Attachment 2 to Letter L-2016-040

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PRESSURIZED WATER REACTOR OWNERS GROUP

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Revision 0

WESTINGHOUSE NON-PROPRIETARY CLASS 3

St. Lucie Units 1 and 2 Participation in Additional Work under the "Support for Applicant Action Items 1, 2, and 7 from the Final Safety Evaluation on MRP-227, Revision 0" PA-MSC-0983 R2 Cafeteria Task 8 and "Acceptance Criteria for Measurement of CE Internals: MRP-227 SE Action Item 5" PA-MSC-0984: Responding to Items 1 and 3

Materials Committee

PA-MSC-0983 Task 8

February 2016

Westinghouse

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PA-MSC-0983 Task 8

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February 2016

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1 PURPOSE AND BACKGROUND

As requested by Florida Power & Light (FPL), St. Lucie Units 1 and 2, Westinghouse Electric Company LLC is providing this letter report under PA-MSC-0983, Revison 2, Task 8.

FPL submitted a letter to respond to U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) for the review of the St. Lucie Units 1 and 2 License Renewal Application. The NRC reviewed the information and identified areas where additional information is still needed.

This report provides Westinghouse's responses, for Items 1 and 3 [1], as authorized by Mr. Scott Boggs, to support of FPL's request for service.

ATTACHMENT 1: NON-PROPRIETARY SUMMARY LETTER FOR ACCEPTANCE CRITERIA FOR VISUAL EXAMINATION OF GAPS BETWEEN UPPER AND LOWER CORE SHROUD SUBASSEMBLIES AT ST. LUCIE UNITS 1 AND 2

1 BACKGROUND AND PURPOSE

The core shroud (CS) assemblies at St. Lucie Unit 1 (SL1) and St. Lucie Unit 2 (SL2) are each comprised of an upper subassembly and a lower subassembly (refer to Figures 1-1a and 1-2a). The bottom plate of the upper subassembly sits on the top plate of the lower subassembly. The elevation of this bottom plate/top plate interface is close to the axial center of the core; therefore, it is subjected to high levels of irradiation. Figure 1-3 plots the irradiation distribution in these plates for a typical 2,800 MWt or 3,410 MWt Combustion Engineering (CE)-welded core shroud. SL1 uses a typical 2,800 MWt CS design. SL2 uses a shortened version of the 3,410 MWt CS design. Therefore, the relative distribution of irradiation shown in Figure 1-3 can be considered representative of the CS designs for SL1 and SL2. The irradiation dose is highest at the innermost corners of the interfacing plates, which are the eight re-entrant corner locations closest to the lateral center of the core (see Figures 1-1b and 1-2b). This irradiation produces both gamma heating and void swelling in the interfacing plates. The gamma heating will produce a temperature gradient between the center of the bottom plate/top plate combination (at the interfacing surfaces) and the outer surfaces of the bottom plate/top plate combination (see Figures 1-4a and 1-5a). This temperature gradient, like the irradiation dose, will be greatest at the innermost corners of the interfacing plates (see Figures 1-4b and 1-5b). The void swelling increases with temperature and irradiation dose; therefore, it will also be greatest at the innermost corners of the interfacing plates.

These gamma heating and void swelling effects could result in a deflection of the upper CS subassembly bottom plate relative to the lower CS subassembly top plate. The nature of this relative deflection is dependent on the manner in which the upper and lower CS subassemblies are attached. At SL1, the upper and lower CS subassemblies are attached to one another and to the core support plate via eight tie rods. Tapered pins are inserted through the interfacing plates to provide lateral restraint and alignment between the two CS subassemblies. Relative deflection between these interfacing plates could produce gaps between the plates at the inner and outer peripheries of the interface (see Figure 1-6). Gamma heating and void swelling could also cause local increases in plate thickness. Both of these effects would be greatest at the innermost corners of the interfacing plates. The tie rods would continue to clamp the upper and lower CS subassemblies together, and the tapered pins would continue to prevent lateral translation of one plate relative to the other. Therefore, plate-to-plate contact would be maintained at the locations of maximum plate thickness [i.e., at the circumferential locations of innermost corners, between the inner and outer peripheries where the gaps occur (see Figure 1-6)]. However, additional gaps could form between the two plates at circumferential locations away from the innermost corners, where plate thicknesses are smaller, and these gaps could extend through the bottom plate/top plate interface (see Figure 1-7). Accordingly, at SL1, there could be two types of gaps between the interfacing plates of the upper and lower CS subassemblies. The gaps at the innermost corners would not extend through the bottom plate/top plate interface; the gaps away from the innermost corners could extend through this interface.

At SL2, the bottom plate of the upper CS subassembly and the top plate of the lower CS subassembly are attached to one another via a full penetration weld around the outside circumference. Relative deflection between these interfacing plates, due to gamma heating and void swelling, could produce gaps between the plates at the inner periphery of the interface (see Figure 1-8). The largest gaps would occur at the innermost corners where the temperature gradients and void swelling are greatest. The circumferential welded attachment between the upper and lower subassemblies would prevent the interfacing plates from separating at their outer peripheries; therefore, the gaps between the interfacing plates would not extend through the interface, from inside to outside.

At SL1 and SL2, the gaps between interfacing plates of the upper and lower CS subassemblies would have a thermal contribution and a void swelling contribution. The thermal contribution would only be present during power operation. The void swelling contribution would be present under all conditions, including plant shutdown, during which the physical examinations of the CS will be performed.

Applicant/Licensee Action Item 5, as described in Sections 3.3.5 and 4.2.5 of [1], requires that applicants/licensees identify plant-specific acceptance criteria to be applied when performing the physical measurements required by the NRC-approved version of MRP-227 for distortion in the gap between the top and bottom CS segments in CE units with CSs assembled in two vertical sections.

To comply with Applicant/Licensee Action Item 5, Westinghouse assumed the task of identifying and justifying an acceptable size for the gap between the interfacing plates of the upper and lower CS subassemblies for SL1 and SL2. The work associated with this task justified a gap size that is measureable using the specified VT-1 inspection resolution and that is acceptable in terms of functionality. A gap size was chosen and justified based on design and as-built conditions, fluence, circumferential bounds of the gap (how far around the CS can the gap exist), stress, impact on adjacent reactor vessel internals components, impact on core and bypass flow rates, and potential effects on fuel management schemes.

The products of this task are maximum allowable values for the gaps between the upper and lower subassemblies of the CSs at SL1 and SL2, as could be observed during plant shutdown when physical examinations would be performed. These allowable gaps will be used as acceptance criteria during these physical examinations.

