Westinghouse Electric Company

White Paper:

Low Temperature Steam Line Break Contact Pressure and Local Tube Bore Deformation Analysis for H*

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Introduction;

Report WCAP-17071 was issued to the H* participants as the report of record for the Model F steam generators. During the continuing development of H* for the Model D5 steam generators, some questions were encountered that require resolution to facilitate the review of the reference report. This White Paper is an adjunct to WCAP-17071; however, the information in this paper will be included in the Model D5 report. Liberal reference is made to WCAP-17071; "H*: Alternate Repair Criteria for the Tubesheet Expansion Region in Steam Generators with Hydraulically Expanded Tube (Model F)."

Issue summary:

5. The Model D5 main steam line break (SLB) transient defined in the E-spec describes primary fluid temperatures in the steam generator (SG) that are 100°F, or more, colder than the Model F SG SLB transient specification.

6. Preliminary analysis of the tube-to-tubesheet (T/TS) contact pressure when a conservative static, steady-state, application of the as-specified Model D5 SLB transient conditions were used resulted in a case where the design basis accident (DBA) T/TS contact pressures apparently did not exceed the T/TS contact pressures at normal operating condition (NOP) for all depths in the tubesheet (TS).

7. The NRC had requested to be informed if a condition was found under which the DBA T/TS contact pressure did not exceed the NOP T/TS contact pressure at all depths through the TS. The NRC Technical Staff was informed of the situation on April 24, 2009.

8. Westinghouse has reviewed the contact pressure analysis and the preliminary Model D5 results. The T/TS contact pressure during DBA conditions does exceed the T/TS contact pressure during NOP when the appropriate relationship between T/TS contact pressure and tube bore eccentricity is used for the Model D5 SLB condition.

Background:

This White Paper discusses an original fit and a new fit for the relationship between the tubesheet bore eccentricity and contact pressure. Both data fits are derived from a two- dimensional structural model and both data fits are applied for the current H* analysis in the three-dimensional finite element model. For the original fit, tubesheet bore eccentricity was derived from a two-dimensional structural analysis based on higher temperature input and a 4th order polynomial fit was developed for the relationship between tubesheet bore eccentricity and contact pressure. During the continued development of H*, a separate two dimensional finite element model was developed for the express purpose of evaluating contact pressure as a function of tubesheet bore eccentricity. This model used assumed tubesheet bore eccentricities as input, independent of how the values of eccentricity are generated in the H* analysis. The range of the tubesheet tube bore eccentricities considered in the model was based on detailed finite element studies of tubesheet designs with perforations specifically modeled into the structure of the thick plate. The original fit is not appropriate for use at lower temperatures because the 4th order polynomial produces physically impossible results at those temperatures. The original fit, when applied within its supporting database, is conservative relative to the new fit at higher temperatures because it produces lower values of the integrated contact pressure.

Discussion:

The analysis process for H* for the Model D5 steam generators was reviewed to determine the reason for the observations noted above in items 1 and 2. Two key details were observed during the tubesheet bore deformation (eccentricity) calculations in the H* spreadsheet discussed in

WCAP-17071:

- The original calculated hole deformations during SLB were much less than the calculated hole deformations during NOP and FLB. The hole deformations are based on fundamental axisymmetric deformation relationships and were not derived as part of the H* program. These relationships are noted as the second and third equations in Section 6.3 of WCAP-17071-P.

- Despite the fact that the tube hole deformation during SLB was less than the tube hole deformation during NOP/FLB, the T/TS contact pressure was less for SLB than for NOP. This was an inconsistent result because the decrease in tube bore deformation is expected to result in greater T/TS contact. Further, the difference between the tube (T) and tubesheet (TS) coefficients of thermal expansion (ΔCTE) increases at lower temperatures (i.e., $CTE_{TUBE} > CTE_{TS}$) and this should also result in greater T/TS contact pressure.

