VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

November 14, 2001

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

Serial No. 01-490B
NL&OS/ETS R3
Docket Nos. 50-338/339
50-280/281
License Nos. NPF-4/7
DPR-32/37

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNITS 1 AND 2
SURRY POWER STATION UNITS 1 AND 2
SUPPLEMENTAL RESPONSE TO NRC BULLETIN 2001-01 CIRCUMFERENTIAL CRACKING OF REACTOR VESSEL HEAD PENETRATION NOZZLES

On August 31, 2001, Virginia Electric and Power Company (Dominion) responded to NRC Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles." Our response provided information regarding the structural integrity of the reactor pressure vessel head penetration (VHP) nozzles and a proposed schedule with bases for inspection of those penetration nozzles. During recent telephone conference calls with Mr. John Zwolinski and other members of the NRC staff, the NRC requested supplemental information regarding our bulletin response and ongoing inspection activities. Supplemental information is being provided to: 1) establish qualification of the bare-metal visual inspection activities, and 2) update the visual inspection schedules for North Anna Unit 2 and Surry Unit 2.

Since our initial bulletin response, we have performed a plant specific analysis for each of the reactor vessel heads to support a qualified bare-metal visual inspection of the four units. As-built information for both Surry and North Anna has been obtained to demonstrate that all of the associated reactor vessel head penetrations have a sufficient leakage path to the reactor head surface to permit identification of a leaking penetration. The information to support this evaluation is included in Attachment 1.

In our initial response, we committed to perform a bare-metal visual inspection of the reactor vessel heads for both North Anna Unit 1 and Surry Unit 1 during their scheduled Fall 2001 refueling outages. A qualified bare-metal visual inspection has been completed on North Anna Unit 1 and Surry Unit 1. From our inspection results and other industry inspection results, we had intended to establish a statistical basis for determining appropriate scope and schedule for future inspection activities for North Anna Unit 2 and Surry Unit 2.

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However, based on the overall industry inspection results to date, Dominion has determined the use of a statistical basis to determine inspection scope and schedule is impractical. Accordingly, a qualified bare-metal visual inspection of the reactor vessel head penetrations for North Anna Unit 2 was recently completed. In addition, Dominion intends to commence a qualified bare-metal visual inspection of the reactor vessel head penetrations for Surry Unit 2 prior to December 31, 2001.

If you have any further questions or require additional information, please contact us.

Very truly yours,

Leslie N. Hartz
Vice President – Nuclear Engineering

Commitments made in this letter:

Commence a qualified bare-metal visual inspection of the reactor vessel head penetrations for Surry Unit 2 prior to December 31, 2001.

Attachment: Plant Specific Reactor Vessel Head Analysis

cc: U.S. Nuclear Regulatory Commission
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SN: 01-490B
Docket Nos.: 50-338/339
50-280/281
Subject: Supp. Response to NRC Bulletin 2001-01

COMMONWEALTH OF VIRGINIA)
)
COUNTY OF HENRICO)

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Leslie N. Hartz, who is Vice President - Nuclear Engineering, of Virginia Electric and Power Company. She has affirmed before me that she is duly authorized to execute and file the foregoing document in behalf of that Company, and that the statements in the document are true to the best of her knowledge and belief.

Acknowledged before me this 14th day of November, 2001.

My Commission Expires: March 31, 2004.

Maggie McClure
Notary Public

(SEAL)

Attachment 1

Evaluation to Support Qualified Visual Inspections of the Reactor Vessel Heads

Virginia Electric and Power Company
(Dominion)
North Anna Units 1 and 2
Surry Units 1 and 2