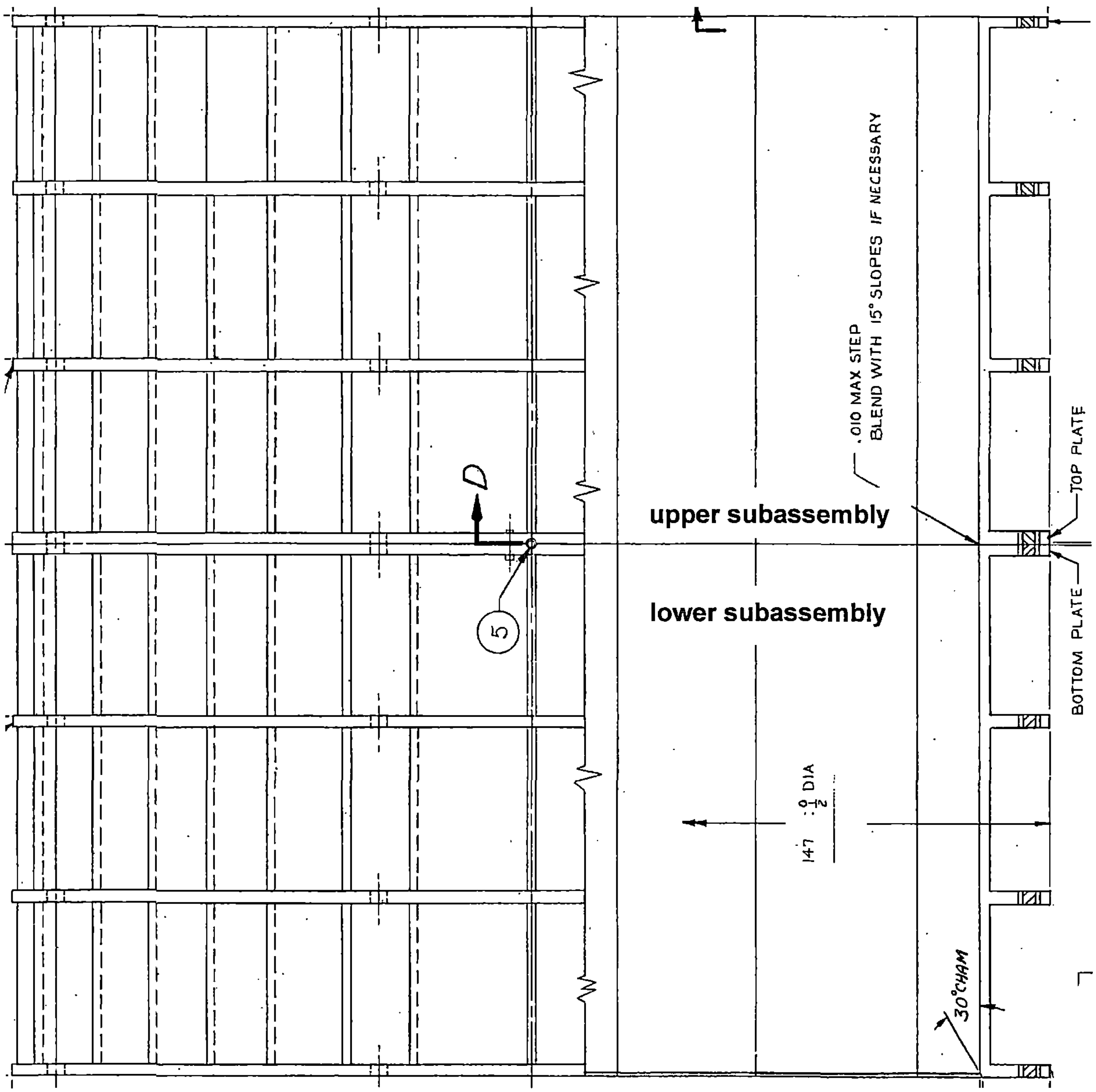

Figure 1-1a: SL1 Core Shroud Assembly – Elevation View

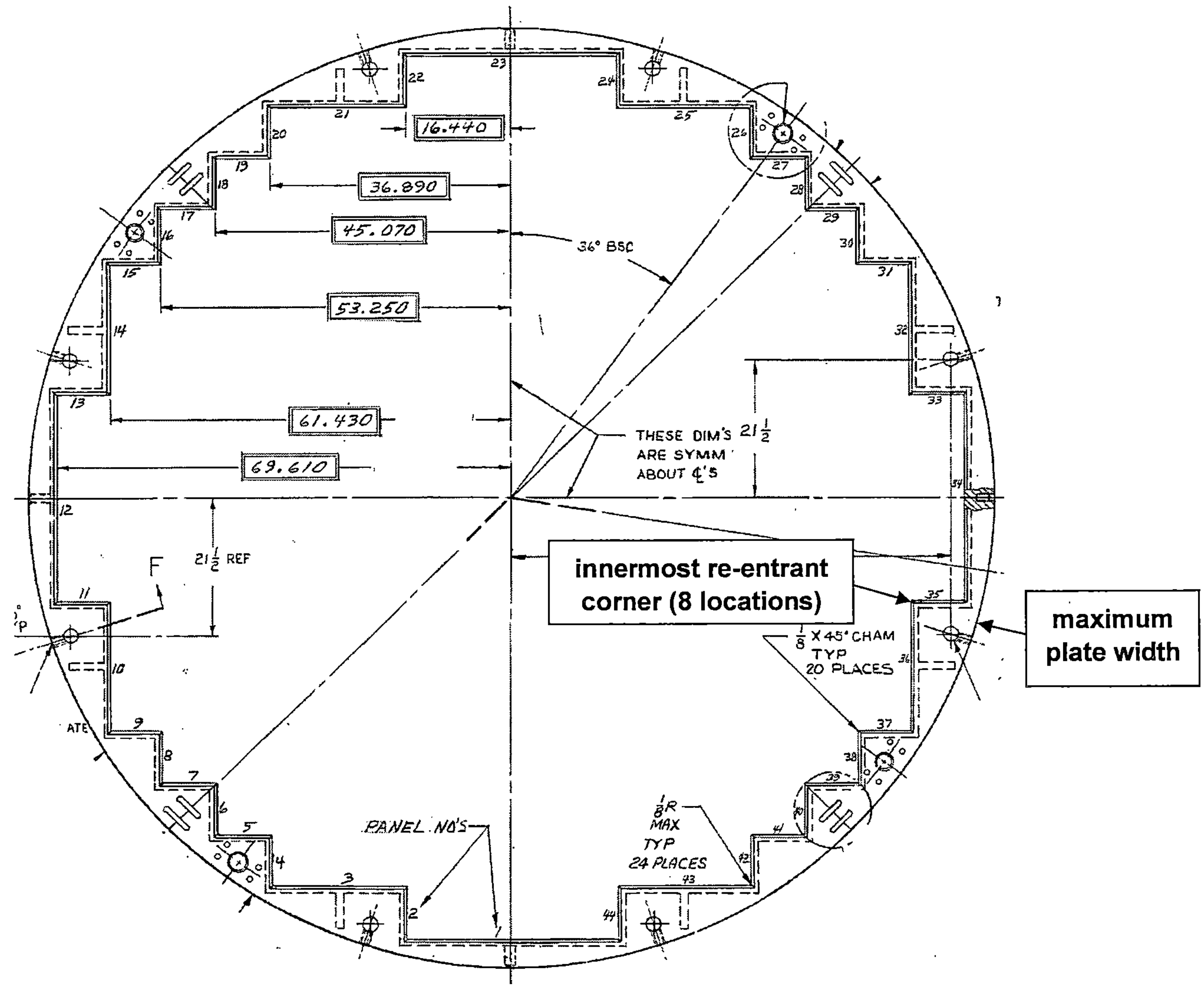

Figure 1-1b: SL1 Core Shroud Assembly – Plan View

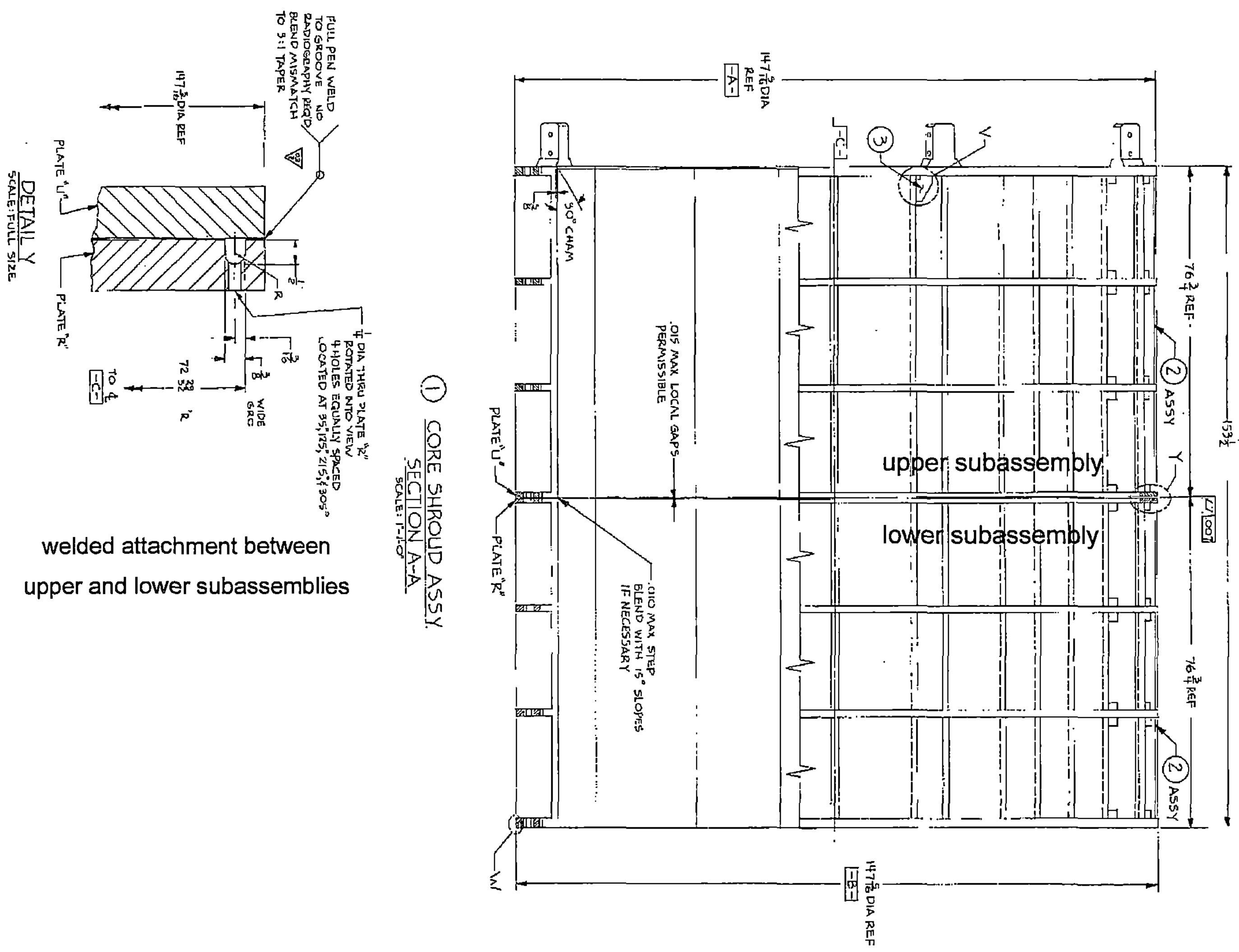

Figure 1-2a: SL2 Core Shroud Assembly – Elevation View

