ENCLOSURE 2

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MONTICELLO SHROUD SUPPORT STRUCTURE FLAW EVALUATION REVIEW AND SUPPORT PLATE WELD INSPECTION RECOMMENDATIONS

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Table of Contents

List of Tables

List of Figures

1.0 BACKGROUND

Xcel Energy has inspected the Monticello Nuclear Generating Plant (MNGP) core shroud support assembly components over the past 3 refueling outages. The core shroud support assembly includes the shroud support plate, connected to the shroud and the reactor vessel by the H8 and H9 welds, and fourteen shroud support legs oriented circumferentially around the base of the shroud. All of the shroud support legs were initially inspected in 2000 following one reported indication identified in the H10 weld of one leg. The initial inspection performed in 2009 was a required repeat inspection on the single reportable indication identified in 2000. Additional reportable indications were observed on other shroud support legs, at the H10 weld location, in 2009.

Reportable indications were first observed on the underside of the shroud support plate, at the H8 and H9 weld locations, in 2011 while in the process of performing successive examinations per IWB-2420(b) on the support leg H10 welds. Figure 1 shows the general configuration of the shroud support structure welds of interest. Originally, the indications in the H8 and H9 welds were thought to be potentially confined to the oxide scale, or "crud" layer, however, they were conservatively reported and evaluated as relevant indications. A follow-up examination on selected locations of the H8 and H9 welds was performed in 2013 to confirm or discount the relevancy of the reported 2011 indications subsequent to removing the oxide layer on the underside of the welds using specialized hydrolazing tools. The results of the 2013 H8 and H9 weld inspections confirmed that the indications reported in 2011 were relevant and located in the weld material.

Structural Integrity Associates, Inc. (SI) has performed four calculations in the past 3 years pertaining to the acceptance of flaws in the shroud support structure [1, 2, 3, 4]. These calculations address cracking in either the shroud support leg welds or shroud support plate welds and utilize various evaluation methods and assumptions for postulated cracking. SI demonstrated that sufficient structural margin would remain in the core shroud support structure to justify continued operation for at least one additional operating cycle in each flaw evaluation.

Xcel Energy intends to continue to inspect the MNGP shroud support components in future outages as required by IWB-2420(b). However, since 100% top side and bottom side inspection coverage of the H8 and H9 core shroud welds is not possible due to inaccessibility and interferences inherent to the RPV internal design, Xcel Energy desires to determine if a reduced inspection coverage can be justified. Xcel Energy has contracted SI to review the previous inspections and evaluations to determine a justifiable inspection coverage for the successive inspections required by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section XI, IWB-2400 [5], understanding that *all* areas containing flaws or relevant conditions cannot be practically examined as required by IWB-2420(b).

2.0 OBJECTIVES

The objectives of this evaluation are to:

1. Consolidate the results of previous flaw evaluations performed for the MNGP core shroud support structure, and
2. Determine a justifiable reduced inspection coverage for the core support plate horizontal welds H8 and H9, due to inability to examine all areas containing flaws or relevant conditions per IWB-2420(b).

3.0 TECHNICAL APPROACH

The following approach is used in this evaluation.

1. The recent inspection history of the core shroud support structure is reviewed to provide information regarding the discovery and subsequent examination of reportable indications.
2. The previous engineering evaluations are reviewed to determine the structural integrity of the shroud support components and to identify conservatisms in each analysis.
3. Water chemistry in the lower plenum is evaluated to determine if the lower plenum is considered mitigated, and to justify appropriate crack growth rates.
4. Crack growth is addressed considering applied loads, reactor environment, and material susceptibility to determine if the previous structural evaluations adequately considered crack growth due to stress corrosion cracking and fatigue.
5. Inspection recommendations are provided which ensure that the structural integrity of the shroud support structure is maintained and the intent of ASME Section XI, IWB-2400 is fulfilled.

4.0 INSPECTION HISTORY

Xcel Energy has inspected the MNGP core support structure using remote visual examination methods. To perform these examinations Xcel Energy lowered cameras into the lower plenum area of the reactor vessel through the inlet nozzle of the jet pumps to perform inspections of the shroud support legs and the underside of the H8 and H9 shroud support plate. Since the cameras are lowered through a jet pump, inspection coverage is limited to the areas directly adjacent to the jet pump. Top side access of the H8 and H9 welds is more readily available in the regions between the jet pumps. Figure 2 provides an illustration of potential shroud support plate inspection locations.

Xcel Energy inspected all shroud support legs during the 2000 refueling outage (RFO). This inspection identified a single relevant indication in a single shroud support leg H10 weld at 210° [6].

Additional relevant indications were observed in repeat inspections of the H10 welds during RFO24 in 2009. This inspection identified the indication previously reported in 2000 as well as additional relevant indications in several other shroud support legs.

During RFO25 in 2011, Xcel Energy used higher resolution cameras to inspect the shroud support leg H10 welds that contained indications identified in RFO24. This inspection identified the indications previously reported in 2000 and 2009 as well as additional relevant indications in other shroud support legs, and a total

of 13 of the 14 H10 welds were identified to contain relevant indications. In the course of inspecting the H10 welds, indications were identified in the shroud support plate H8 and H9 welds [6]. Xcel Energy made unsuccessful attempts to remove the crud layer covering the H8 and H9 welds in order to access the base material and determine if the reportable indications were confined to the surface oxide layer or penetrated into the H8 and H9 weld material. All locations on the underside of the H8 and H9 welds that were inspected contained indications. Enhanced visual (EVT-1) inspections of approximately 17% of the topside of the support plate were also performed and no relevant indications were identified on the topside of the H8 and H9 welds. Additionally, limited ultrasonic (UT) inspections were performed from the outside of the reactor pressure vessel (RPV) in the N1B nozzle window. Insulation was removed to provide 72" of lateral access. The intent of the axial scan was to identify any circumferential cracking in the RPV base material adjacent to the H9 weld. No indications were observed to extend into the low alloy steel RPV [6].