Surry and North Anna Reactor Vessel Head Penetration Plant Specific Analyses

Analyses have been performed to establish that through-wall cracking of a reactor vessel CRDM head penetration above the attachment weld or through the weld itself, would result in leakage which would be detectable by visual examination on the bare surface of the outside diameter (OD) of the head. The attached excerpts from Westinghouse letters, VPA-01-010 for Surry Power Station and VRA-01-079 for North Anna Power Station, indicate a 100% probability that at normal operating conditions the designed interference fit of the head penetrations in the head will actually result in a gap which would allow leakage. As discussed in those letters and the accompanying analyses, the reactor vessel head to penetration connections for both North Anna and Surry Power Station were designed with a diametrical interference fit of between 0.01-mm (0.0004 inch) and 0.03-mm (0.0012 inch). The "Reactor Vessel Final Stress Report(s)," (Document No. 30660-1130, Rev. 1 for North Anna and Document No. 30678-1130, Rev. 1 for Surry) prepared by The Rotterdam Dockyard Company document the same range of interference fits by design, as do fabrication drawings reviewed in conjunction with this effort. The Rotterdam Stress Reports, based on finite element analyses and normal operating conditions, demonstrate that even for the maximum designed interference fit, operating conditions produce differential dilation of the penetration tubes and the holes in the head that result in diametrical gaps that would allow leakage. Furthermore, the calculations performed by Westinghouse in conjunction with the recent effort to demonstrate the likelihood of leakage, show that for the design interference fit, operating conditions produce a gap of approximately 0.0013 inch that would allow leakage between the penetrations and the head.

Research of fabrication records for the Surry and North Anna reactor vessel heads recovered information relative to dimensions of the penetration tubes and the holes in the vessel heads. For both North Anna units, the as-built dimensions of the reactor vessel head penetration holes were located but as-built measurements of the penetration tube diameters were not located. For the Surry units, the as-built dimensions were located for the reactor vessel holes and penetration tubes. However, on both the North Anna and Surry units' closure head assembly drawings, an instruction specified that each penetration tube be custom ground for its mating penetration hole to achieve the design interference fit of 0.01 mm to 0.03 mm. This specification forms the basis of the Westinghouse analyses. In addition, the previously referenced reactor vessel head stress reports state, "The dimension reports of the C.R.D.-housing and the holes in the vessel wall show a shrink fit equal to 0.03 mm over the diameter." Furthermore, there is anecdotal evidence that the fabricating organizations for reactor vessel heads were sensitive to the need to closely control the dimensions of the mating parts of the shrink fit because of concerns with the parts becoming stuck before complete insertion if dimensional tolerances were not adhered to closely.

Given the above information indicating that the design and fabrication requirements included stringent limitation on the shrink fit and lack of any evidence that the existing penetrations do not conform to design and fabrication requirements, the Westinghouse evaluation assumed that each penetration had the worst case interference fit, as did the

Rotterdam Stress Reports. Both of the attached analyses have concluded that at normal operating conditions the interference fits will relax to create gaps of approximately 0.0013 inches. Given these values, the maximum design interference of 0.0012 inches could be 2 times as great and there would still be a high probability of leakage occurring if there were through-wall cracks in or above the attachment weld.

Based on the above discussion, because through-wall cracking in the reactor vessel head penetrations or the attachment weld has a 100% probability of producing discernable leakage, the visual examinations of the heads is considered "qualified" as discussed in NRC Bulletin 2001-01.

Evaluation of the Detectability of Leakage in North Anna Units 1 and 2 Reactor Vessel Heads

1.0 INTRODUCTION

The purpose of this Attachment is to perform an evaluation of the probability for detectable leakage on the North Anna Units 1 and 2 reactor vessel heads. It provides an assessment of the validity of the visual inspection to be used as a tool to detect the potential primary water corrosion cracking of the reactor vessel head CRDM nozzles and attachment welds. This evaluation is based on the possible interference fits between the head hole and CRDM nozzle at the as-installed condition and during the normal plant operation.

The following approach has been adopted for this evaluation. An initial review was performed of shop data available for North Anna heads and Control Rod Housings, manufactured by the Rotterdam Dockyard Company. A total of 130 head hole measurements were reviewed and tabulated. No actual diameter measurements were available for the nozzles. However, a note on a Control Rod Housing fabrication drawing defined that each nozzle is to be matched to a penetration and ground to a diameter such that the design interference fit is maintained. Therefore, a conservative maximum interference fit was assumed for all penetrations.