Review of Reference 6-15 in WCAP 17071-P, which defines the relationship between tube bore eccentricity and contact pressure, showed that colder primary fluid conditions (less than [ ]^{a,c,e} – [ ]^{a,c,e} °F) and lower pressure conditions (less than 2250 psi) were not considered in prior analyses (dating back to 2003). The relationship between tube bore eccentricity and contact pressure is described in Section 6.3 of the Model F H* report, WCAP-17071. The data in Section 6.2.5 of the Model F H* WCAP proved that the relationship between tube bore eccentricity and contact pressure was conservative for all of the Model F operating conditions. The fit of the relationship between tubesheet bore eccentricity and contact pressure that is described in Section 6.3 on page 6-85 relies on data from finite element models that used boundary conditions representative of NOP conditions. The eccentricity and contact pressure analysis described in Section 6.3 produced a 4^{th} order polynomial fit that was specific to a range of temperature and pressure conditions that are different from the Model D5 SLB conditions. Prior Model D5 analyses included the B* approach, which, in all cases, was bounded by H*; therefore, the relative arrangement of the SLB vs. NOP contact pressures was not identified as a concern. Prior analyses were based on the use of ratios to determine the applicable tubesheet deformations from the results of 2D axisymmetric unit load cases. Evolution of the H* calculation process to the use of a 3D FEA approach now requires that a specific relationship between contact pressure and input temperatures be used when evaluating operating conditions outside of those on which the original fit was based.

Because of the observations noted above, it is not appropriate to apply the same relationship in Section 6.3 of WCAP-17071 to the analysis of the T/TS contact pressure during the Model D5 SLB condition. Therefore, it was required to develop a new relationship between tube bore eccentricity and contact pressure for the different Model D5 SLB condition. An analysis, documented in WCAP-17071, Section 7.2.2, performed to determine the variability of contact residual pressure for varying parameter inputs, showed that the Model F tubesheet properties represented the bounding case among the population of H* candidate plants with respect to reduction of contact pressure due to tubesheet bore eccentricity. A separate planar model was constructed, based on the Model F geometry, to evaluate the contact pressure for a range of tubesheet bore deformation (eccentricity). This analysis is documented in WCAP-17071, Section 6.2.5. This model was driven by assumed hole displacements to bound the actual displacement calculated in the H*analysis that result from applied pressure and thermal loads. In this manner, it was possible to construct a relationship between tubesheet bore eccentricity and tube to tubesheet contact pressure.

Figure 1 shows the bounding fit of the T/TS contact pressure described in Section 6.2.5 from the data from Table 6-18 of WCAP 17071. The tube bore eccentricity in this analysis is assumed but represents the tubesheet bore eccentricity resulting from applied pressures to the diameter of the tubesheet bore, thermal growth of the tubesheet and local effects acting to further deform the tubesheet bore. The tubesheet bore eccentricity (e), or differential tubesheet cell displacement, is the maximum distance that the major axis of the diameter of the tubesheet bore is displaced relative to the minor axis of the tubesheet bore.

Section 6.4.1 of WCAP-17071 summarizes the equations for calculating the contact pressures used to determine the value of H*. With reference to the final equation in Section 6.4.1, the final term in the numerator, ΔR_{ROT}, represents the effect of tubesheet bore eccentricity, as shown in Figure 1, on the T/TS contact pressure, P_2. A maximum value of ΔR_{ROT} results in a minimum value of P_2. Therefore, the fit in Figure 1 is bounding because it results in the least amount of contact pressure (P_2) at smaller tubesheet bore deformations (which corresponds to a longer value of H*) and zero contact pressure at the smallest tubesheet bore deformations.

The data used for the fit in Figure 1 is valid regardless of the applied temperature or pressure because the data in the finite element analysis used to develop the new relationship is based on an assumed range of worst case tube bore eccentricity values at room temperature together with a reduction in NOP primary pressure of 45% (i.e., the analysis assumes a hot tubesheet during normal operating conditions with cold tubes at low pressures). Two data points are provided on Figure 1 that demonstrate that increasing the temperature of the tube in the finite element analysis increases the T/TS contact pressure. The data from those two points show a significant increase in the T/TS contact pressure relative to the cold tube conditions for the same value of tube bore eccentricity. Similarly, an increase in the internal tube pressure would also act to increase the T/TS contact pressure. Because both the internal tube pressure and the tube temperature used in the analysis bound the lowest operating pressures and temperatures, the fit described in Figure 1 is a conservative representation of the reduction of T/TS contact pressure with respect to tube bore eccentricity. The slope of the fit is significant because the bounding fit should represent the most rapid decrease in contact pressure as a function of tubesheet bore eccentricity. Thus, the linear fit shown on Figure 1 represents the most rapid reduction in contact pressure due to tubesheet bore eccentricity as well as the lowest contact pressure as a function of tubesheet bore eccentricity.