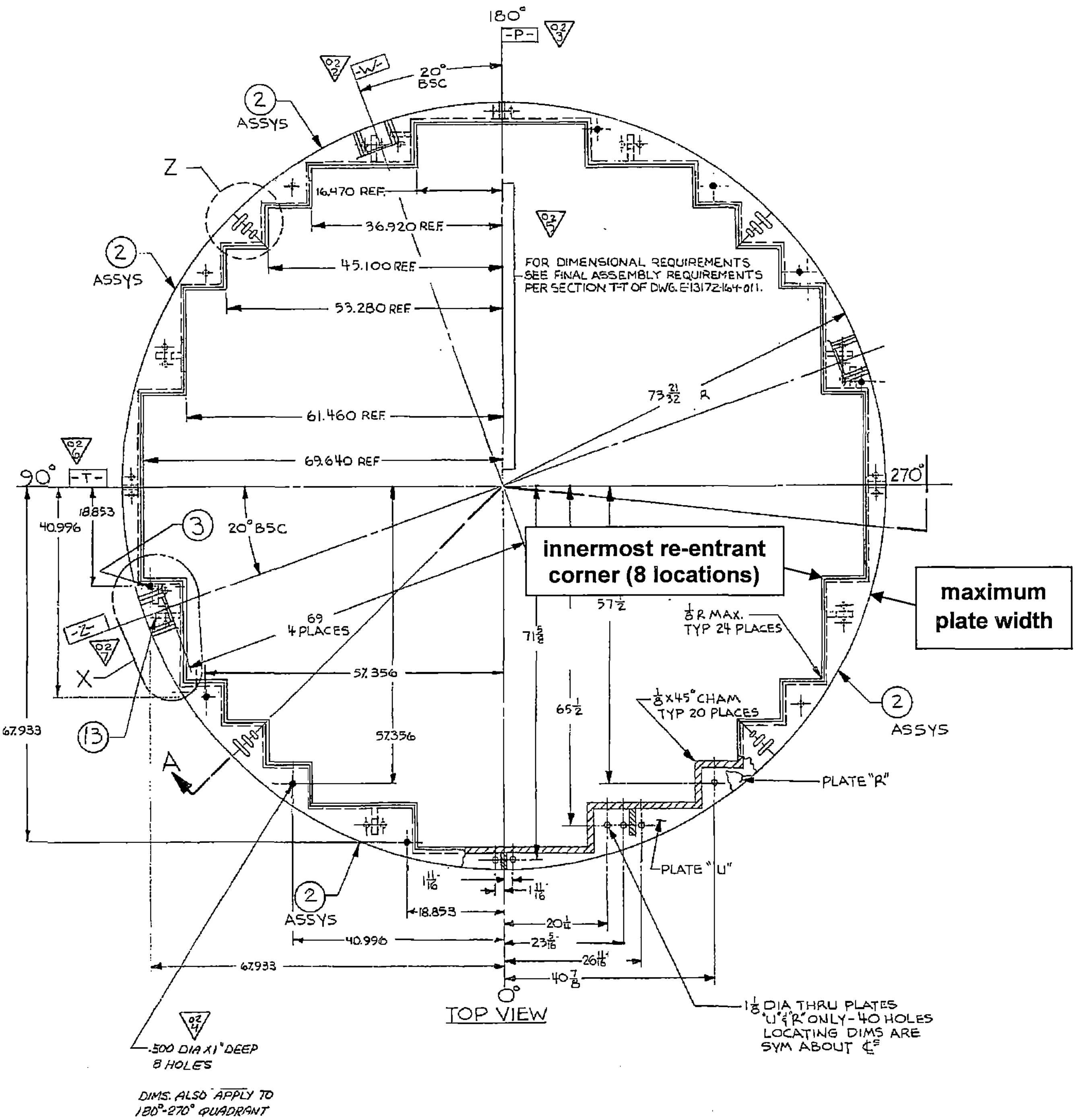

Figure 1-2b: SL2 Core Shroud Assembly – Plan View

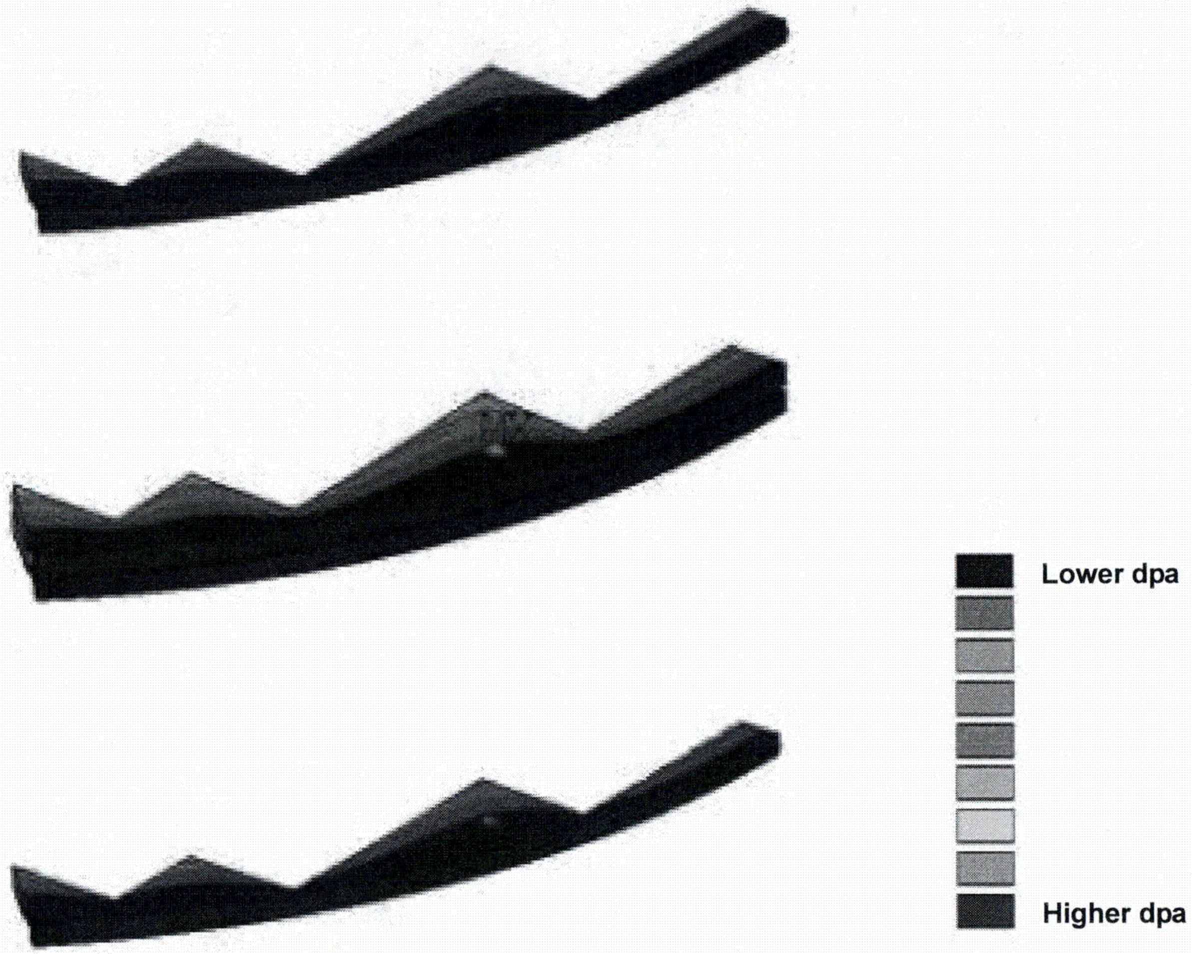

Figure 1-3: Irradiation Dose (dpa) Contour Plots in Central CS Horizontal Plates after 40 Fuel Cycles