Special tooling designed to provide more effective cleaning of the H8 and H9 welds was successfully used to remove the crud layer during RFO26 in 2013 on select, limited locations that had indications representative of the balance of the welds' undersides. This cleaning allowed Xcel Energy to confirm that the H8 and H9 indications were relevant and were present in the H8 and H9 weld material. One additional relevant indication was also identified in a H10 weld. Currently, all 14 of the shroud support leg H10 welds contain relevant indications [7]. Topside EVT-1 inspections were completed in all accessible regions of the support plate and no relevant indications were identified. Inspection coverage on the topside of the welds was approximately 32% of the H8 weld and 35% of the H9 weld. Additionally, limited UT inspections were performed from the outside of the reactor pressure vessel (RPV) in the N1A nozzle window. Insulation was removed to provide 57.5" of lateral access. The intent of the axial scan was to identify any circumferential cracking in the RPV base material adjacent to the H9 weld. No indications were observed to extend into the low alloy steel RPV [7].

Review of previous inspection video from 2000 revealed that many of the H10 weld indications were present but were dispositioned as non-relevant [6]. This observation supports the position that the indications observed in the additional H10 welds since 2000 were likely the result of higher quality examinations and not the result of new intergranular stress corrosion cracking (IGSCC) initiation. That is, the indications were likely present in the H10 welds prior to the examinations performed in 2000.

5.0 REVIEW OF PREVIOUS EVALUATIONS

SI performed two structural evaluations to address the observed indications in 2011. The flaws in the shroud support leg H10 welds were evaluated with no structural credit taken for the shroud support plate H8 and H9 welds [1], and the shear capacity of the H8 and H9 welds were evaluated for two flaw cases using conservative assumptions [2]. The general methodology used to evaluate the structural stability of the MNGP core support structure at this time was to treat the core support legs (H10 location) as completely independent of the baffle plate (H8 and H9 location). In other words, no credit was taken for the ability of the baffle plate to support some of the applied loading, which essentially treats the H8 and H9 welds as though they are completely failed or non-existent. In this way the structural evaluation of the H10 welds is very conservative. Stability of the H8 and H9 weld location was then demonstrated by considering only the uplift loads acting across the baffle plate since the shroud support legs were already shown capable of supporting the bending moments acting on the core shroud.

Prior to the 2013 inspections, the 2011 evaluations were updated [3, 4] to address possible errors in recirculation line break (RLB) acoustic loads (AC) documented in DRAFT GE-H safety communications (SC) 12-20 and 13-08 regarding acoustic loads. At the time the evaluations were updated the final SCs had not been published; however, conservative assumptions were made in an attempt to ensure that the eventual issuance of these SCs would not affect the conclusions made from the flaw evaluations.

Details of the H10 and H8/H9 evaluations are provided in the following sections.

5.1 Shroud Support Plate Welds H8 and H9

The shroud support plate welds were evaluated using limit load methods for a plate loaded in shear. Two cases were evaluated that considered:

1. Distributed through wall flaws in the uninspected regions with part through wall flaws in the inspected regions
2. Fully circumferential part through wall flaw with a depth equal to 75% of the wall thickness.

Both of these evaluation cases include an assumption that 100% of the underside surface of the H8 and H9 welds is cracked circumferentially.

This evaluation also inherently assumes that all lateral bending moments on the core shroud are supported by the shroud support legs. Adequate margin is confirmed to be present in the support legs in the evaluation of the H10 welds discussed in Section 5.2.

The shroud support plate is located sufficiently below the core such that it does not receive a significant amount of neutron radiation. Therefore, failure of the shroud support plate and weld material is appropriately considered to be by plastic collapse. Consequently, linear elastic fracture mechanics (LEFM) techniques are not necessary, and limit load techniques are appropriate due to expected material ductility and toughness.

5.1.1 H8/H9 Evaluation Performed Following the RFO25 2011 Inspections

The structural integrity of the shroud support plate welds H8 and H9 was evaluated following RFO25 in 2011 [2]. Two separate assumed flaw distributions were evaluated:

1. Through-wall cracks were postulated in all 10 of the uninspected regions based on limited extent of the topside visual exams. No indications were identified on the top side of the shroud support plate. For those areas that were examined on the top side, a remaining ligament of 1/3 of the plate thickness was postulated in the inspected regions. The 1/3 wall thickness remaining ligament was based on field experience for BWR shroud welds and documented weld residual stress (WRS) evaluations that show compressive stress fields at approximately 1/2 to 2/3 of the weld thickness [8, Section 3.2].

2. A surface crack at the bottom plate surface extending along the circumferential length of Weld H8 and H9 with a crack depth at 75% of the support plate thickness is postulated. This corresponds to a remaining ligament of 0.625 inches in the entire circumference of the support plate.

In Case 1, the flaw growth at each end of each uninspected region was applied using the BWRVIP-76 [9, 10] plateau crack growth rate (CGR) of 5×10^{-5} in/hr over a two year evaluation interval. Flaw growth in the depth direction was not considered for Case 1 or Case 2 because the flaw depths assumed, 66% and 75% of the wall thickness, are greater than the maximum depths typically observed in shroud circumferential welds

based on BWR fleet operating experience. Further justification for this assumption is provided in Section 5.5, where crack growth in the depth direction over a 2 year operating period is calculated.

The flaw evaluation technical approach was based on the BWRVIP-76 [9] limit load methodology. This methodology is also consistent with the current version of BWRVIP-76, Rev. 1 [10]. Since the most significant loads are the vertical seismic loads and the reactor internal pressure difference (RIPD) across the support plate, the loading in the H8 and H9 welds was assumed to be in pure shear. Based on the maximum shear stress failure theory, the shear flow stress was taken as one-half the tensile flow stress of the Alloy 600 base material. Therefore, the shear flow stress is 34.95 ksi [2]. The required safety factors used were 2.77 for normal/upset (Level A/B) conditions and 1.39 for emergency/faulted conditions (Level C/D).