During the next stage of the analysis, the effects of pressure and temperature at normal operating conditions on the as-installed interference fit were evaluated. [(1)] The calculations were made for the center penetration of the head using classical formulations. This location was used since it is believed to be the worst case condition because of its symmetry. Other locations on the head (particularly toward the periphery where the penetrations are non-radial and where the flange affects the stress field around the penetration) would favor the formation of leakage gaps due to ovalization.

Calculated changes to the as-installed interference fit, combined with assumed maximum interference fit at the as-installed condition, allowed the determination of the interference for CRDM penetrations at normal operating conditions. At penetrations where there is a "zero" interference or a gap at normal operating conditions, it is reasonable to assume that leakage onto the head would occur for a through-wall crack in the CRDM nozzle or in the attachment weld and that a bare-metal, visual inspection would be able to detect that leakage.

This analytical work is performed in accordance with the requirements of the Westinghouse Electric Company CE Nuclear Power LLC Quality Procedure Manual QPM-101 (Reference 6.1)

[(1)] The calculations used material properties from ASME B&PV Code 1989 Edition, for elastic modulus, coefficient of thermal expansion and Poisson's ratio.

2.0 ASSUMPTIONS

The following assumptions were used in this analysis:

a) the center CRDM penetration on the head is assumed to be the worst case condition because of its symmetry. Other locations, particularly toward the periphery of the head, are more favorable to the formation of leakage gaps due to ovalization;
b) the material properties used in this analysis are taken from ASME B&PV Code 1989 Edition (No Addenda);
c) ambient temperature is 70°F, and the normal operation temperature is assumed at 600°F.

All other assumptions are stated in the body of the analysis.

3.0 INTERFERENCE FITS AT THE AS-INSTALLED CONDITION

A review of shop data available for both North Anna fabricated heads and nozzles was performed. A total of 130 head hole measurements (65 per unit) were reviewed and tabulated (References 6.4 and 6.5). Average holes diameter was calculated as 4.002 inch for Unit 1 and 4.0004 inch for Unit 2.

No actual diameter measurements were available for the nozzles on the Control Rod Housing fabrication drawing (Reference 6.6). However, a note on a drawing defined that each nozzle is to be matched to a penetration and ground to a diameter such that diametrical interference fit between 0.01 mm (0.4 mils) and 0.03 mm (1.2 mils) is maintained.

Therefore, a conservative maximum interference fit of 1.2 mils is assumed for all penetrations.

4.0 INTERFERENCE FIT CHANGE AT NORMAL OPERATION

The effects of pressure and temperature at normal operating conditions on the as-installed interference fit are evaluated in this section.

4.1 Effect of Pressure

CRDM nozzle is considered as a thick-walled cylinder under uniform internal pressure, acting in all directions. Nozzle radial expansion is calculated with the use of Table 32, case 1b of Reference 6.2.

$$\Delta a = \frac{qa}{E}\frac{b^2(2-\mu)}{a^2-b^2} = 0.23 \times 10^{-3} \text{ inch} = 0.23 \text{ mils}$$

where

q = 2,250 psi – operating pressure (Reference 6.7)
a = 102.2 mm/2 = 2.012 inch – nominal outside radius of the nozzle (Reference 6.8.4)

b = 69.8 mm/2 = 1.374 inch – nominal inside radius of the nozzle (Reference 6.8.4)
μ = 0.3 – Poisson's ratio (Reference 6.3)
E = 2.87E^7 psi – modulus of elasticity at 600°F (Reference 6.3)

Radial expansion of the hole in the reactor vessel head is calculated with the use of formula for deformation in thin-walled sphere, according to Table 28, case 3a of Reference 6.2.

$$\Delta R = \frac{qR_m^{\ 2}(1-\mu^*)\sin\theta}{2E^*t} = 1.47 \times 10^{-3} \text{ inch} = 1.47 \text{ mils}$$

where

q = 2,250 psi – operating pressure (Reference 6.7)
R = 101.6 mm/2 = 2.00 inch – nominal radius of the hole (Reference 6.8.2)
R_m = (2009 + 4 + 160/2) mm = 82.4 inch – mean radius of the vessel head (References 6.8.1 and 6.8.3)
t = 160 mm = 6.3 inch – thickness of the vessel head (Reference 6.8.3)
sinθ = R/R_m = 2/82.4 = 0.0243
μ*, E* – Poisson's ratio and modulus of elasticity of the perforated reactor vessel head at 600°F.