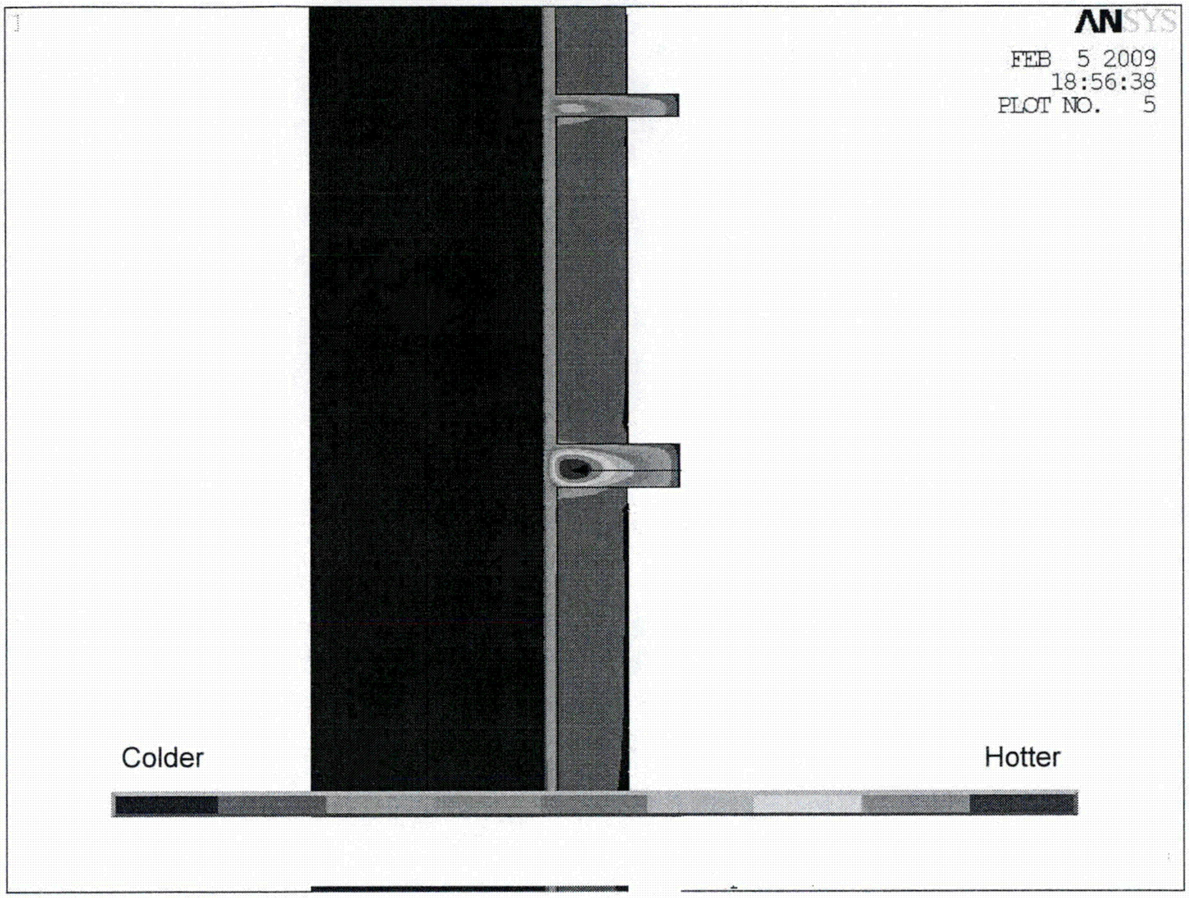

Figure 1-4a: Temperature Gradients at Interface between Upper and Lower CS Subassemblies for SL1 – Elevation View

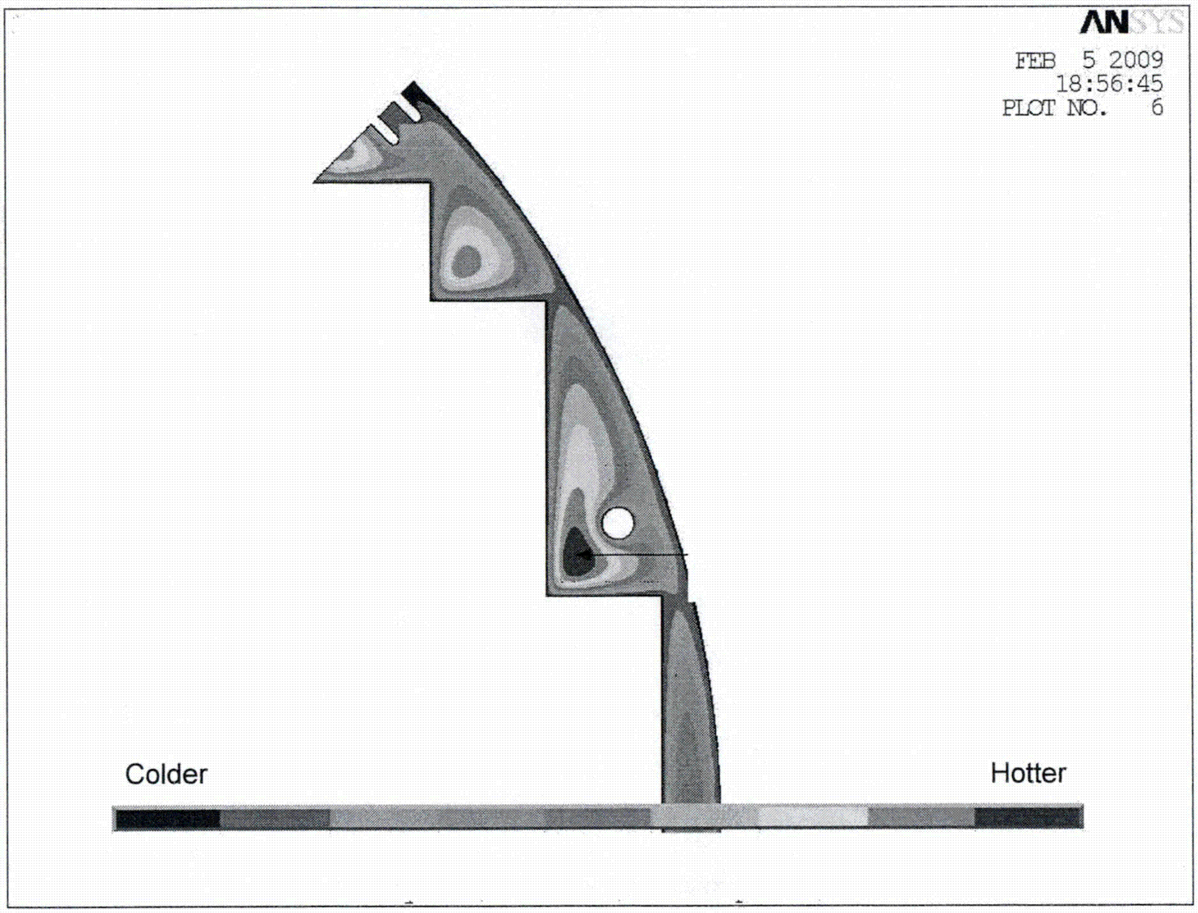

Figure 1-4b: Temperature Gradients at Interface between Upper and Lower CS Subassemblies for SL1 – Plan View