Since the Level C/D RIPD value is typically developed for a steam line break, the RLB AC load contribution on the support plate was also evaluated. A conservative lower bound for the pressure above the support plate is the saturation pressure at the annulus temperature. A low pressure above the support plate is appropriate because it maximizes lifting force on the plate due to the pressure differential across the plate. Recognizing that the short term decompression from the RLB event will drop the local pressure in the annulus region to the saturation pressure, at most, and assuming that the pressure in the lower plenum under the support plate remains unchanged will give a bounding pressure difference across the shroud support plate. From Reference [2], the pressure in the lower plenum was taken as:

$$Lower\ Plenum\ Pressure = Operating\ Pressure + Static\ Head + Level\ A/B\ RIPD$$

$$Lower\ Plenum\ Pressure = 1025\ psi + 11.3\ psi + 29.03\ psi = 1065.33\ psi$$

The operating pressure was corrected for the water height above the shroud support plate and the maximum Level A/B RIPD. The RIPD across the support plate is then the pressure in the lower plenum minus the saturation pressure in the annulus. From Reference [2], the AC load RIPD is calculated as follows:

$$AC\ Load\ RIPD = Lower\ Plenum\ Pressure - Annulus\ Saturation\ Pressure$$

$$AC\ Load\ RIPD = 1065.33\ psi - 886.25\ psi = 179.08\ psi$$

The vertical force due to the AC load RIPD is then conservatively calculated by applying the pressure to the full area of the shroud support plate. The area would be expected to be smaller due the jet pump holes, which would result in a smaller vertical force. From Reference [2], the acoustic load vertical force is calculated as follows:

$$AC\ Load\ Vertical\ Force = AC\ Load\ RIPD \cdot Uplift\ Area$$

$$AC\ Load\ Vertical\ Force = 179.08\ psi \cdot 12399.15\ in^2 = 2{,}220{,}440\ lbs$$

Seismic vertical loads are also considered and are developed by multiplying the total weight due to the internal structure and periphery fuel, jet pumps and water weight by the OBE and SSE vertical seismic accelerations of 0.06g and 0.12g, respectively [2].

$$Seismic\ Vertical\ Force = Total\ Weight \cdot Seismic\ Accleration\ Factor$$

$$OBE\ Vertical\ Force = 1279\ kips \cdot 0.06g = 76.74\ kips$$

$$SSE\ Vertical\ Force = 1279\ kips \cdot 0.12g = 153.48\ kips$$

Table 1 summarizes all of the loads considered in the Reference [2] evaluation. Using the loads in Table 1, both flaw distribution cases were evaluated assuming that the loads were evenly distributed between the H8 and H9 welds. To simplify the calculation, an average weld length was calculated as follows [2]:

$$Average\ Weld\ Length = \frac{H8\ Weld\ Length + H9\ Weld\ Length}{2}$$

$$Average\ Weld\ Length = \frac{512.865\ in + 647.18\ in}{2} = 580.02\ in$$

The total flaw growth in the length direction over a 2 year evaluation period for Case 1 was determined to be 17.52 inches [2]. This includes flaw growth at both ends of all 10 uninspected regions and the bounding IGSCC CGR of $5\text{x}10^{-5}$ in/hr. Combining the inspection regions that were free of relevant indications, an average inspected weld length was determined to be 130.6 inches. The final intact weld length was evaluated by subtracting flaw growth each end of the inspected regions as follows:

$$Intact\ Weld\ Length = Average\ Inspected\ Length - Total\ Flaw\ Growth$$

$$Intact\ Weld\ Length = 130.6\ in - 17.52\ in = 113.08\ in$$

The assumed remaining ligament in the inspected regions is used with the intact weld length to determine the available shear area for Case 1 and Case 2. The shear flow stress is multiplied by the available shear area to determine the shear limit load. The shear limit load is then divided by the applied shear load on a single weld (half the total vertical load) for each service level to determine the structural margin. The structural margin is then compared to the required structural factor for each service level to determine the acceptability (i.e. structural margin > structural factor). In all cases, sufficient structural margin was available. The detailed results are provided in Tables 2 and 3.

5.1.2 H8/H9 Evaluation Performed for the RFO26 2013 Inspections

In support of RFO26 in 2013, the evaluation in Reference [2] was updated to determine the required amount of inspection coverage considering revised structural factors and uncertainties in the acoustic loads due to recent GE-H SC's 12-20 and 13-08. This revised evaluation was documented in Reference [4]. The same general methodology was utilized for a 2 year evaluation interval, and again two separate assumed flaw distributions were evaluated:

1. Through-wall cracks were postulated in all 10 of the uninspected regions based on the topside visual exams, and a remaining ligament of 1/2 of the plate thickness was postulated in the inspected regions. This is increased from the remaining ligament of 1/3 of the plate thickness utilized in Reference [2]. The 1/2 plate thickness was used as the remaining ligament because of the conservative increase in AC required that more material was remaining to demonstrate adequate structural margin. The effects of the conservative assumptions regarding AC loads is further discussed in Section 6.0, and it is shown that the original assumption of 1/3 is acceptable.
2. A surface crack at the bottom plate surface extending along the circumferential length of Weld H8 and H9 with a crack depth at 75% of the support plate thickness is postulated. This corresponds to a remaining ligament of 0.625 inches in the entire circumference of the support plate. This case is consistent with the Reference [2] evaluation.

The revised structural factors were taken from the 2007 Edition with 2008 Addenda of ASME Section XI [5], and are as follows:

- Level A/B Structural Factor = 2.4
- Level C/D Structural Factor = 1.4

In 2009 GE-H released SC09-03 [11], which related to the omission of RLB AC loads from shroud screening reports. Subsequently, in 2013 GE-H released SC12-20 [12], which identified an error in the boundary break flow condition input for the Method of Characteristics (MOC) code used to determine RLB AC loads for some shroud horizontal welds. At the time the Reference [4] evaluation was performed, SC12-20 was still in DRAFT form and indicated that the AC loads were being under predicted by a factor of 2 for the assumption of an instantaneous break opening. Therefore, SI doubled the AC vertical load for the revised H8/H9 evaluation [4]. In addition, the vertical load due to the Level C/D RIPD of 47 psi was added to the total vertical load. These revisions resulted in a very conservative Level C/D vertical load, which was used to ensure that the pending GE-H SCs would not impact the results of Reference [4]. The loads used for the Reference [4] evaluation are summarized in Table 4.