Figure 2 shows how the bounding fit relationship is implemented in the H* contact pressure analysis discussed in Section 6.4.1 of WCAP 17071-P. Figure 2 is derived by taking the fit in Figure 1 and inverting the relationship such that the decrease in T/TS contact pressure from the maximum value at 0 inch tube bore eccentricity is predicted. Note that because the new fit relationship is linear it is valid at a wide range of temperatures and pressures. The prior data fit was a 4th order polynomial fit, which, if extrapolated significantly outside its supported data range, provided physically unrealistic results. The linear relationship is an excellent fit to the data, which accurately predicts the maximum reduction in contact pressure at the minimum value of tube bore eccentricity. This relationship should be used whenever a transient condition is defined with the primary fluid at temperatures less than [ ]^{a,c,e} °F, such as the Model D5 SLB condition. The original fit that is described in the Model F H* report is conservative for all other operating conditions at higher temperatures because it predicts lower T/TS contact pressure than the new linear fit described in Figure 2. Applying the new relationship to NOP or FLB conditions in the Model F or Model D5 SG would increase the T/TS contact pressure during the NOP and FLB conditions. Thus it is conservative to apply the original contact pressure and tubesheet bore eccentricity relationship for the Model F SGs and for the current NOP and FLB evaluation of the Model D5 SGs.

A comparison of the new data fit to the old data fit shown on page 6-85 of WCAP-17071 reveals that in the range where the tube bore eccentricities are common the new data fit predicts greater contact pressure than the original data fit. Therefore, it is not necessary to apply this relationship to the Model F H* analysis; however, the new relationship should be applied in T/TS contact pressure analyses that involve primary fluid temperatures equal to, or less than [ ]^{a,c,e} °F. The only region in the Model F TS that this new data fit could apply is in the cold leg, and the H* results in the Model F cold leg are bounded by the Model F H* results in the hot leg. A review of the Model F cold leg contact pressure data shows that with the new data fit the cold leg contact pressures would increase compared to those predicted by the original data fit. Therefore, it is not necessary to apply the new data fit for the Model F cold leg and hot leg contact pressures used in the H* analysis.

The radius dependent tubesheet stiffness adjustment is not required at internal tube pressures less than [ ]^{a,c,e} psi or primary fluid temperatures less than [ ]^{a,c,e} °F because the difference between the standard thick shell equation for the tubesheet bore and the adjusted relationship is insignificant under those conditions. No changes to the H* calculation methodology are required to accommodate the difference in eccentricity relationship.

Figure 3 shows the Model D5 tube to tubesheet contact pressure at the limiting tubesheet radius with the appropriate tubesheet bore eccentricity relationship. The original relationship is conservatively used for the NOP condition and the new relationship between tubesheet bore eccentricity and contact pressure is used for the SLB condition to accurately address the lower temperature conditions. The SLB tube to tubesheet contact pressures are determined to bound the NOP contact pressures at all elevations. Application of the resulting contact pressure distributions shows that for the limiting structural condition for H* (NOP, Low T_{avg}) the worst case mean H* is [ ]^{a,c,e} inches. This is similar to the Model F H* results; the small difference reflects the differences in the Model D5 and Model F SG tubesheet complex (i.e., tube pitch, tube diameter, support ring).

Conclusions:

6. The applicable design transient conditions for the Model F SG and the Model D5 SG during SLB are significantly different with respect to their maximum temperatures. The Model D5 SLB design transient is specified as having a maximum temperature of approximately 300°F, whereas, the limiting design transient for the Model F has a maximum temperature of approximately 420°F.