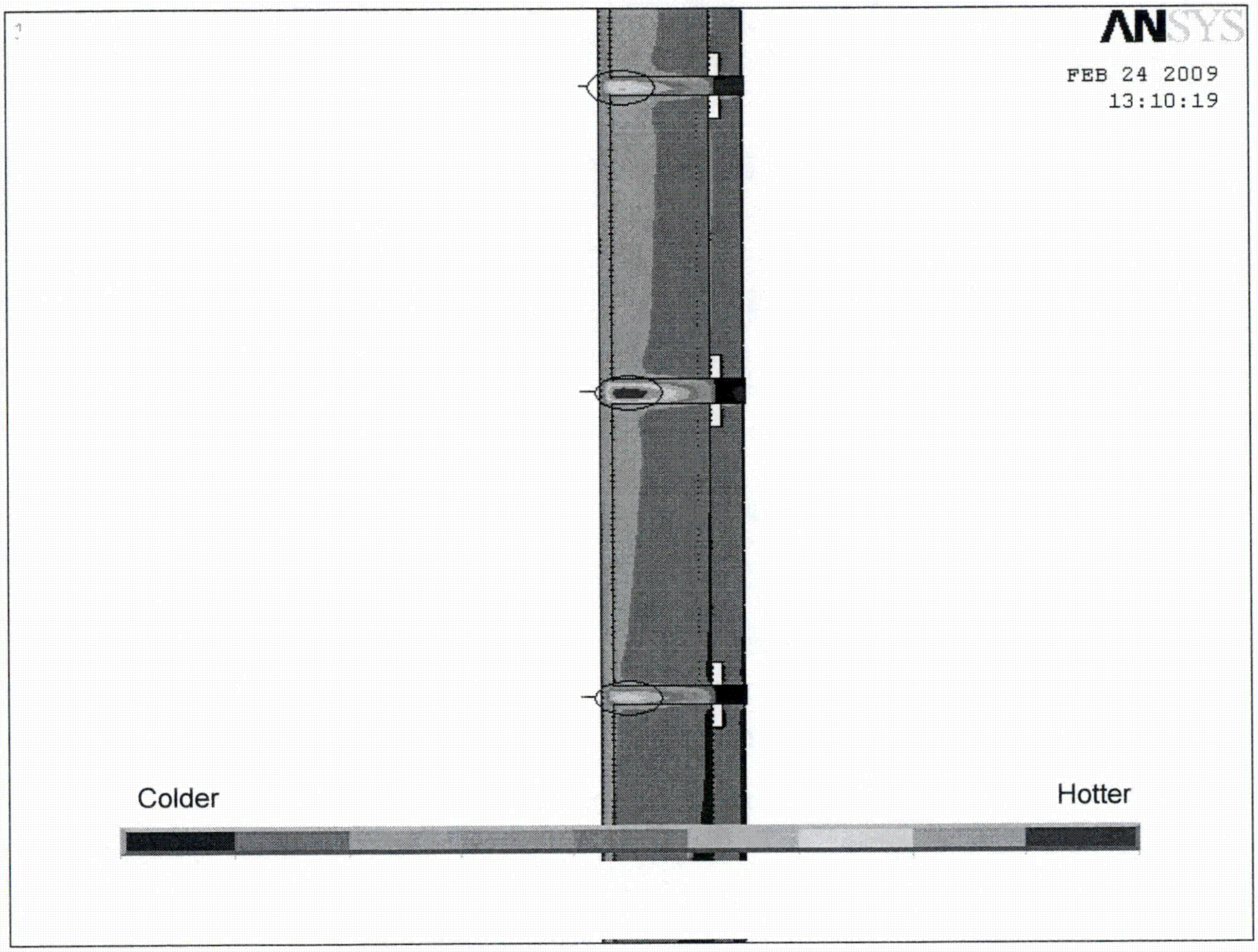

Figure 1-5a: Temperature Gradients at Interface between Upper and Lower CS Subassemblies for SL2 – Elevation View

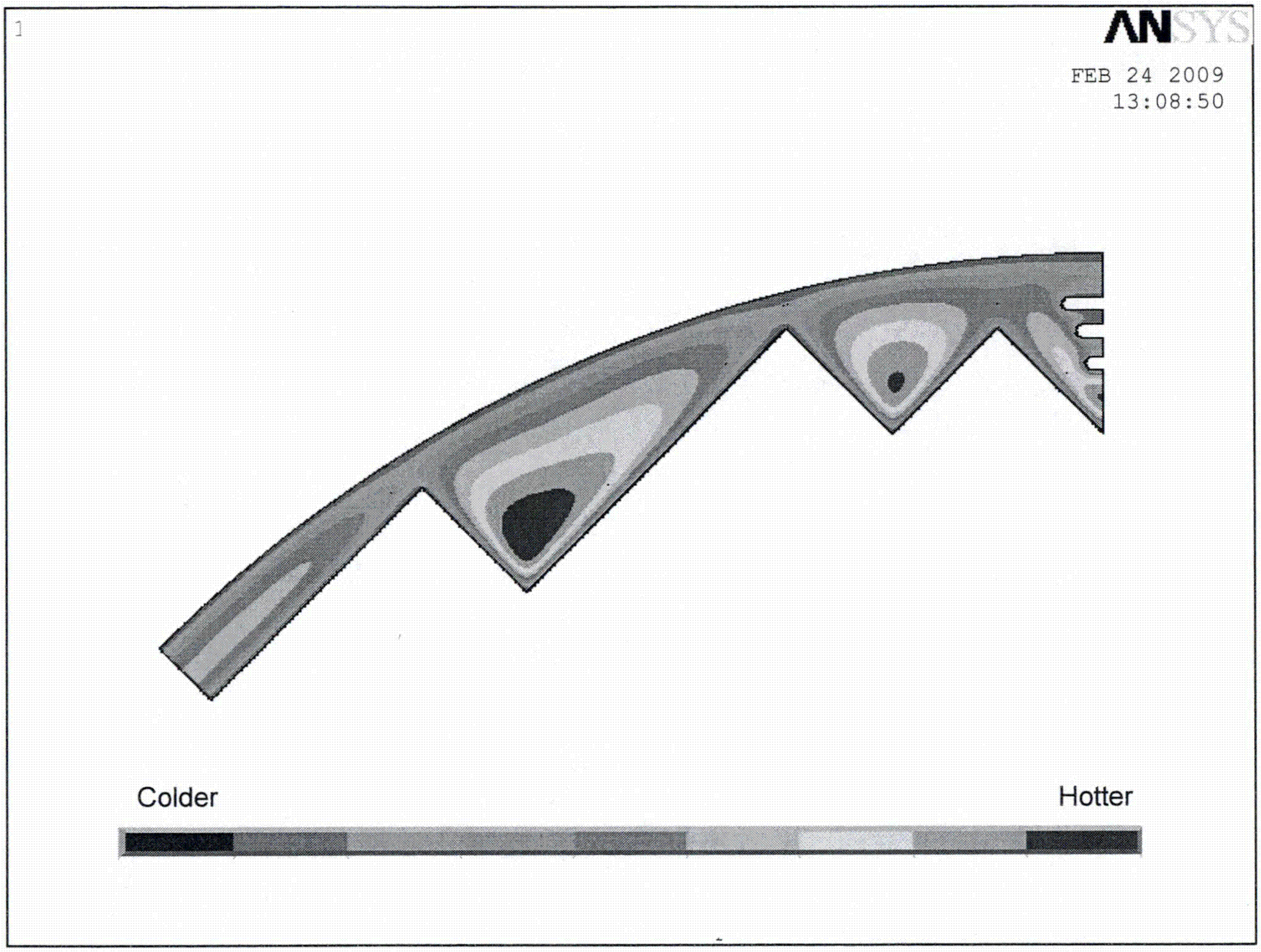

Figure 1-5b: Temperature Gradients at Interface between Upper and Lower CS Subassemblies for SL2 – Elevation View