The length of weld that is required to be free of through-wall indications for Case 1 and a 2 year evaluation interval was determined by using the shear flow stress, the applied vertical loads (split evenly between both welds) and the assumed remaining ligament of 1/2 the wall thickness. The required shear area was determined for each service level as follows:

$$Required\ Shear\ Area = (Structural\ Factor \cdot Total\ Vertical\ Load/2)/Shear\ Flow\ Stress$$

Using the crack growth of 17.52 inches from Reference [1], the required weld length for Case 1 was then determined as follows:

$$Required\ Weld\ Length = (Required\ Shear\ Area/Remaining\ Ligament) + Crack\ Growth$$

The results indicate that sufficient structural margin for Case 1 was available with only 18% of the topside weld material being intact with a remaining ligament of 1/2 the wall thickness (i.e. cracked 50% through-wall from the bottom surface). Case 2 was evaluated using the same methodology in Reference [2], but with the updated structural factors and AC loads. Case 2 was shown to have sufficient structural margin. The detailed results are provided in Tables 5 and 6.

It should be noted that during the RFO26 visual inspections, more than 30% weld coverage was achieved on the topside of the H8/H9 welds, which significantly exceeds the minimum required to demonstrate structural margin.

5.2 Shroud Support Leg Weld H10

The shroud support legs were evaluated using a methodology similar to the methodology provided in BWRVIP-38 [13] and assuming that the shroud support plate H8 and H9 welds contained through-wall flaws for the entire length of each weld. This was conservatively assumed so that no structural contributions from the H8 or H9 welds were considered and represented a worst case loading scenario for the H10 welds. This also assured that any future indications observed in the H8 or H9 welds would not impact the results of the shroud support leg evaluations [1, 3].

The shroud support legs are located sufficiently below the core such that they do not receive significant amounts of radiation. Therefore, linear elastic fracture mechanics (LEFM) techniques are not necessary, and limit load techniques are appropriate due to expected material ductility. Since the shroud support legs are essentially "a cylindrical shell with holes," a limit load solution applicable to cylinders may be used. Therefore, the ANSC computer program [14] was selected for use. The ANSC program was used because of its ability to analyze cracks in cylindrical structures without consideration of the cracks taking compression. This was important for these evaluations since the spaces between legs, which are effectively treated as flaws in this analysis, have no capability to take compression. Crack growth was qualitatively included in the H10 weld evaluations. Crack growth was evaluated by showing that the time to reach the maximum crack size was on the order of 30 years, and that the observed cracks were small. Therefore, several cycles of growth could be demonstrated as acceptable. Crack growth for the H10 welds is discussed further in Section 5.5 of this evaluation.

5.2.1 H10 Evaluation Performed Following the RFO25 2011 Inspections

The structural integrity of the shroud support legs, H10 welds, was evaluated following RFO25 in 2011. All of the shroud support legs were conservatively assumed to be cracked 40% of the length of the H10 weld, with one leg assumed to be 100% cracked. No structural credit was taken for the H8 or H9 welds. Consistent with limit load techniques, two stresses were computed for use in the analysis: (1) the primary membrane stress, P_m, and (2) the primary bending stress, P_b. Consistent with BWRVIP-38 methodology, calculation of these stresses was based on the stresses for the shroud H7 weld. The determination of each of these stresses is detailed in Reference [1]. The stress values used are summarized in Table 7. It should be noted that the shear term in the calculation of P_b was conservatively taken to the bottom of the shroud support legs (weld H11) versus weld H10. This is consistent with the BWRVIP-38 methodology.

The results from the Reference [1] evaluation are summarized in Table 8. Based on the structural factors shown in Table 8, the required structural factor was reached when 40% of the leg length was assumed cracked through-wall for all of the legs along with one leg cracked 100%. These results are considered to be extremely conservative because no structural support from welds H8 and H9 was considered. Therefore, if some structural support from welds H8 and H9 is considered, it is expected that significantly larger margins would be obtained.

5.2.2 H10 Evaluation Performed for the RFO26 2013 Inspections

In support of RFO26 in 2013, the evaluation in Reference [1] was updated to incorporate revised structural factors and uncertainties in the acoustic loads due to recent GE-H safety communications (SC). This revised evaluation was documented in Reference [3]. The same general methodology was utilized for a 2 year evaluation interval, and no structural credit was taken for the H8 or H9 welds. Instead of assuming an amount of cracking, the maximum percent of the H10 welds that could be cracked was determined.

MNGP currently inspects to the 2007 Edition with 2008 Addenda of ASME Section XI [5]. Therefore, the revised evaluation utilizes structural factors consistent with this newer edition of the Code:

- Level A/B Structural Factor = 2.4
- Level C/D Structural Factor = 1.4

Due to the anticipated issue of SC12-20 [12], which indicated that the AC loads developed with MOC were being under predicted by a factor of 2 for some shroud weld locations, the P_m and P_b stresses were recalculated for the H10 weld to incorporate the effect of increased AC loads. This was appropriate because the calculation of H10 weld stresses was based on the stresses for the shroud H7 weld, which may have been developed using MOC. The determination of each of these stresses is detailed in Reference [3]. The stress values used are summarized in Table 9. To remove excess conservatism, the shear term moment arm in the calculation of P_b was reduced from the distance to the bottom of the shroud support legs (weld H11) to the H10 weld location.

The results from the Reference [3] evaluation are summarized in Table 10. Based on the structural factors shown in Table 10, the required structural factor was reached when 31.2% of the leg length was assumed cracked through-wall for all of the legs. The reduction in the percent cracked in the 2013 evaluation [3] compared to the 2011 evaluation [1] is due primarily to the increase in the RLB AC loads. These results are considered to be conservative because the observed indications are relatively small and no structural support from welds H8 and H9 was considered. Therefore, if some structural support from welds H8 and H9 is considered, it is expected that larger margins would be obtained.

5.3 Applied Conservatisms

There are numerous conservatisms in the evaluations reviewed in the preceding sections. This section identifies those conservatisms.