For the material of the vessel head, the values of μ and E at 600°F are equal 0.3 and 2.64E^7 psi, correspondingly (Reference 6.3). However, in order to modify these values for the presence of many holes in the head, the methodology of analysis of circular perforated area is employed. According to Article A-8000 of Reference 6.3, effective Poisson's ratio and modulus of elasticity for perforated plate, μ* and E*, are calculated as a function of Ligament Efficiency, (h/p).

Ligament Efficiency for square penetration pattern can be calculated in accordance to Reference 6.9:

$$\frac{h}{p} = \frac{\sqrt{(a^2+a^2)}-2R}{\sqrt{(a^2+a^2)}} = 0.666$$

h – minimum ligament width
p – pitch of hole pattern

where, from References 6.8.2 and 6.8.4
a = 215.04 mm = 8.466 in – minimum distance between the center of the holes
R = 2.00 in – nominal radius of the hole

Using the value of 0.666 and Figure A-8131-1 of Reference 6.3, the effective Poisson's ratio and modulus of elasticity of the reactor vessel head equal:
μ* = 0.29μ = 0.087
E* = 0.69E = 1.822E^7 psi.

4.2 *Effect of Temperature*

The differential thermal expansion between CRDM nozzle and reactor vessel head changes the as-installed interference fit. This change equals the difference between interference fit at normal operating conditions (IF_T) and the as-installed interference fit (IF_A) at ambient temperature. According to Reference 6.6, maximum interference fit between the CRDM nozzle and reactor vessel head hole equals 0.03 mm (1.2 mils).

Therefore:

$$\Delta IF_T = IF_T - IF_A = (d_T - D_T) - (d_A - D_A) = (d_T - D_T) - 1.2 \text{ mils}$$

where

D_A and d_A – diameter of the reactor vessel head hole and the nozzle at ambient temperature, correspondingly
D_T and d_T – diameter of the reactor vessel head hole and the nozzle at normal operating temperature, correspondingly

D_T and d_T may be evaluated with the use of standard equations:

$$D_T = D_A + D_A \alpha_h \Delta T$$
$$d_T = d_A + d_A \alpha_n \Delta T$$

where

$D_A = 4.00$ inch (Reference 6.8.2)
$d_A = 4.00 + 0.0012 = 4.0012$ inch (Reference 6.6)
$\alpha_h = 7.83E\text{-}06$ in./in./°F – mean CTE for material of the vessel head, A-533 (Reference 6.3)
$\alpha_n = 7.82E\text{-}06$ in./in./°F – mean CTE for material of the nozzle, SB-167 (Reference 6.3)
$\Delta T = T_{NOP} - T_{amb.} = 600 - 70 = 530°F$

Therefore, using equations and data above, the change in interference fit between the CRDM nozzle and reactor vessel head hole is calculated as follows:

$$D_T = D_A + D_A \alpha_h \Delta T = 4.0166 \text{ inch}$$
$$d_T = d_A + d_A \alpha_n \Delta T = 4.01778 \text{ inch}$$
$$\Delta IF_T = (d_T - D_T) - 1.2 \text{ mils} = -0.02 \text{ mils}$$

Note: The values of mean CTE used in this analysis are taken from ASME B&PV Code 1989 Edition. The ASME B&PV Code of the year close to the date of manufacturing of the North Anna plants has different mean CTE values that tend to increase the interference fit at normal operating conditions.