7. The existing relationship between tubesheet bore deformation and contact pressure was defined based on high temperature, high pressure conditions and is inappropriate for use at lower temperatures because it requires extrapolation far outside its supporting database. This had not been discovered previously because prior analyses were based on the use of ratios to determine the applicable tubesheet deformations from the results of 2D axisymmetric unit load cases. The original approach provided conservative values of H* but was not constrained by a desire to show that contact pressure at DBA conditions exceed the contact pressure at NOP conditions.

8. Data developed during the evolution of the H* calculation process using new finite element models, which is included in the reference report, WCAP-17071, was used to define a new relationship between contact pressure and tubesheet bore eccentricity which adequately bounds the range of eccentricities that would be expected under any temperature and pressure conditions. Therefore, this relationship is appropriate for low temperatures under either high pressure or low pressure conditions.

9. When the appropriate relationship between tubesheet tube bore eccentricity and contact pressure is used, the DBA tube-to-tubesheet contact pressures exceed the NOP contact pressure at all elevations in the tubesheet at the limiting tubesheet radius and at all other tubesheet locations for the Model D5 SGs.

10. No change to WCAP-17071 for the Model F SG is required because the original contact pressure relationship used is appropriate for the Model F conditions and provides conservative results with respect to contact pressures at the applicable temperature conditions.

a, c, e

Figure 1 Calculated T/TS Contact Pressure as a Function of Tube Bore Eccentricity Based on FEA in Section 6.2.5 of WCAP-17071