1. For the H8/H9 weld evaluations, through-wall cracking is assumed in all of the uninspected regions for Case 1. However, no evidence of through-wall cracking has been observed. Additionally, the bounding IGSCC crack growth rate of $5x10^{-5}$ in/hr is applied to both ends of all of the uninspected regions.
2. For the H8/H9 weld evaluations, fully circumferential cracking to a depth of 75% of the wall thickness is assumed for Case 2. It is important to note that BWR shroud cracking history has shown that typically cracks in shroud welds grow to approximately 2/3 of the shroud wall thickness and then appear to become essentially inactive. This is supported by the through-wall stress profiles in BWRVIP-59-A [8], which indicate that the IGSCC growth will begin to slow significantly beyond approximately 50% of the wall thickness, and may even completely arrest prior to 75% of the wall thickness.
3. For the H8/H9 weld evaluations, seismic and RLB AC loads are conservatively combined in order to increase conservatism in the evaluation.
4. The Reference [4] H8/H9 evaluation was performed by SI prior to the issuance of the final SC12-20 document. In order to ensure that the findings in SC12-20 would not affect the Reference [4] evaluation after it was issued, the RLB AC loads were conservatively doubled in the evaluation. This was not necessary, as the AC vertical load of 2,220 kips is identical to what was developed by evaluating the AC RIPD due to depressurization of the annulus region in Reference [2]. Since the MOC code was not used to develop this load, SC12-20 would not apply. Additionally, the Level C/D RIPD for a steam line break is imposed on top of the RLB AC RIPD, which is overly conservative because the RIPDs are not cumulative (i.e. the larger of the two RIPD values should be used).

5. For the H10 weld evaluation [4], all legs are conservatively assumed to be cracked to a depth of 31.2% of the H10 weld length. The observed flaws are small relative to this assumption.
6. For the H10 weld evaluations, no structural credit is taken for the H8 and H9 welds. If structural support from welds H8 and H9 is considered, it is expected that significantly larger margins would be obtained.
7. Where IGSCC growth is considered, bounding plateau CGRs are used.

5.4 Water Chemistry

MNGP has operated on hydrogen water chemistry (HWC) since 1989, and has implemented Online Noble Metal Chemistry (OLNC) beginning in 2013 [7]. Consistent with the guidance in BWRVIP-62, Rev. 1, all components and welds in contact with the lower plenum water are considered mitigated with the use of OLNC [16, Section 4.3.5]. Mitigated water chemistry prevents new initiation of IGSCC flaws and also significantly reduces the CGR of existing flaws.

5.5 Crack Growth Considerations

The shroud support plate evaluations for welds H8 and H9 [2, 4] consider IGSCC growth in the length direction of through-wall flaws using the plateau CGR of $5x10^{-5}$ in/hr over a two year evaluation interval.

The shroud support plate evaluations for welds H8 and H9 [2, 4] do not consider IGSCC growth in the depth direction. IGSCC growth in the depth direction is omitted since no volumetric sizing information is available and the assumptions for initial flaw size are considered to be sufficiently conservative that additional IGSCC growth in the depth direction is argued as not necessary for a single cycle justification for continued operation.

Since IGSCC growth is time dependent, the relevant loads that contribute to the tensile stress necessary for IGSCC are loads that are sustained for long periods of time. In other words, normal operating loads and weld residual stresses (WRS) are the primary contributors to IGSCC. Transient loads are not sustained for significant amounts of time, and therefore, will not contribute significantly to IGSCC. Shroud support plate loads during normal operation are primarily due to deadweight and normal operating RIPD, which are relatively low compared to the WRS. The combined operating stress and WRS distributions for the H8 and H9 welds provided in BWRVIP-59-A [8] show that the WRS tends to become compressive at approximately 50% of the wall thickness. However, the stress intensity factor, K_I, distributions for the H8 and H9 welds show that depending on the shape of the flaw, the K_I value may still be positive beyond where the stress profile is compressive.

To consider the relative contribution of IGSCC growth in the depth direction, the K-independent crack growth rate (CGR) for HWC conditions of $5x10^{-6}$ in/hr from BWRVIP-59-A is used. Crack growth is applied over the 2 year evaluation interval utilized in the flaw evaluations reviewed in this calculation as follows:

$$IGSCC\ Growth = 2\ yr \cdot 365\ \frac{days}{yr} \cdot 24\ \frac{hr}{day} \cdot 5x10^{-6}\ \frac{in}{hr} \cdot = 0.088\ in$$

The IGSCC contribution to crack growth is expected to be less than this value at the postulated 75% through-wall location, but would contribute only 3.5% of the wall thickness over the 2 year evaluation interval using a worst case CGR. Based on BWR operating experience flaws are expected to arrest or grow significantly slower at approximately 2/3 of the wall thickness. Therefore, the assumption of a 75% through-wall flaw contains sufficient conservatism to account for any unexpected growth over the evaluation interval.

The shroud support leg evaluations for the H10 welds [1, 3] address IGSCC growth using the HWC K-independent CGR to demonstrate that for the flaws to grow from 0% to 40% of the weld length (considering 2 crack tips) would take 31.9 years, which is large compared to the 2 year evaluation interval and considering that the observed flaws were relatively small. Therefore it is not necessary to consider additional crack growth in the H10 welds over the evaluation interval.

Fatigue crack growth is not specifically addressed in the evaluations reviewed in this calculation. Fatigue is not expected to contribute any significant crack growth because of the relatively low applied stresses and the low number of cycles, especially over a 2 year evaluation interval.

6.0 DISCUSSION

The structural evaluations [1, 2, 3, 4] reviewed in this calculation are very conservative. They demonstrate significant margin in the shroud support components. The increases in RLB AC loads were responsible for the reduction in the assumed flaw geometries and the associated observed reduction in margin. However, the loads shown in Table 1 are the appropriate loads for the H8 and H9 welds, since the acoustic loads do not need to be doubled at this location.