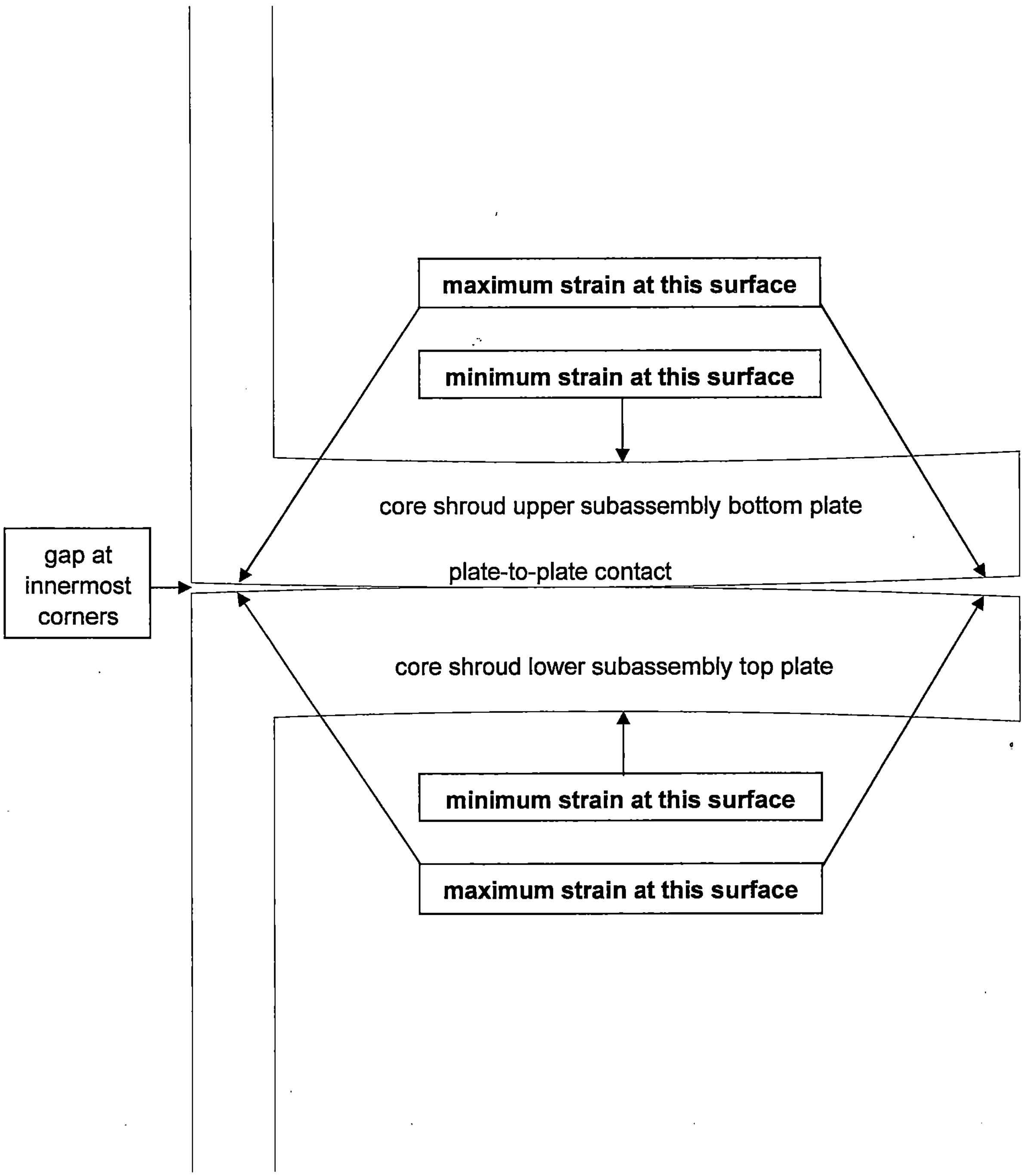

Figure 1-6: Gap between Upper and Lower CS Subassemblies at Innermost Corners for SL1

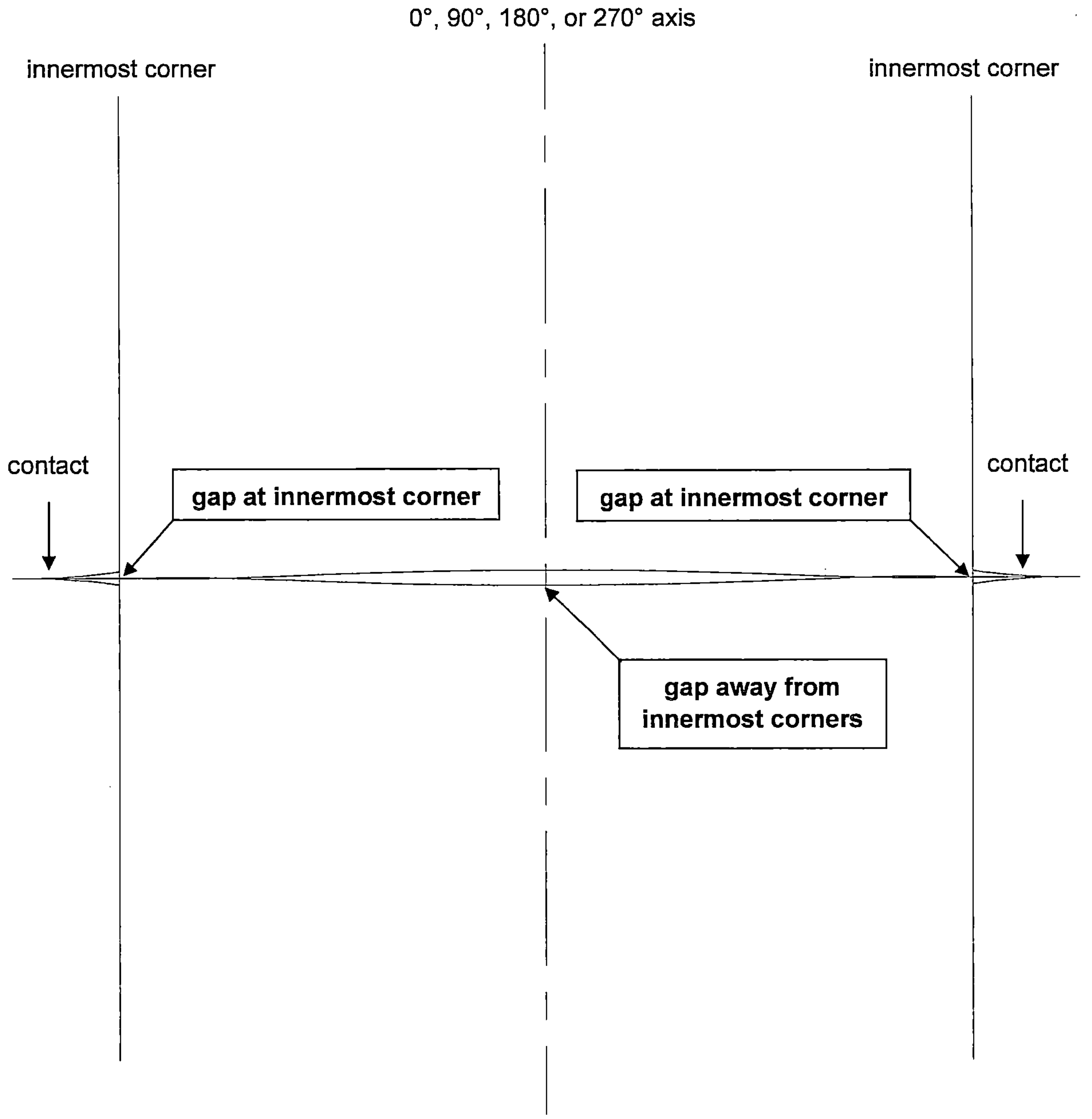

Figure 1-7: Gap between Upper and Lower CS Subassemblies Away from Innermost Corners for SL1

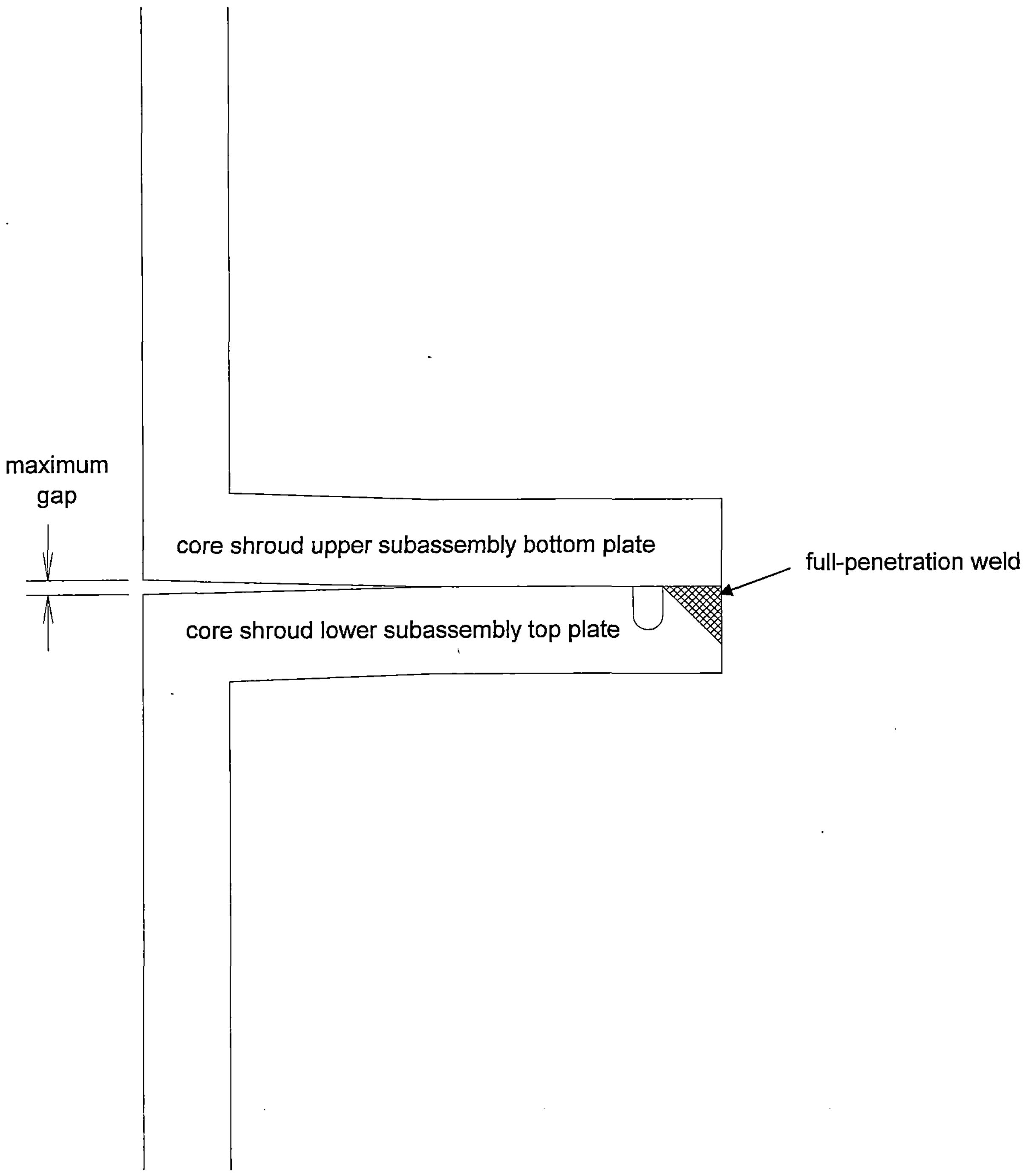

Figure 1-8: Gap between Upper and Lower CS Subassemblies at Innermost Corners for SL2