4.3 *Resulting Change in Interference Fit*

Resulting reduction in the diametrical interference fit between CRDM nozzle and reactor vessel head hole at normal operating conditions may be calculated as follows:

$\Delta IF_{NOP} = 2\Delta R$ (Section 4.1) - $2\Delta a$ (Section 4.1) – ΔIF_T (Section 4.2)

$\Delta IF_{NOP} = 2.94 - 0.46 - (-0.02) = 2.50$ mils

5.0 CONCLUSION

The effects of pressure and temperature at normal operating conditions result in reduction on the as-installed interference fit. The interference fit at normal operating conditions will be reduced by 2.50 mils. That means that if the head/nozzle penetrations were initially assembled with the interference fit more then 2.50 mils, they would continue to keep the interference at normal operating conditions. However, as shown in Section 3.0, the maximum as-installed interference fit at all penetrations is 1.2 mils maximum. Thus, all head/nozzle assemblies will tend to have a gap at normal operating conditions and would be expected to allow leakage onto the head from a through-wall crack in the CRDM nozzle or in the attachment weld, should such crack occurs.

Therefore, it can be concluded that there is a 100% probability that an external visual inspection will identify leakage from CRDM.

6.0 REFERENCES

6.1 Westinghouse Electric Company CE Nuclear Power LLC Quality Procedures Manual QPM-101, Revision 05.

6.2 "Roark's Formulas for Stress and Strain," Warren C. Young, Sixth Edition, 1989, McGraw-Hill.

6.3 American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Sections II and III, 1989 Edition.

6.4 North Anna Unit #1 Manufacturing Data for the Vessel Closure Head Penetrations, Drawing No. 5655D14, sheets 8 and 9.

6.5 North Anna Unit #2 Manufacturing Data for the Vessel Closure Head Penetrations, Drawing No. 5655D15, sheets 8 and 9.

6.6 DE Rotterdamsche Droogdok MU Drawing No. 30660-1103, Rev. D, "157" PWR Vessel "Westinghouse", Closure Head Assembly, CRD Housing Assembly".

6.7 North Anna Units 1 & 2 (VRA/VGB): Approval of Category IVP PCWG Parameters to Support Tavg Coastdown Efforts, PCWG-2539, dated 04/2000.

6.8 DE Rotterdamsche Droogdok MU Drawing No.

1. 30678-1184, Rev. A, "157" PWR Vessel "Westinghouse", Closure Head Sub-Assembly, Final Machining"
2. 30660-1154, Rev. A, "157" PWR Vessel "Westinghouse", Closure Head Sub-Assembly, Drilling of Adapter Holes and Stud Holes"
3. 30660-1080, Rev. F, "157" PWR Vessel "Westinghouse", General Arrangement"
4. 30660-1099, Rev. F, "157" PWR Vessel "Westinghouse", Control Rod Mechanism Housing"

6.9 Paper No. 72-PVP-9, "Effective Elastic Constants for the Bending of Thin Perforated Plates with Triangular and Square Penetration Patterns", Pressure Vessel and Piping Division of the ASME Headquarters, September 1972

Evaluation of The Detectability of Leakage in Surry Units 1 and 2 Reactor Vessel Heads

1.0 INTRODUCTION

The purpose of this Attachment is to perform an evaluation of the probability for detectable leakage on the Surry Units 1 and 2 reactor vessel heads. It provides an assessment of the validity of the visual inspection to be used as a tool to detect the potential primary water corrosion cracking of the reactor vessel head CRDM nozzles and attachment welds. This evaluation is based on the possible interference fits between the head hole and CRDM nozzle at the as-installed condition and during the normal plant operation.

The following approach has been adopted for this evaluation. An initial review was performed of shop data available for Surry heads and Control Rod Housings, manufactured by the DE Rotterdam Dockyard Company. A total of 130 head hole and nozzle outside diameter measurements were reviewed and tabulated. However, the following evaluation was based on a note on a Closure Head Assembly fabrication drawing which defined that each nozzle is to be matched to a penetration and ground to a diameter such that the design interference fit is maintained. Therefore, a conservative maximum interference fit was assumed for all penetrations.