If the Table 1 Level C/D loads are used to determine the minimum required un-cracked length of H8/H9 weld for Case 1 with a structural factor of 1.4, a reduced amount of inspection coverage could be justified. The required shear area is calculated as follows:

$$Required\ Shear\ Area = \frac{Structural\ Factor \cdot Total\ Vertical \frac{Load}{2}}{Shear} Flow\ Stress$$

$$Required\ Shear\ Area = (1.4 \cdot 2373.9\ kips/2)/34.95\ ksi = 47.5\ in^2$$

The required weld length for a 2/3 through-wall flaw in the inspected region, consistent with Reference [2], is then determined as follows:

$$Required\ Weld\ Length = (Required\ Shear\ Area/Remaining\ Ligament) + Crack\ Growth$$

$$Required\ Weld\ Length = 47.5\ in^2/(0.33 \cdot 2.5\ in) + 17.52\ in = 74.6\ in$$

The percentage of the total weld is then:

$$\%\ Required\ Weld\ Length = 74.6/580.02 = 13\%$$

This indicates that 87% of the H9 and H8 welds can be completely cracked through-wall, assumed evenly distributed, and the remaining 13% can be cracked 2/3 of the way through-wall, and the H8 and H9 welds will still meet the ASME code requirements for structural margin. Further, all of the H10 welds can also be cracked to 31.2% of the weld length and still meet the ASME code requirements.

The results in Table 6 show that the H8 and H9 welds retain significant structural margin even when assumed to contain fully circumferential flaws at 75% of the wall thickness, Case 2, and are subject to the extremely conservative loads which unnecessarily double the RLB acoustic loads and unnecessarily include an additional Level C/D RIPD [4]. The results in Table 3 more accurately represent the available margin.

7.0 INSPECTION RECOMMENDATIONS

The evaluations discussed in this calculation demonstrate that the H8 and H9 welds have significant structural margin. The examination of the H8, H9 and H10 welds are limited to visual surface exams because volumetric examination techniques are not currently available for these locations. Since a surface examination cannot determine the depth of an indication, the value of dual sided examination of the H8 and H9 welds is limited. Given the amount of margin available, it is only necessary to verify that more than 13% of the H8 and H9 welds are not cracked through-wall. This could readily be accomplished by a top side examination of available portions of the shroud support plate, since all of the observed indications are located on the bottom side of the shroud support plate. However, monitoring a subset of the known indications on the bottom side of the shroud support plate may provide useful information regarding any additional flaw growth. The following minimum inspections are recommended for the upcoming successive examinations:

1. At least 15% coverage of the top side of welds H8 and H9 with the objective of identifying at least 13% of the top side weld length to be unflawed.
    a. The extent of top side coverage should be increased until at least 13% of the weld length for both H8 and H9 are shown to be unflawed.
2. 5% coverage of the bottom side of welds H8 and H9 in areas with known flaws with the objective of monitoring for unexpected change of flaw appearance.

Per ASME Section XI, IWB-2400 [5], following 3 successive examinations that reveal that the indications remain essentially unchanged, the examination schedule may revert to the original schedule.

It is important to note that since volumetric data has not been historically available, due to lack of available tooling and technology, assumptions regarding flaw depth have been made. While the assumptions related to the flaw depth and remaining ligament of the H8 and H9 welds are very conservative, based on material properties, welding processes and industry operating experience, volumetric data will provide additional confidence in the assumptions made in the existing evaluations. Further, successive inspections using a technique able to determine flaw depth and/or remaining ligament, of the extent of coverage identified above, would provide a more robust means of demonstrating no change in flaw dimension and subsequently reverting to a longer re-inspection interval as permitted by IWB-2420(c). SI recommends that Xcel Energy pursue identification of an NDE technique that is able to determine either the flaw depth or the remaining ligament in the H8 and H9 welds. Once the technology for the technique becomes available and is successfully demonstrated as qualified to interrogate the H8 and H9 welds, SI recommends that Xcel Energy implement an inspection as soon as is practical. In the meantime, Xcel Energy should continue to perform the visual inspections as described earlier as part of their successive inspection program.

8.0 CONCLUSIONS

A recommended inspection interval for the remaining successive examinations of the H8 and H9 welds is developed, which requires examination coverage in excess of the minimum coverage demonstrated as needed by analytical evaluation. The following conclusions are also supported by this evaluation:

- The structural evaluations [1, 2, 3, 4] contain numerous conservatisms and demonstrate significant margin for the H8, H9 and H10 welds.
- The shroud support plate welds are structurally redundant to the shroud support legs, and acceptable margin is achieved assuming that the H8 and H9 welds are completely failed.
- The acoustic loads utilized in the 2013 H8/H9 structural evaluation [4] do not need to be doubled because the vertical AC loads were not developed using MOC.
- The flaws in the H8 and H9 welds are not expected to propagate through more than approximately 66% of the weld material due to the compressive WRS distribution, the favorable water chemistry conditions and the negligible contribution of fatigue crack growth. This is also supported by BWR operating experience.
- Since 100% of the H8 and H9 welds are assumed to be flawed on the bottom side of the shroud support plate, visual examination adds no value and is consequently considered not to be necessary. Instead a small amount of bottom side coverage is recommended only for informational purposes.

9.0 REFERENCES

1. SI Calculation No. 1100560.301, Rev. 0, "Evaluation of the Monticello Shroud with Indications at Welds H8 and H9."
2. SI Calculation No. 1100626.301, Rev. 0, "Evaluation of Shear Capacity of Monticello Shroud Welds H8 and H9."
3. SI Calculation No. 1300180.302, Rev. 2, "Evaluation of the Monticello H10 Weld."
4. SI Calculation No. 1300180.301, Rev. 2, "Evaluation of Shear Capacity of Monticello Shroud Welds H8 and H9."
5. ASME Boiler and Pressure Vessel Code, Section XI, 2007 Edition with Addenda through 2008.
6. Xcel Energy EC Report No. EC18068, "Summary of 2011 Shroud Summary Inspection and Evaluation Activities," SI File No. 1301525.201.
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Table 1. Loads Used in the 2011 H8 and H9 Weld Evaluation [2]

Service Level	RIPD Uplift Load (kips)	Vertical Seismic Load (kips)	Total Vertical Load (kips)
A/B	363.30	76.74	440.04
C/D	2220.44	153.48	2373.92

Table 2. 2011 H8 and H9 Weld Evaluation Results for Case 1 [2]

