ENCLOSURE 9

Summary of SCC Assessment of SS Welds in 24P and 32P NUHOMS® Dry Storage Casks – Non-Proprietary

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Calvert Cliffs Nuclear Power Plant, LLC
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AREVA

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Title Summary of SCC Assessment of SS Welds in 24P and 32P NUHOMS® Dry Storage Casks

PURPOSE AND SUMMARY OF RESULTS:

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The purpose of this document is to provide stress corrosion cracking (SCC) growth evaluation of potentially initiated flaws on the OD surface of circumferential and axial stainless steel (SS) welds in the NUHOMS® Dry Shield Canister (DSC) in the Independent Spent Fuel Storage Installation (ISFSI) at the Calvert Cliffs Nuclear Power Plant site.

Since residual stresses are a key driver of SCC, residual stresses are first calculated by finite element analyses of the circumferential and axial SS welds in the DSC. The analyses involve simulation of the circumferential and axial SS welds in the canister shell. Both the NUHOMS® 24P and 32P DSC designs are analyzed. The states of stresses after welding and the minimum normal operating conditions ID shell temperature of **[ ]** (**[ ]** - corresponding to the **[ ]** case) as predicted by finite element analysis are generated. Stresses along paths through the center of welds are extracted and used as in the flaw evaluations of the circumferential and axial SS welds. Axial and circumferential outside surface flaws are postulated and crack growth calculations are performed for both the circumferential and axial welds.

The results from the fracture mechanics analysis performed to evaluate the DSC show that the limiting postulated outside surface flaws in the circumferential and axial welds will take 48 years to grow near-through-wall for both the 24P and the 32P designs. These near through-wall flaws are shown to be stable against unstable ductile fracture. Note that conservatively the SCC initiation criterion is not checked in this assessment.

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THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

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1.0 PURPOSE

The purpose of this document is to provide stress corrosion cracking (SCC) growth evaluation of potentially initiated flaws on the OD surface of circumferential and axial stainless steel (SS) welds in the NUHOMS® Dry Shield Canister (DSC) in the Independent Spent Fuel Storage Installation (ISFSI) at the Calvert Cliffs Nuclear Power Plant site.

2.0 ASSUMPTIONS

This section discusses assumptions and modeling simplifications applicable to the present evaluation of DSC in the ISFSI at CCNPP site.

1) The crack growth rate is assumed to be **[ ]** m/s [5] when $K_I \geq 0.5\ \mathrm{MPa}\sqrt{m}$. An additional crack growth criterion proposed (WRS > 0.5 YS, WRS is the welding residual stress, and YS is the yield strength) in Reference 5, were conservatively not considered in this analysis.

2) In the circumferential seam welds, the postulated circumferential flaws are treated as full 360° circumferential flaws. Axially oriented flaws are also conservatively postulated in circumferential seam welds and treated as semi-elliptical flaw with 1:6 aspect ratio. In the axial seam welds, the postulated axial flaws are treated as axial slits that extend through the full length of the weld. In addition, circumferentially oriented flaws are conservatively postulated in the axial seam welds and treated as semi-elliptical flaws with an aspect ratio of 1:6. These simplified assumptions result in conservative stress intensity factor (SIF) estimates for both circumferential and axial flaws in the welds.

3) Stability of the final flaw size was evaluated using flaw evaluation formulation in C-5000 of ASME Code Section XI [6]. The final flaw sizes were larger than the limits of applicability of article C-5000 ($a/t \leq 0.75$). The formulation is assumed to be valid for $a/t > 0.75$ in the current application.

4) In this evaluation, the SIF threshold for crack growth is assumed to be $\geq 0.5\ \mathrm{MPa}\sqrt{m}$. (Slightly higher stress intensity factor threshold, say $\geq 2.0\mathrm{MPa}\sqrt{m}$ significantly decreases the crack growth.)

2.1 Design inputs

2.1.1 Geometry

The detailed dimensions of the DSC shells and welds modeled in the WRS finite element analysis are obtained from References [1] and [2]. The key dimensions are shown in Table 2-1.

Table 2-1: DSC Shells and Welds Dimensions for 24P and 32P

Dimension	Value
DSC Shell/Weld ID	
DSC Shell/Weld OD	
Thickness (Nominal) at Shell/Weld	

2.1.2 Welding Parameters

References [3] and [4] provide a set of welding procedure or parameters that are used in the present welding simulations to establish required parameters for the SS welds. The welding parameters used in the modeling of the welding processes are shown in Table 2-2.