2 METHODOLOGY

As discussed in Section 1, the nature of the relative deflection between the interfacing plates of the upper and lower CS subassemblies, and the gaps resulting from these deflections, is dependent on the manner in which the upper and lower CS subassemblies are attached. SL1 uses a mechanical attachment (via tie rods); SL2 uses a welded attachment. Therefore, two different methodologies were employed to calculate these gaps. The first, described in Section 2.1, was applied to SL1. The second, described in Section 2.2, was applied to SL2.

2.1 METHODOLOGY FOR SL1

Differential thermal expansion (due to gamma heating) and irradiation-induced void swelling could cause local gaps to form between the interfacing plates of the upper and lower CS subassemblies. These gaps could occur both at, and away from, the innermost corners of the interfacing plates (see Figures 1-6 and 1-7). Both types of gaps would have a thermal contribution and a void swelling contribution. The thermal contribution would only be present during power operation. The void swelling contribution would be present under all conditions, including plant shutdown, during which physical examinations of the CS will be performed.

Maximum, bounding values for the thermal portions of these gaps were calculated using conservative, simplifying methods:

- The maximum and minimum temperatures in the CS assembly were obtained.
- The maximum and minimum thermal strains were calculated.
- The nominal thickness of a CS horizontal plate was obtained.
- The maximum permissible as-fabricated local gap between CS plates was obtained.
- The maximum width of a CS horizontal plate from one of the eight innermost corners to the outer periphery was calculated (see Figure 1-1b).
- This maximum plate width was applied to the two interfacing horizontal plates that form the bottom of the upper CS subassembly and the top of the lower CS subassembly. The maximum thermal strain was applied to the interfacing surfaces of these plates. The minimum thermal strain was applied to the opposite surfaces of these plates (see Figure 1-6).
- For each plate, the differential thermal expansion was calculated between the interfacing surface and the opposite surface.
- Per Section 3, it is assumed that the plate is unrestrained and free to deflect as a circular arc in response to the imposed differential thermal expansion.

- The differential thermal expansion was applied as the difference between two circular arc lengths, representing the deflected surfaces of the plate.
- The vertical deflection at one end of the deflected plate was geometrically determined.
- The maximum thermal gap between the innermost corners of the interfacing plates is defined as twice the vertical deflection calculated for one plate.
- The maximum thermal strain applies to the plate thickness at the innermost corners. The minimum thermal strain applies to the plate thickness away from the innermost corners. The differential plate thickness between the locations at and away from the innermost corners is determined using the difference between maximum and minimum thermal strain.
- The maximum thermal gap between the interfacing plates away from the innermost corners is defined as twice the differential thickness calculated for one plate.

Maximum values for the void swelling portions of these gaps would be very difficult to predict, and were not explicitly calculated. Instead, the following process was used to determine the maximum void swelling gaps:

- A maximum void swelling gap was selected based on the ability to readily detect the presence of gaps during the physical examinations of the CS assembly.
- Relative magnitudes of void swelling gaps at different circumferential locations were obtained.
- The assumed maximum gap was used in conjunction with the relative gap data to determine the maximum void swelling gaps both at, and away from, the innermost corners of the interfacing plates.
- The maximum void swelling gaps were adjusted, as necessary, for the potential adverse structural and functional effects, as identified below, to be acceptable.

The total gaps that could occur during power operation would include thermal swelling contribution, void swelling contribution, and the permissible as-fabricated gaps. Maximum total gaps were determined as follows:

- The maximum total gap is equal to the sum of the thermal gap, the void swelling gap, and the permissible as-fabricated gap.
- The maximum total gaps were determined both at, and away from, the innermost corners of the interfacing plates.

The potential adverse effects of these total gaps on the structural integrity of both the fuel assemblies and the reactor vessel internals, along with the potential system level effects, were identified and evaluated. These potential adverse effects include:

1. structural effect on interfacing CS horizontal plates

2. coolant flow jetting through the gap and impinging on the fuel assemblies

3. coolant flow jetting through the gap and impinging on the core support barrel (CSB)

4. *increased gamma heating of the CSB directly adjacent to the gaps*

5. increased fluence applied to the CSB and the reactor vessel directly adjacent to the gaps

6. turbulence in the main coolant flow adjacent to the gap

7. effect on CS-to-CSB bypass coolant flow

8. peripheral fuel assembly grid hanging up on the gap during insertion or withdrawal

9. inward deflection of interfacing CS horizontal plates encroaching on fuel space

2.2 METHODOLOGY FOR SL2

Differential thermal expansion (due to gamma heating) and irradiation-induced void swelling could cause local gaps to form between the interfacing plates of the upper and lower CS subassemblies. The maximum gap would occur at the innermost corners of the interfacing plates (see Figure 1-8). This maximum gap would have a thermal contribution and a void swelling contribution. The thermal contribution would only be present during power operation. The void swelling contribution would be present under all conditions, including plant shutdown, during which physical examinations of the CS will be performed. Conservative, simplifying methods were employed to calculate a maximum, bounding value for the thermal portion of this maximum gap.

A maximum value for the void swelling portion of this maximum gap would be very difficult to predict, and is not explicitly calculated. Instead, a maximum void swelling gap value was selected based on the ability to readily detect the presence of gaps during the physical examinations of the CS.

The maximum total gap that could occur during power operation would include the thermal and the void swelling contributions, as well as the permissible as-fabricated gap. The following methodology was employed to determine this maximum total gap:

- The maximum and minimum temperatures in the CS assembly were obtained.

- The maximum and minimum thermal strains were calculated.

- The nominal thickness of a CS horizontal plate was obtained.

- The maximum permissible as-fabricated local gap between CS plates was obtained.
- The maximum width of a CS horizontal plate from one of the eight innermost corners to the outer periphery was calculated (see Figure 1-2b).
- This maximum plate width was applied to the two interfacing horizontal plates that form the bottom of the upper CS subassembly and the top of the lower CS subassembly. The maximum thermal strain was applied to the interfacing surfaces of these plates. The minimum thermal strain was applied to the opposite surfaces of these plates (see Figure 1-8).
- For each plate, the differential thermal expansion was calculated between the interfacing surface and the opposite surface.
- Per Section 3, it is assumed that the plate is unrestrained and free to deflect as a circular arc in response to the imposed differential thermal expansion.
- The differential thermal expansion was applied as the difference between two circular arc lengths, representing the deflected surfaces of the plate.
- The vertical deflection at one end of the deflected plate was geometrically determined.
- The maximum thermal gap is defined as twice the vertical deflection calculated for one plate.
- A maximum void swelling gap was selected based on the ability to readily detect the presence of gaps during the physical examinations of the CS.
- The maximum total gap is equal to the sum of the thermal gap, the void swelling gap, and the permissible as-fabricated gap.

The potential adverse effects of this maximum total gap on the structural integrity of both the fuel assemblies and the reactor vessel internals, along with the potential system level effects, were identified and evaluated. These potential adverse effects include:

1. structural effect on interfacing CS horizontal plates (including attachment weld)
2. turbulence in the main coolant flow adjacent to the gap
3. peripheral fuel assembly grid hanging up on the gap during insertion or withdrawal
4. inward deflection of interfacing CS horizontal plates encroaching on fuel space

As discussed in Section 1, the circumferential welded attachment between the upper and lower CS subassemblies would prevent the interfacing horizontal plates from separating at their outer peripheries. Therefore, any gaps between the interfacing plates would not extend through the interface, from inside to outside, and would not accommodate coolant flow jetting or neutron streaming. Accordingly, the following potential adverse effects were eliminated from consideration:

1. no coolant flow jetting through the gap and impinging on the fuel assemblies

2. no coolant flow jetting through the gap and impinging on the CSB

3. no increased gamma heating of the CSB directly adjacent to the gaps

4. no increased fluence applied to the CSB and the reactor vessel directly adjacent to the gaps

5. no effect on CS-to-CSB bypass coolant flow

3 SIGNIFICANT ASSUMPTIONS

As a conservative, simplifying measure, adopted to provide a bounding value for the gap between the interfacing horizontal plates of the CS upper and lower subassemblies, it is assumed that deflection of the plates is unrestrained, and that each plate is free to deflect as a circular arc in response to imposed differential thermal expansion.