Item	Description	Level A/B	Level C/D
(1)	EOI un-cracked length (in)	113.08	113.08
(2)	Support plate thickness (in)	2.5	2.5
(3)	Remaining ligament (in)	0.833	0.833
(4)	Available shear area (in^2) (=(1)*(3))	94.20	94.20
(5)	Total applied shear load (kips)	440.04	2373.92
(6)	Applied shear in each weld (kips) (=(5)/2)	220.02	1186.96
(7)	Tensile Flow Stress (ksi)	69.9	69.9
(8)	Shear Flow Stress (ksi)	34.95	34.95
(9)	Shear limited load (kips) (=(8)*(4))	3292.29	3292.29
(10)	**Safety Factor (=(9)/(6))**	**14.96**	**2.77**
(11)	Required Safety Factor	2.77	1.39

Table 3. 2011 H8 and H9 Weld Evaluation Results for Case 2 [2]

Item	Description	Level A/B	Level C/D
(1)	EOI un-cracked length (in)	580.02	580.02
(2)	Support plate thickness (in)	2.5	2.5
(3)	Remaining ligament (in)	0.625	0.625
(4)	Available shear area (in^2) (=(1)*(3))	362.51	362.51
(5)	Total applied shear load (kips)	440.04	2373.92
(6)	Applied shear in each weld (kips) (=(5)/2)	220.02	1186.96
(7)	Tensile Flow Stress (ksi)	69.9	69.9
(8)	Shear Flow Stress (ksi)	34.95	34.95
(9)	Shear limited load (kips) (=(8)*(4))	12669.7	12669.7
(10)	**Safety Factor (=(9)/(6))**	**57.58**	**10.67**
(11)	Required Safety Factor	2.77	1.39

Table 4. Loads Used in the 2013 H8 and H9 Weld Evaluation [4]

Service Level	Pressure Differential (kips)	Vertical Seismic Load (kips)	Total Acoustic Load (kips)	Total (kips)
A/B	359.95	76.74	0	436.69
C/D	582.76	153.48	4400	5136.24

Table 5. 2013 H8 and H9 Weld Evaluation Results for Case 1 [4]

Item	Description	Level A/B	Level C/D
(1)	EOI un-cracked length (in)	86.88	86.88
(2)	Support plate thickness (in)	2.50	2.50
(3)	Remaining ligament (in)	1.25	1.25
(4)	Available shear area (in^2) (=(1)*(3))	108.61	108.61
(5)	Total applied shear load (kips)	436.69	5136.24
(6)	Applied shear in each weld (kips) (=(5)/2)	218.34	2568.12
(7)	Tensile Flow Stress (ksi)	69.90	69.90
(8)	Shear Flow Stress (ksi)	34.95	34.95
(9)	Shear limited load (kips) (=(8)*(4))	3795.75	3795.75
(10)	**Safety Factor (=(9)/(6))**	**17.38**	**1.48**
(11)	Required Safety Factor	2.4	1.4

Table 6. 2013 H8 and H9 Weld Evaluation Results for Case 2 [4]

Item	Description	Level A/B	Level C/D
(1)	EOI un-cracked length (in)	580.02	580.02
(2)	Support plate thickness (in)	2.50	2.50
(3)	Remaining ligament (in)	0.63	0.63
(4)	Available shear area (in^2) (=(1)*(3))	362.51	362.51
(5)	Total applied shear load (kips)	436.69	5136.24
(6)	Applied shear in each weld (kips) (=(5)/2)	218.34	2568.12
(7)	Tensile Flow Stress (ksi)	69.90	69.90
(8)	Shear Flow Stress (ksi)	34.95	34.95
(9)	Shear limited load (kips) (=(8)*(4))	12669.87	12669.87
(10)	**Safety Factor (=(9)/(6))**	**58.03**	**4.93**
(11)	Required Safety Factor	2.4	1.4

Table 7. Primary Stresses Used in the 2011 H10 Weld Evaluation [1]

Service Level	P_m (psi)	Total P_b (psi)
A/B	521	1633
C/D	1100	5486

Table 8. 2011 H10 Weld Evaluation Results [1]

Service Level	P_b' (ksi)	Calculated Structural Factor	Required Structural Factor
A/B	8.458	4.168	2.77
C/D	8.223	1.416	1.39

Table 9. Primary Stresses Used in the 2013 H10 Weld Evaluation [3]

Service Level	P_m (psi)	Total P_b (psi)
A/B	521	1302
C/D	1100	7159

Table 10. 2013 H10 Weld Evaluation Results [3]

Service Level	P_b' (ksi)	Calculated Structural Factor	Required Structural Factor
A/B	10.661	6.13	2.40
C/D	10.473	1.40	1.40