During the next stage of the analysis, the effects of pressure and temperature at normal operating conditions on the as-installed interference fit were evaluated. [1] The calculations were made for the center penetration of the head using classical formulations. This location was used since it is believed be the worst case condition because of its symmetry. Other locations on the head (particularly toward the periphery where the penetrations are non-radial and where the flange affects the stress field around the penetration) would favor the formation of leakage gaps due to ovalization.

Calculated changes to the as-installed interference fit, combined with assumed maximum interference fit at the as-installed condition, allowed the determination of the interference for CRDM penetrations at normal operating conditions. At penetrations where there is a "zero" interference or a gap at normal operating conditions, it is reasonable to assume that leakage onto the head would occur for a through-wall crack in the CRDM nozzle or in the attachment weld and that a bare metal, visual inspection would be able to detect that leakage.

This analytical work is performed in accordance with the requirements of the Westinghouse Electric Company CE Nuclear Power LLC Quality Procedure Manual QPM-101 (Reference 6.1)

[1] The calculations used material properties from ASME B&PV Code 1989 Edition, for elastic modulus, coefficient of thermal expansion and Poisson's ratio.

2.0 ASSUMPTIONS

The following assumptions were used in this analysis:

a) the center CRDM penetration on the head is assumed to be the worst case condition because of its symmetry. Other locations, particularly toward the periphery of the head, are more favorable to the formation of leakage gaps due to ovalization;
b) the material properties used in this analysis are taken from ASME B&PV Code 1989 Edition (No Addenda);
c) ambient temperature is 70°F, and the normal operation temperature is assumed at 600°F.

All other assumptions are stated in the body of the analysis.

3.0 INTERFERENCE FITS AT THE AS-INSTALLED CONDITION

A review of shop data available for both Surry fabricated heads and nozzles was performed. A total of 130 head hole and nozzle outside diameter measurements (65 per unit) were reviewed and tabulated (References 6.4 and 6.5). Average holes diameter was calculated as 4.0008 inch for Unit 1 and 4.0010 inch for Unit 2, while average nozzle diameter was calculated as 4.0027 inch for Unit 1 and 4.0022 inch for Unit 2.

While actual diameter measurements presented above produce an average interference fit of 1.9 mils for Unit 1 and 1.2 mils for Unit 2, a note on a Closure Head Assembly / CRD Housing Assembly fabrication drawing (Reference 6.6) defined that each nozzle is to be matched to a penetration and ground to a diameter such that diametrical interference fit between 0.01 mm (0.4 mils) and 0.03 mm (1.2 mils) is maintained.

Therefore, a conservative maximum interference fit of 1.2 mils is assumed for all penetrations.

4.0 INTERFERENCE FIT CHANGE AT NORMAL OPERATION

The effects of pressure and temperature at normal operating conditions on the as-installed interference fit are evaluated in this section.

4.1 Effect of Pressure

CRDM nozzle is considered as a thick-walled cylinder under uniform internal pressure, acting in all directions. Nozzle radial expansion is calculated with the use of Table 32, case 1b of Reference 6.2.

$$\Delta a = \frac{qa}{E}\frac{b^2(2-\mu)}{a^2-b^2} = 0.23 \times 10^{-3} \text{ inch} = 0.23 \text{ mils}$$

where

q = 2,250 psi – operating pressure (Reference 6.7)
a = 102.2 mm/2 = 2.012 inch – nominal outside radius of the nozzle (References 6.8.5 and 6.8.6)
b = 69.8 mm/2 = 1.374 inch – nominal inside radius of the nozzle (References 6.8.5 and 6.8.6)

μ = 0.3 – Poisson's ratio (Reference 6.3)
E = 2.87E^7 psi – modulus of elasticity at 600°F (Reference 6.3)

Radial expansion of the hole in the reactor vessel head is calculated with the use of formula for deformation in thin-walled sphere, according to Table 28, case 3a of Reference 6.2.

