparent BET position will be 0.1 inch greater than design nominal plus mandrel positioning variation without affecting the contact length between the tube and tubesheet.

The typical cumulative design tolerance for the tubesheet plus cladding minimum thickness is approximately [ ]^{a,c,e} inch. Only a minimum thickness is specified by the design of the Model 44F SGs; thus the actual maximum dimension is not known. The same typical tolerance, [ ]^{a,c,e} *inch, is assumed to apply for the Model 44F SGs at Indian Point Unit 2.*

The current EC techniques have good capabilities for identifying the edge of a significant structure such as the top of the tubesheet; however, identification of the TTS and the BET can sometimes be confused by other manufacturing artifacts. The precision of the measurement can be affected by deposits on the top of the tubesheet and manufacturing artifacts such as bulges and overexpansions near the top of the tubesheet. Close manual examination of the data can usually discriminate between the tubesheet and deposits or manufacturing anomalies, however, there are occasions when the identified location of the TTS can be confused by the sludge signal or local anomalies, leading to an apparently greater distance between the TTS and the BET. Variation due to deposit accumulation is not significant for the Indian Point Unit 2 SGs because the data used for determining the BETpositions is from an inspection prior to SG operation (Reference 4).

The limiting expected BET variation, relative to the TTS, is estimated as follows:

Design BET Location	[ ]^{a,c,e} inch
Maximum Mandrel Mal-positioning	[ ]^{a,c,e} inch
Structure Tolerances	[ ]^{a,c,e} inch
EC Accuracy (estimate based on field of view of the bobbin probe)	-0.20 inch
Total	**[ ]^{a,c,e} inch**

This assessment is not a comprehensive assessment. It is to be interpreted as an estimate of the maximum possible position of the BET below the TTS because the maximum tolerances are included. Occurrence of a value of this magnitude or greater would be expected to be extremely rare.

Results of BET Position Studies for Indian Point Unit 2

Table 1 summarizes the results of the BET position study for Indian Point Unit 2 (Reference 4). The 95th and 99th percentile positions were developed for each SG including both the hot leg and the cold leg transitions. The results show that the 95th percentile values of the BET positions are less than 0.3 inch from the top of the tubesheet except for SG 4 for which the 95th percentile value is 0.31. The 99th percentile BET positions SG 1 and SG 3 are less than 0.3 inch; for SGs 2 and 4, the 99th percentile positions are 0.32 inch and 0.36 inch, respectively.

Table 1 also shows the mean and maximum BET positions. In the Indian Point Unit 2 SGs, there are no tubes that exhibit a BET location greater than 0.74 inch below the TTS.

Assessment of the Impact of the Location of the BET on H*

The H* results for Indian Point Unit 2, developed using the square cell tube-to-tubesheet interaction model, have rendered a BET measurement adjustment unnecessary, as the square cell model shows a loss of contact pressure at the top of the tubesheet that is greater than the possible variation in the BET location. As can be seen in Table 2 (reproduced from Table 3-34 of Reference 1), the 95/95 H* calculation result for Indian Point Unit 2 has zero contact pressure at the critical radius for a distance of greater than 5 inches from the top of the tubesheet. As noted above, the limiting BET distance for the Model 44 F SGs at Indian Point Unit 2 is 0.74 inch below the TTS in tube R44C48 at a tubesheet radius of 55.28 inches.

Effect of BET Location on the H* Pull-out Resistance Calculations at Other than the Critical Radius

H* is defined by an integration of the contact pressure profile from the top of the tubesheet downward to determine the axial position at which the integrated resisting forces are equal to the applied pull out forces. Therefore, the rate of change (slope) of the contact pressure profile from the top of the tubesheet is a reasonable indicator of the effect on H* of a postulated TTS non-contact initial condition. If the slope of the contact pressure profile through the tubesheet from top to bottom is positive, the predicted required length of contact (i.e., H*) would decrease if the position of the BET in a tube were greater than [ ]^{a,c,e} inch below the TTS because the integrated resisting force would be greater, deeper within the tubesheet.

During an NRC Staff audit of H* on June 14 and 15, 2010, (Reference 5), the NRC requested verification that the argument for the critical radius is true for tubesheet radii for which the predicted H* value was within 1 inch of the maximum H* position. Table 2 is a reproduction of Table 3-34 of Reference 1 which provides the maximum 95/95 value of H* (18.85 inches) for Indian Point Unit 2. A value of 17.85 inches (18.85-1) is approximately 95% of the maximum value.

Figure 1 is a normalized representation of mean H* values related to tubesheet radius from Reference 6. It is judged that a similar normalized relationship would apply for the calculation of probabilistic H* values for these radii. From Figure 1, the minimum and maximum radii for the

Indian Point Unit 2 SGs are defined by the normalized radial H* profile at the 95% normalized value. The radii that exhibit an H* value 1 inch less than the maximum H* value are approximately 14 inches and 29 inches as summarized on Table 3.

Figure 2 shows the mean contact pressure profiles at the critical radius ([ ]^{a,c,e} inches) and the two adjacent evaluated radii (7.219 and 28.21 inches) for the Indian Point Unit 2 Model 44F SGs. These radii reasonably represent the tubesheet radii within which the H* value is 1 inch less than the requested H* value.