4 ACCEPTANCE CRITERIA

1. The maximum total gaps between the interfacing horizontal plates of the upper and lower CS subassemblies, which occur during plant operation, must be acceptable from both structural and functional standpoints.

2. The maximum gap during plant shutdown, constituting the acceptance criterion for physical examination of gaps in the CS, must be within the range that can be detected by VT-1 visual examination. Per [2, paragraph 2.3.6.3b.1.]: "Remote EVT-1 or VT-1 examination processes shall be demonstrated as capable of resolving lowercase characters... with character heights no greater than 0.044 in. (1.1 mm) at the maximum examination distance." To distinguish between different characters of 0.044-inch height, it is reasonable to conclude that features of one-half that size (i.e., 0.022 inches or greater) can be resolved by VT-1 visual examination. Therefore, the acceptance criterion for physical examination of gaps in the CS must be $\geq$ 0.022 inches.

5 SUMMARY OF RESULTS AND CONCLUSIONS

Differential thermal expansion (due to gamma heating) and irradiation-induced void swelling could cause local gaps to form between the interfacing plates of the upper and lower CS subassemblies. Accordingly, the total gap at any location would include a thermal contribution and a void swelling contribution. The thermal contribution would only be present during power operation. The void swelling contribution would be present under all conditions, including plant shutdown, during which physical examinations of the CS will be performed.

Per Sections 2.1 and 2.2, the maximum thermal gaps were explicitly calculated, and the maximum void swelling gap was selected based on the ability to readily detect the presence of gaps during physical examinations of the CS. Initially, a maximum void swelling gap of 0.125 inches was assumed to satisfy this subjective requirement.

For SL2, this maximum void swelling gap was combined with the maximum thermal gap and the permissible as-fabricated gap to obtain a maximum total gap. This maximum total gap occurs at the innermost corners of the interfacing plates, and there are no through-gaps because the interfacing plates are welded together at their outer peripheries. The potential adverse effects of this maximum total gap, identified in Section 2.2, were evaluated and determined to be acceptable with one qualification. These results are summarized, and the qualification is described, in Section 5.1.

However, for SL1, the interfacing plates are not welded together. As discussed in Section 1, the maximum gaps (at the innermost corners) do not extend through the interface, but it is possible that smaller through-gaps could form at locations away from the innermost corners. Additional adverse effects associated with these through-gaps are identified in Section 2.1. It was not possible to demonstrate that all of these additional adverse effects are acceptable with a maximum void swelling gap of 0.125 inches. Specifically referring to adverse effect number 7, the additional bypass flow through these through-gaps caused the total bypass flow to exceed the allowable percentages of 4.2% defined in [3, Table 15.2.11-1]. This bypass flow analysis assumed that these through-gaps extended around the entire circumference of the interfacing plates. This assumption is conservative; however, because the locations of maximum void swelling (defining the points of plate-to-plate contact) are circumferentially localized, the through-gaps could certainly extend around most of the circumference. Accordingly, it was necessary to reduce the magnitude of the assumed maximum void swelling gaps so that the bypass flow criteria could be satisfied. Results of this process are summarized in Section 5.2.

5.1 Summary of Results for SL2

The maximum acceptable value for the gap between the interfacing plates of the CS upper and lower subassemblies during normal operation is 0.453 inches. This maximum gap, which occurs at the innermost corners of these interfacing plates, reflects both differential thermal expansion (from gamma heating) and irradiation-induced void swelling, and also includes the permissible as-fabricated gap. The structural and functional effects associated with the presence of this gap, identified in Section 2.2, have been evaluated and are acceptable. However, the acceptability of one of these effects (i.e., inward deflection of interfacing CS horizontal plates encroaching on fuel space) was confirmed using Westinghouse fuel assembly parameters. This effect will also be acceptable with other fuel assemblies, provided that those other fuel assemblies satisfy the following criteria:

1. The axial locations of the spacer grids on the other fuel assemblies must be compatible with those on the Westinghouse fuel assemblies, as would be required with a mixed core of both fuel assembly types.

2. The amount by which the spacer grids overhang the fuel rods on the other fuel assemblies must be greater than the maximum inward deflection of the interfacing CS horizontal plates, which is 0.042 inches. A minimum spacer grid/fuel rod overhang of 0.050 inches will provide acceptable margin.

That portion of the total gap due to differential thermal expansion (0.313 inches) would only be present during power operation. That portion of the total gap due to irradiation-induced void swelling would be present under all conditions, including plant shutdown, during which physical examinations of the CS will be performed.

During plant shutdown, the maximum value for the gap between the interfacing plates of the upper and lower CS subassemblies, reflecting irradiation-induced void swelling and accounting for the permissible fabrication gap, is 0.125 inches. The maximum gap would occur at the innermost corners.

Based on these results, a maximum, bounding gap between the interfacing plates of the upper and lower CS subassemblies, as could be present during plant shutdown, is set at 0.125 inches at the eight innermost corners. These innermost corners correspond to the re-entrant corners identified for coverage via enhanced visual examination (EVT-1) in [4, Table 4-2]. This gap may be used as an acceptance criterion for these examinations of the SL2 CS. This acceptance criterion is greater than the minimum value of 0.022 inches defined in Section 4.

5.2 Summary of Results for SL1

The maximum acceptable value for the gap between the interfacing plates of the CS upper and lower subassemblies during normal operation is 0.128 inches. This maximum gap, which occurs at the innermost corners of these interfacing plates, reflects both differential thermal expansion (from gamma heating) and irradiation-induced void swelling. This maximum gap includes the permissible as-fabricated gap. The maximum gap away from the innermost corners is 0.053 inches. The structural and functional effects associated with the presence of these gaps, identified in Section 2.1, have been evaluated and are acceptable.

Those portions of these total gaps due to differential thermal expansion (0.058 inches at the innermost corners and 0.010 inches away from the innermost corners) would only be present during power operation. Those portions of the total gaps due to irradiation-induced void swelling would be present under all conditions, including plant shutdown, during which physical examinations of the CS will be performed.

During plant shutdown, the maximum gap due to void swelling, which occurs at the innermost corners, is 0.055 inches. The maximum void-swelling gap away from the innermost corners, which is derived from the corner gap using relative void swelling gap distributions, is 0.028 inches. The total gaps during plant shutdown, which include the permissible fabrication gap, are 0.070 inches at the innermost corners and 0.043 inches away from the innermost corners.

Based on these results, a maximum, bounding gap between the interfacing plates of the CS upper and lower subassemblies, as could be present during plant shutdown, is set at 0.070 inches at the eight innermost corners. These innermost corners correspond to the re-entrant corners identified for coverage via enhanced visual examination (EVT-1) in [4, Table 4-2]. This gap may be used as an acceptance criterion for these examinations of the SL1 CS. This acceptance criterion is smaller than the initially-assumed value of 0.125-inch (see Section 5), but is still greater than the minimum value of 0.022 inches defined in Section 4. The gaps away from the innermost corners, which are derived from the corner gaps, as discussed above, need not be examined.

6 REFERENCES

1. Letter from the U.S. NRC to Neil Wilmshurst of EPRI, "Revision 1 to the Final Safety Evaluation of Electric Power Research Institute (EPRI) Report, Materials Reliability Program (MRP) Report 1016596 (MRP-227), Revision 0, 'Pressurized Water Reactor (PWR) Internals Inspection and Evaluation Guidelines' (TAC No. ME0680)," December 16, 2011. (ADAMS Accession Number ML11308A770)
2. *Materials Reliability Program: Inspection Standard for PWR Internals – 2012 Update (MRP-228, Rev 1)*. EPRI, Palo Alto, CA: 2012. 1025147.
3. St. Lucie Nuclear Power Plant Unit 1 Final Safety Analysis Report, Amendment No. 25.
4. *Materials Reliability Program: Pressurized Water Reactor Internals Inspection and Evaluation Guidelines (MRP-227-A)*. EPRI, Palo Alto, CA: 2011. 1022863.