$$\Delta R = \frac{qR_m^{\ 2}(1-\mu^*)\sin\theta}{2E^*t} = 1.5 \times 10^{-3} \text{ inch} = 1.5 \text{ mils}$$

where

q = 2,250 psi – operating pressure (Reference 6.7)
R = 101.6 mm/2 = 2.00 inch – nominal radius of the hole (References 6.8.1 and 6.8.2)
R_m = (2009 + 4 + 157.2/2) mm = 82.35 inch – mean radius of the vessel head (References 6.8.1, 6.8.2, 6.8.3 and 6.8.4)
t = 157.2 mm = 6.189 inch – thickness of the vessel head (References 6.8.3 and 6.8.4)
$\sin\theta = R/R_m$ = 2/82.35 = 0.0243
μ^*, E^* – Poisson's ratio and modulus of elasticity of the perforated reactor vessel head at 600°F.

For the material of the vessel head, the values of μ and E at 600°F are equal 0.3 and 2.64E^7 psi, correspondingly (Reference 6.3). However, in order to modify these values for the presence of many holes in the head, the methodology of analysis of circular perforated area is employed. According to Article A-8000 of Reference 6.3, effective Poisson's ratio and modulus of elasticity for perforated plate, μ^* and E^*, are calculated as a function of Ligament Efficiency, (h/p).

Ligament Efficiency for square penetration pattern can be calculated in accordance to Reference 6.9:

$$\frac{h}{p} = \frac{\sqrt{(a^2+a^2)} - 2R}{\sqrt{(a^2+a^2)}} = 0.666$$

h – minimum ligament width
p – pitch of hole pattern

where, from References 6.8.1 and 6.8.2
a = 215.04 mm = 8.466 in – minimum distance between the center of the holes
R = 2.00 in – nominal radius of the hole

Using the value of 0.666 and Figure A-8131-1 of Reference 6.3, the effective Poisson's ratio and modulus of elasticity of the reactor vessel head equal:

$\mu^* = 0.29\mu = 0.087$
$E^* = 0.69E$ = 1.822E^7 psi.

4.2 *Effect of Temperature*

The differential thermal expansion between CRDM nozzle and reactor vessel head changes the as-installed interference fit. This change equals the difference between interference fit at normal operating conditions (IF_T) and the as-installed interference fit (IF_A) at ambient temperature. According to Reference 6.6, maximum interference fit between the CRDM nozzle and reactor vessel head hole equals 0.03 mm (1.2 mils).

Therefore:

$$\Delta IF_T = IF_T - IF_A = (d_T - D_T) - (d_A - D_A) = (d_T - D_T) - 1.2 \text{ mils}$$

where

D_A and d_A – diameter of the reactor vessel head hole and the nozzle at ambient temperature, correspondingly
D_T and d_T – diameter of the reactor vessel head hole and the nozzle at normal operating temperature, correspondingly

D_T and d_T may be evaluated with the use of standard equations:

$$D_T = D_A + D_A \alpha_h \Delta T$$
$$d_T = d_A + d_A \alpha_n \Delta T$$

where

D_A = 4.00 inch (References 6.8.1 and 6.8.2)
d_A = 4.00 + 0.0012 = 4.0012 inch (Reference 6.6)
α_h = 7.83E-06 in./in./°F – mean CTE for material of the vessel head, A-533 (Reference 6.3)
α_n = 7.82E-06 in./in./°F – mean CTE for material of the nozzle, SB-167 (Reference 6.3)
$\Delta T = T_{NOP} - T_{amb.} = 600 - 70 = 530°F$

Therefore, using equations and data above, the change in interference fit between the CRDM nozzle and reactor vessel head hole is calculated as follows:

$$D_T = D_A + D_A \alpha_h \Delta T = 4.0166 \text{ inch}$$
$$d_T = d_A + d_A \alpha_n \Delta T = 4.01778 \text{ inch}$$
$$\Delta IF_T = (d_T - D_T) - 1.2 \text{ mils} = -0.02 \text{ mils}$$

Note: The values of mean CTE used in this analysis are taken from ASME B&PV Code 1989 Edition. The ASME B&PV Code of the year close to the date of manufacturing of the Surry plants has different mean CTE values that tend to increase the interference fit at normal operating conditions.