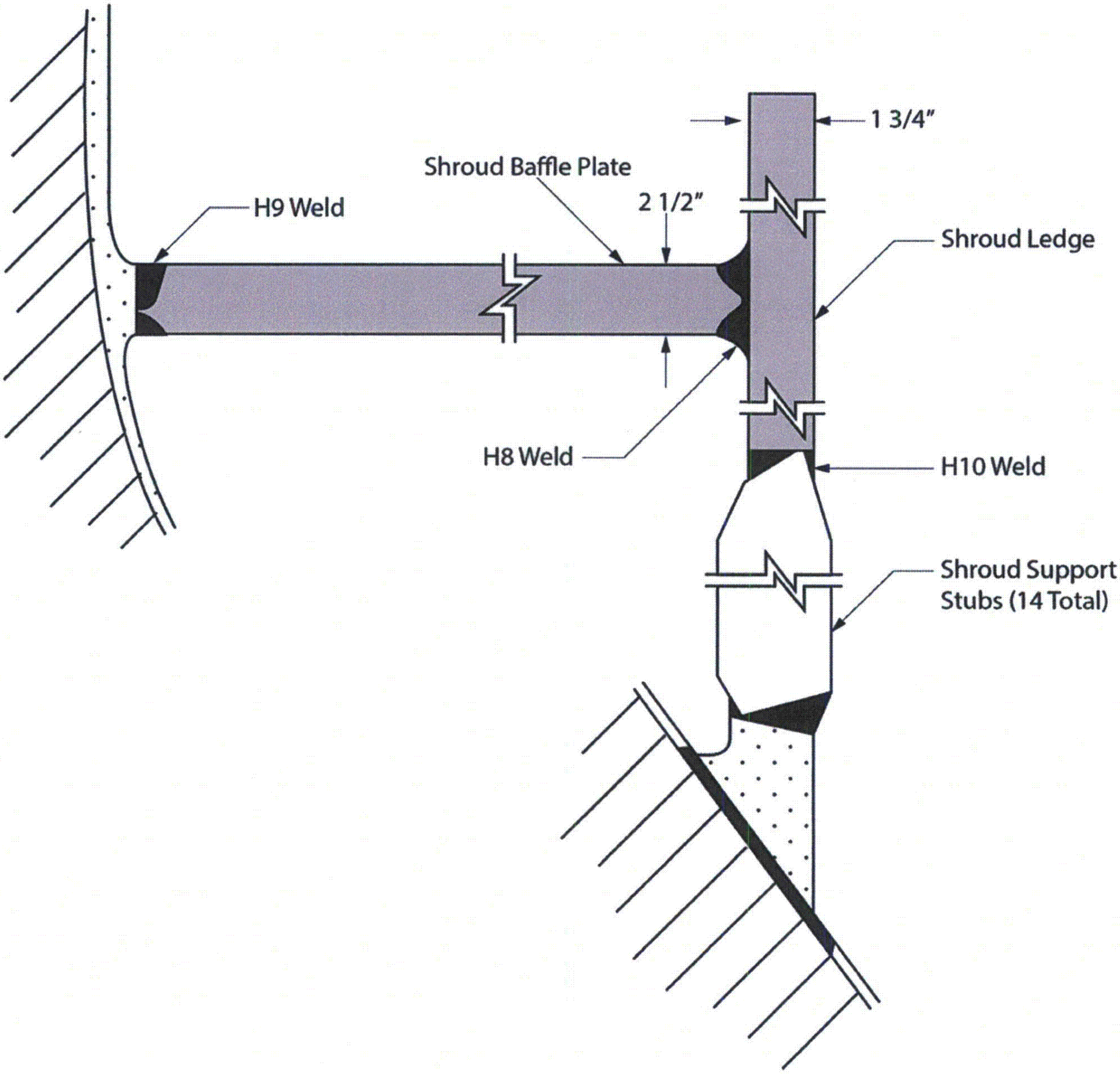

Figure 1. General Vessel Shroud Support Structure Attachment Configuration

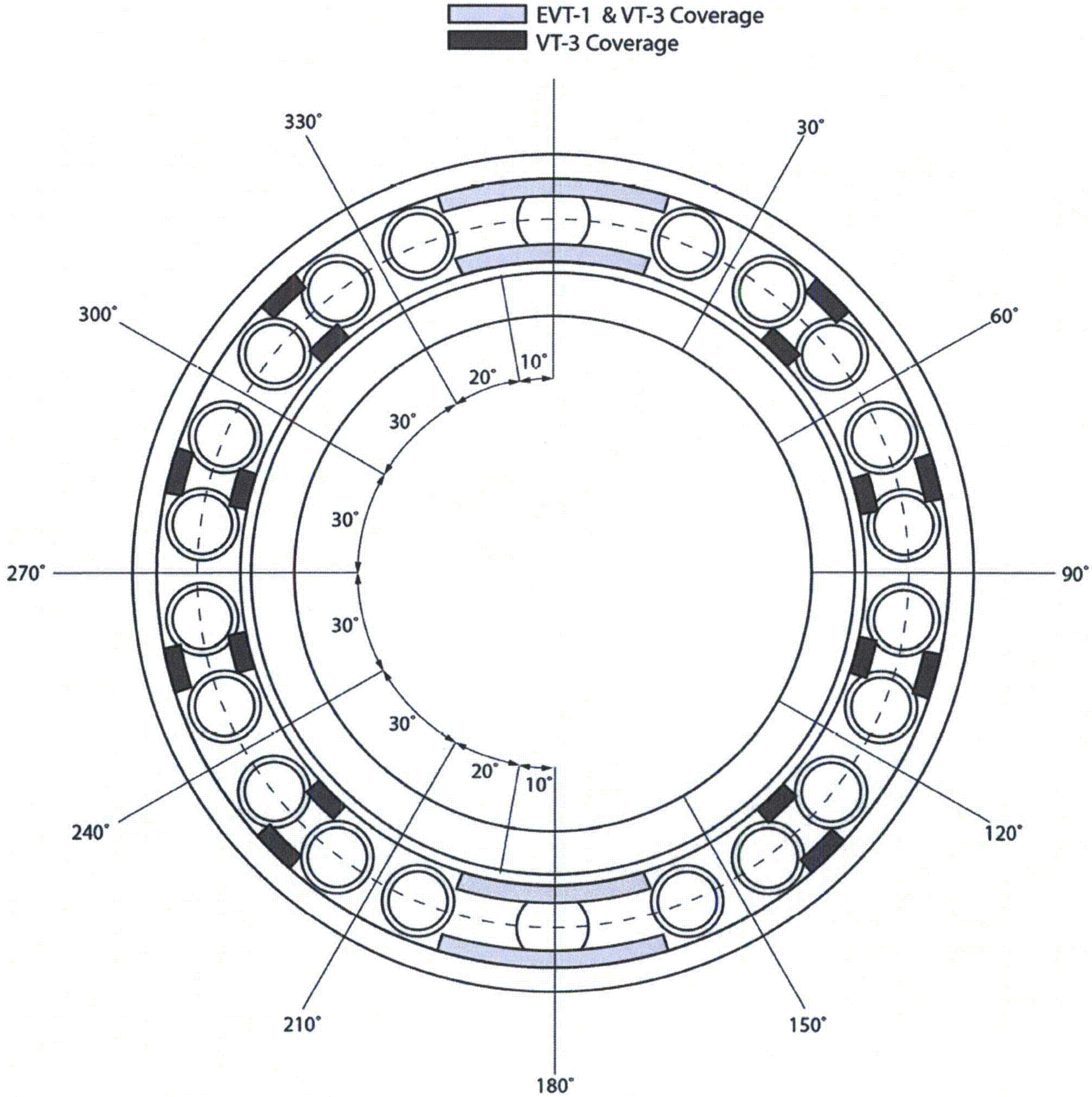

Figure 2. Shroud Support Plate Inspection Illustration