Table 2-2: Welding Parameters

Welding Parameters	24P Welds [3]	32P Welds [4]
Rod Diameter		
Current		
Voltage		
Travel Speed		
Arc Efficiency		
Maximum Interpass Temperature		

†These values are average from indicated procedure specifications for different welds used in the build-up of the weld.

2.1.3 SCC CGR

SCC growth is calculated using crack growth rate provided by Transnuclear [5]. This crack growth rate model is based on industry/academic research data for stress corrosion cracking of SS material in brine environment. The crack growth rate is:

when $K_I \geq 0.5$ MPa√m, and WRS > 0.5 YS, where K_I is the stress intensity factor, WRS is the welding residual stress, and YS is the yield strength. However, the present analysis conservatively did not consider the yield strength criterion for crack initiation (WRS > 0.5 YS).

2.1.4 Crack Growth and Flaw Evaluation

Crack growth was performed by calculating the stress intensity factor and updating the flaw size at intervals of 1 year until the crack grows near through-wall. Size of the flaw at the end of year-before it grows through-wall is taken as the final flaw size. An evaluation of the final flaw is performed based on Appendix C of the ASME Code [6]. Axial flaws are evaluated using Article C-5420 and circumferential flaws are evaluated based on Article C-5320. However, note that as per the ASME Code [6] limits of applicability of equations in C-5000 are only up to $a/t \leq 0.75$.

3.0 RESULTS OF WELD RESIDUAL STRESS ANALYSIS

Following the completion of the weld simulation, a steady state temperature of **[ ]** [5] (corresponds to DSC shell temperature for the **[ ]** case) at the ID which uniformly decreases to **[ ]** at the OD is applied.

3.1 DSC 24P Design

The longitudinal and hoop stress contours for the circumferential weld are shown in Figure 3-1 and Figure 3-2 respectively. Figure 3-3 and Figure 3-4 respectively show the longitudinal and hoop stress contours for the axial weld. The longitudinal and hoop stress distributions along the path through the center of the circumferential weld through the thickness are shown in Figures 3-5 and 3-6 respectively. The distributions of longitudinal and hoop stresses along paths through the center of the axial weld are shown in Figures 3-7 and 3-8 respectively.

Figure 3-1: 24P DSC Circumferential Weld: Longitudinal stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

Figure 3-2: 24P DSC Circumferential Weld: Hoop stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

Figure 3-3: 24P DSC Axial Weld: Longitudinal stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] °F at the ID and decay to [ ] at the OD following completion of the weld.)

Figure 3-4: 24P DSC Axial Weld: Hoop stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

Figure 3-5: 24P DSC Circumferential Weld: Longitudinal stress distributions at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

Figure 3-6: 24P DSC Circumferential Weld: Hoop stress distributions at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

Figure 3-7: 24P DSC Axial Weld: Longitudinal stress distributions at an ID operating temperature of [ ] . (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

Figure 3-8: 24P DSC Axial Weld: Hoop stress distributions at an ID operating temperature of [ ] . (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

3.2 DSC 32P Design

The longitudinal and hoop stress contours for the circumferential weld are shown in Figure 3-9 and Figure 3-10 respectively. Figure 3-11 and Figure 3-12 respectively show the longitudinal and hoop stress contours for the axial weld. The longitudinal and hoop stress distributions along the path through the center of the circumferential weld through the thickness are shown in Figures 3-13 and 3-14 respectively. The distributions of longitudinal and hoop stresses along paths through the center of the axial weld are shown in Figures 3-15 and 3-16 respectively.

Figure 3-9: 32P DSC Circumferential Weld: Longitudinal stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

Figure 3-10: 32P DSC Circumferential Weld: Hoop stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

Figure 3-11: 32P DSC Axial Weld: Longitudinal stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

Figure 3-12: 32P DSC Axial Weld: Hoop stress contours at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

Figure 3-13: 32P DSC Circumferential Weld: Longitudinal stress distributions at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

Figure 3-14: 32P DSC Circumferential Weld: Hoop stress distributions at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

Figure 3-15: 32P DSC Axial Weld: Longitudinal stress distributions at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

Figure 3-16: 32P DSC Axial Weld: Hoop stress distributions at an ID operating temperature of [ ]. (Obtained by applying [ ] at the ID and decay to [ ] at the OD following completion of the weld.)

[ ]

4.0 RESULTS OF FLAW GROWTH ANALYSIS

The following tables present the results of the flaw growth analysis performed for the 24P and 32P DSC designs.