4.3 *Resulting Change in Interference Fit*

Resulting reduction in the diametrical interference fit between CRDM nozzle and reactor vessel head hole at normal operating conditions may be calculated as follows:

$$\Delta IF_{NOP} = 2\Delta R \text{ (Section 4.1)} - 2\Delta a \text{ (Section 4.1)} - \Delta IF_T \text{ (Section 4.2)}$$

$$\Delta IF_{NOP} = 3.00 - 0.46 - (-0.02) = 2.56 \text{ mils}$$

5.0 CONCLUSION

The effects of pressure and temperature at normal operating conditions result in reduction on the as-installed interference fit. The interference fit at normal operating conditions will be reduced by 2.56 mils. That means that if the head/nozzle penetrations were initially assembled with the interference fit more then 2.56 mils, they would continue to keep the interference at normal operating conditions. However, as shown in Section 3.0, the maximum as-installed interference fit at all penetrations is 1.2 mils maximum. Thus, all head/nozzle assemblies will tend to have a gap at normal operating conditions and would be expected to allow leakage onto the head from a through-wall crack in the CRDM nozzle or in the attachment weld, should such crack occurs.

Therefore, it can be concluded that there is a 100% probability that an external visual inspection will identify leakage from CRDM.

6.0 REFERENCES

6.1 Westinghouse Electric Company CE Nuclear Power LLC Quality Procedures Manual QPM-101, Revision 05.

6.2 "Roark's Formulas for Stress and Strain," Warren C. Young, Sixth Edition, 1989, McGraw-Hill.

6.3 American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Sections II and III, 1989 Edition.

6.4 Surry Unit #1 Manufacturing Data; Westinghouse Drawing No.
1. 500B893, "VPA As Built Coordinate Location of Vessel Closure Head Penetrations As per Figure No. 8"
2. 500B895, "VPA Reactor Vessel – As Built Drawings – Control Rod Housing Measurements"

6.5 Surry Unit #2 Manufacturing Data; Westinghouse Drawing No.
1. 500B897, "VIR As Built Coordinate Location of Vessel Closure Head Penetrations As per Figure No. 8"
2. 500B896, "VIR Reactor Vessel – As Built Drawings – Control Rod Housing Measurements"

6.6 DE Rotterdamsche Droogdok MU Drawing No.
1. 30678-1185, Rev. A, "157" PWR Vessel "Westinghouse", Closure Head Assembly, CRD Housing Assembly"
2. 30679-1202, Rev. A, "157" PWR Vessel "Westinghouse", Closure Head Assembly, CRD Housing Assembly"

6.7 Surry Units 1 & 2 (VPA/VIR): Power Capability Parameters, Issue No.: PCWG/VPA/87-2, dated 03/1987.

6.8 DE Rotterdamsche Droogdok MU Drawing No.
1. 30678-1184, Rev. A, "157" PWR Vessel "Westinghouse", Closure Head Sub-Assembly, Drilling of Adapter Holes and Stud Holes and Final Machining"
2. 30679-1201, Rev. A, "157" PWR Vessel "Westinghouse", Closure Head Sub-Assembly, Drilling of Adapter Holes and Stud Holes and Final Machining"
3. 30678-1186, Rev. C, "157" PWR Vessel "Westinghouse", General Arrangement"
4. 30679-1200, Rev. D, "157" PWR Vessel "Westinghouse", General Arrangement"
5. 30678-1188, Rev. C, "157" PWR Vessel "Westinghouse", Control Rod Mechanism Housing"
6. 30679-1216, Rev. B, "157" PWR Vessel "Westinghouse", Control Rod Mechanism Housing"

6.9 Paper No. 72-PVP-9, "Effective Elastic Constants for the Bending of Thin Perforated Plates with Triangular and Square Penetration Patterns", Pressure Vessel and Piping Division of the ASME Headquarters, September 1972.