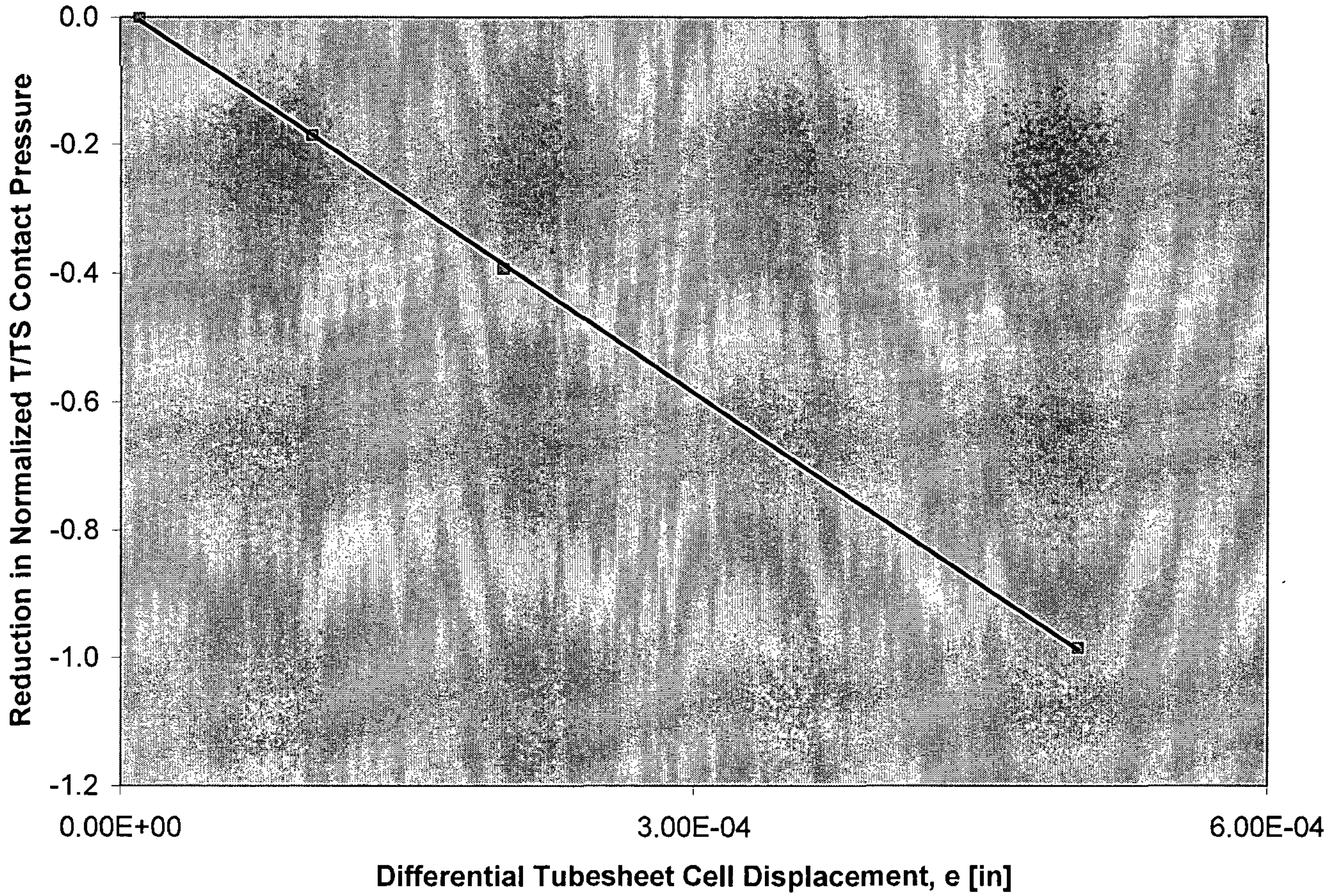

Figure 2 Reduction in T/TS Contact Pressure based on Limiting Fit from Figure 1

a, c, e

Figure 3 Model D5 T/TS Contact Pressure Results Based on Appropriate Cold Temperature Tubesheet Bore Eccentricity Relationship (BTS = TS Elevation 0.0 inch, TTS = TS Elevation 21.03 inch)

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May 13, 2009

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-SGMP-09-66 P-Attachment, "White Paper: Low Temperature Steam Line Break Contact Pressure and Local Tube Bore Deformation Analysis for H*" (Proprietary)

Reference: Letter from J. A. Gresham to Document Control Desk, LTR-NRC-09-26, dated May 13, 2005

The application for withholding is submitted by Westinghouse Electric Company LLC (Westinghouse) pursuant to the provisions of paragraph (b)(1) of Section 2.390 of the Commission's regulations. It contains commercial strategic information proprietary to Westinghouse and customarily held in confidence.

The proprietary material for which withholding is being requested is identified in the proprietary version of the subject report. In conformance with 10 CFR Section 2.390, Affidavit AW-09-2578 accompanies this application for withholding, setting forth the basis on which the identified proprietary information may be withheld from public disclosure.

Accordingly, it is respectfully requested that the subject information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.390 of the Commission's regulations.

Correspondence with respect to this application for withholding or the accompanying affidavit should reference AW-09-2578 and should be addressed to J. A. Gresham, Manager of Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P. O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

cc: A. Mendiola, NRR
R. Lobel, NRR
G. Bacuta, NRR

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared J. A. Gresham, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse) and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

J. A. Gresham

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed before me
this 13th day of May, 2009.

Sharon L. Markle

Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
Member, Pennsylvania Association of Notaries

(1) I am Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse) and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 of the Commission's regulations and in conjunction with the Westinghouse "Application for Withholding" accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) Pursuant to the provisions of paragraph (b)(4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The application of that system and the substance of that system constitute Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10 CFR Section 2.390, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked LTR-SGMP-09-66 P-Attachment, "White Paper: Low Temperature Steam Line Break Contact Pressure and Local Tube Bore Deformation Analysis for H*" (Proprietary), for submittal to the Commission, being transmitted by Westinghouse letter (LTR-NRC-09-26) and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk. The proprietary information as submitted by Westinghouse Electric Company is that associated with a discussion of the methodology for calculating tube-to-tubesheet contact pressures in hydraulically expanded tubes during a postulated steam line break for Model D5 steam generators..

This information is part of that which will enable Westinghouse to:

(a) Provide information to the NRC regarding Westinghouse proprietary H* licensing initiatives and associated activities for the Model D5 steam generators.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of the information to its customers for the purpose of meeting NRC requirements for technical/licensing documentation.

(b) Westinghouse can use this information to further enhance their technical/licensing position with their competitors.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar licensing capabilities and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended.

Further the deponent sayeth not.

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

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