4.1 24P Circumferential Welds

Table 4-1: Results of Flaw Growth Analysis of Axial Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Aspect Ratio	6	
Initial Flaw Length	0.236	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	48	years

A semi-elliptical axial flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) will reach [ ]% of through-wall depth ([ ] inch) at the end of 48th iteration. A flaw evaluation based on methodology prescribed in C-5420 [6] shows that the final flaw is stable. Therefore, the SCC crack propagation time is estimated as 48 years.

Table 4-2: Results of Flaw Growth Analysis of Circumferential Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Initial Flaw Length	207.35	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	>60	years

A full 360° cylindrical flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) [ ] and therefore the postulated flaw can remain in the weld for more than 60 years.

4.2 24P Axial Welds

Table 4-3: Results of Flaw Growth Analysis of Axial Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Initial Flaw Length	[ ]	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	48	years

A full length axial flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) will reach [ ]% of through-wall depth ([ ] inch) at the end of 48th iteration. A flaw evaluation based on methodology prescribed in C-5420 [6] shows that the final flaw is stable. Therefore, the SCC crack propagation time is estimated as 48 years.

Table 4-4: Results of Flaw Growth Analysis of Circumferential Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Aspect Ratio	6	
Initial Flaw Length	0.24	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	48	years

A semi-elliptical circumferential flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) will reach [ ]% of through-wall depth ([ ] inch) at the end of 48th iteration. A flaw evaluation based on methodology prescribed in C-5320 [6] shows that the final flaw is stable. Therefore, the SCC crack propagation time is estimated as 48 years.

4.3 32P Circumferential Welds

Table 4-5: Results of Flaw Growth Analysis of Axial Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Aspect Ratio	6	
Initial Flaw Length	0.236	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	48	years

A semi-elliptical axial flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) will reach [ ] % of through-wall depth ([ ] inch) at the end of 48th iteration. A flaw evaluation based on methodology prescribed in C-5420 [6] shows that the final flaw is stable. Therefore, the SCC crack propagation time is estimated as 48 years.

Table 4-6: Results of Flaw Growth Analysis of Circumferential Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Initial Flaw Length	[ ]	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	>60	years

A full 360° cylindrical flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) [ ] and therefore the postulated flaw can remain in the weld for more than 60 years.

4.4 32P Axial Welds

Table 4-7: Results of Flaw Growth Analysis of Axial Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Initial Flaw Length	[ ]	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	>60	years

A full axial flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) [ ] and therefore the postulated flaw can remain in the weld for more than 60 years.

Table 4-8: Results of Flaw Growth Analysis of Circumferential Flaws

Thickness	[ ]	inch
Initial Flaw Depth	0.0394	inch
Aspect Ratio	6	
Initial Flaw Length	0.24	inches
Inner radius, R_i	[ ]	inches
Final Flaw Depth	[ ]	inch
Time for Flaw Growth	48	years

A semi-elliptical circumferential flaw with an assumed initial flaw depth of 0.0394 inch (1 mm) will reach [ ]% of through-wall depth ([ ] inch) at the end of 48th iteration. A flaw evaluation based on methodology prescribed in C-5320 [6] shows that the final flaw is stable. Therefore, the SCC crack propagation time is estimated as 48 years.

5.0 CONCLUSIONS

The results from the fracture mechanics analysis performed to evaluate the DSC show that limiting postulated external surface flaws in the circumferential and axial welds will take 48 years to grow near through-wall. These near through-wall flaws are shown to be stable against unstable ductile fracture. Note that conservatively the SCC initiation criterion is not checked in this assessment.

Recommendations:

- Since the current analysis studies the growth of postulated initial flaws and calculated the life after crack initiation as 48 years, periodic monitoring for crack initiation is recommended.
- A more comprehensive and less conservative analysis based on more accurate weld parameters and applicable operation conditions are recommended.

6.0 REFERENCES

1. AREVA Document 38-9203276-000, " Transnuclear Weld Records for 24P Canister"
2. AREVA Document 38-9203299-000, " Transnuclear Weld Records for 32P Canister"
3. AREVA Document 38-9203278-000, "Transnuclear Weld Procedures for 24P Canister"
4. AREVA Document 38-9203300-000, "Transnuclear Weld Procedures for 32P Canister"
5. AREVA Document 38-9203575-000, "Technical Inputs for TN CC ISFSI Cask Welds Project"
6. ASME B&PV Code 2004 Edition, Section XI