The mean contact pressure profiles at the radii considered exhibit the same characteristic increase in contact pressure with increasing depth into the tubesheet as the critical radius. The contact pressure profiles for all radii considered are similar in slope; thus it is reasonable to conclude that the profiles at the specific maximum and minimum radii at which the probabilistic H* value is predicted to be 1 inch less than the maximum value will also exhibit the same characteristic trend. For the same reason as the critical radius, because of the increasing contact pressure further into the expansion region, a position of the BET more than [ ]^{a,c,e} inch below the TTS will not result in an increase in the predicted value of H*.

For the larger TS radii, where the mean H* margin is the greatest, the slope of the contact pressure curve becomes negative over the thickness of the tubesheet from the top of the tubesheet to the bottom. In that event, a small increase in the required tube to tubesheet contact length could be expected if it were assumed that the BET is located at more than [ ]^{a,c,e} inch below the top of the tubesheet.

Figure 3 shows the mean contact pressure profiles for the Model 44F SG including two larger radii (≥34 inches). At 34 inches radius, the slope of the contact pressure profile is still positive; however, at much larger tubesheet radii, the slope of the contact pressure axial profile flattens and becomes negative from top to bottom (for example, at 48 inches radius). The margins to the calculated H* values are large at the larger radii.

Reference 3 is a prior study for other models of SGs with similar contact pressure characteristics through the tubesheet. It was concluded that, although at larger tubesheet radii the slope of the contact pressure axial profile may become negative so that the contact pressure decreases with increasing depth into the tubesheet, the net effect to increase the H* distance resulting from this is very small. At the larger radii, the mean H* radial profile falls off rapidly (see Figure 1); therefore, the available margin to the requested value of H* increases rapidly, so that the small increase in the predicted value of H* and BET location uncertainty is easily accommodated at these radii.

Summary and Conclusions

1. The margins between the inspection depth and the calculated H* values increase as the position in the bundle varies from the limiting position.
2. A variation of the BET position of a minimum of 1.0 inch is readily accommodated by the available margins between the planned inspection depth and the calculated H* values. This conclusion is true for all radii at which the predicted value of H* is within 1 inch of the maximum H* value.
3. At larger radii where a reversal of slope of the axial contact pressure profile may occur, the net increase in required H* length is negligible compared to the increase in margin at these locations.

4. A BET location of 1.0 inch below the TTS is acceptable for the implementation of H* without any adjustment in inspection depth.
5. The largest distance from the TTS to the BET in the Indian Point Unit 2 SGs is 0.74 inch.

References

1. WCAP-17828-P, "Indian Point Unit 2 H* Alternate Repair Criteria for the Tubesheet Hydraulic Expansion Region (Model 44F – 4-Loop)," January 2014.
2. EPRI 1013706, "Pressurized Water Reactor Steam Generator Examination Guidelines: Revision 7," October 2007.
3. LTR-SGMP-09-111, Rev. 1, "Acceptable Value of the Location of the Bottom of the Expansion Transition (BET) for Implementation of H*," September 2010.
4. LTR-SGMP-14-21, "Indian Point Unit 2: Position of the Bottom of the Tubesheet Expansion Transition," March 2014.
5. USNRC Memorandum, "Vogtle Electric Generating Plant- Audit of Steam Generator H* Amendment Reference Documents (TAC Nos. ME3003 and ME3004)," June 29, 2010.
6. LTR-SGMP-09-92, Rev. 1, "Tubesheet Sector Definition for H* Revised Probabilistic Analysis," November 2013.

Table 1

Summary of BET Measurements for Indian Point Unit 2

Plant	Model	SG	No.> 1.0 in.	Max (in.)	Mean (in.)	95%ile (in.)	99%ile (in.)
Indian Point Unit 2	44F	1	0	0.41	0.08	0.18	0.24
		2	0	0.45	0.16	0.26	0.32
		3	0	0.29	0.03	0.10	0.15
		4	0	0.74	0.23	0.31	0.36

Table 2

H* Calculation Including Poisson Attenuation Model 44F (Indian Point Unit 2)
(With Attenuation, MC Rank 9886)

NOP, [ ]^{a,c,e} in. Radius			
End Cap Load = [ ]^{a,c,e} pounds			
Elevation Above Bottom of TS (in)	**Distance from TTS (in)**	**P_{con} (psi)**	**Accumulated Pull Out Load (pounds)**
0.000	21.810		
2.000	19.810		
3.523	18.287		
5.442	16.368		
6.932	14.878		
10.905	10.905		
16.368	5.442		
18.287	.3523		
19.810	2.000		
21.810	0.000		
H* (inches)		18.85 from TTS (with Crevice Pressure Correction)	
Reproduction of Table 3-34 from Reference 1.			

a,c,e

Table 3
Indian Point Unit 2: Tubesheet Radii at which the H* Value is within 1 inch of the Calculated H* Value

SG Model	95/95 Calculated H* (in.)	(H*-1):H* Ratio[1]	(H*-1) Radius (in.)		Radius Evaluated (in.)	
			Min	Max	Min	Max
44F	18.85	0.95				

a,c,e

Notes: (1) The ratio is defined as the calculated (maximum) value of H* minus 1 divided by the calculated value of H*.

Figure 1
Indian Point Unit 2 Tubesheet Sector Definition

[ ] a,c,e

Figure 2
Model 44F (Indian Point Unit 2) Contact Pressure Axial Profile at Various Tubesheet Radii

a,c,e

Figure 3
Model 44F (Indian Point Unit 2) Contact Pressure Axial Profile at Larger Tubesheet Radii

a,c,e