Assessment of the Discrepancy in the RPV Internals Seismic Analysis Dresden Unit 3 and Quad Cities Units 1 and 2

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Table of Contents

1.0 Background Information and Introduction

The original design basis seismic analysis of the Dresden and Quad Cities Reactor Pressure Vessel (RPV) Internals were performed in the late nineteen sixties and early nineteen seventies using a primary structure seismic model (see References 1 and 2). These models included the Turbine and Reactor Buildings, the shield wall, the RPV and the RPV internals such as the core shroud and the fuel. As part of ComEds preparation to address issues associated with flaws in the RPV internals, new rebaselined seismic models were prepared for the Dresden and Quad Cities Stations in 1994 (References 3 and 4). The new models were verified versus the original design basis models. These rebaselined seismic models were then used as the primary design input for the analysis and design of the core shroud repair hardware.

As part of a recent internal review of the Dresden core shroud repair hardware design, a discrepancy was identified in the mass used at one node point representing the top guide, part of the fuel and a portion of the core shroud. The total mass modeled at this location, node 19 for Dresden (Reference 3) and node 16 for Quad Cities (Reference 4), represents the real mass plus hydrodynamic mass (including the mass of the top guide, the mass of part of the fuel and the hydrodynamic mass). The total mass at this node point was identified as being reduced by one order of magnitude. This is a single mass point discrepancy, out of many mass points in a very large seismic model. Consequently, the potential analytical impact is primarily limited to a localized area of the shroud at the top guide location. The total mass modeled at this node point was 1.73E3 slugs instead of 17.3E3 slugs. ComEd has determined that this discrepancy was replicated from the original design basis seismic analysis (Reference 1) into the rebaselined seismic analysis (References 3 and 4). The Dresden and Quad Cities original design basis seismic analysis was previously used for core shroud flaw evaluations and the rebaselined seismic models were used for the core shroud repair design (References 5 through 8).

Once this analytical discrepancy was identified, Dresden and Quad Cities Stations generated a Problem Identification Form (PIF) to identify and track the issue. In addition, each Station performed a Plant Operability determination to identify any potential impact on plant equipment or system operability. Design Engineering at each station has determined the effected Units (Dresden Unit 3 and Quad Cities Unit 1 and 2) to be operable based on the operability determination assessments.

This assessment has been prepared to provide a preliminary evaluation of the scope and impact of the identified seismic mass discrepancy, and to identify the plan for the resolution of this discrepancy. The following sections of this report present the methodology and results of the preliminary evaluations. The preliminary results, where data is available, were compared to the original evaluations. Section 2 addresses the revised seismic analysis results, and Section 3 addresses the evaluation of the impact on the inspected Units (Dresden Unit 3 and Quad Cities Unit 1). Section 4 addresses the evaluation of the impact on the repaired Unit, Quad Cities Unit 2. The conclusions of these preliminary evaluations are provided in Section 5 and the references are listed in Section 6.

2.0 Revised Seismic Analysis Results

2.1 Dresden Unit 3 and Quad Cities Unit 1

A preliminary analysis was performed using the rebaselined seismic models for both Dresden and Quad Cities with the revised total mass at the top guide location. A comparison of the results of these new analyses versus the original design basis analysis is provided in Tables 2.1 and 2.2. Both of these models include the stiffness properties of an intact shroud. The effect of the mass change at this one specific node is most pronounced in the localized response of the core shroud.

Table 2.1 Dresden Units 2 and 3 Summary of Design Basis OBE Seismic Moments

Horiz. Weld No.	Node No.	Original Design Basis Moment (In.-Kips)	Revised Analysis Moment (In.-Kips)
H1		3,240	5,100
H2		6,780	12,300
H3		7,220	13,300
H4		23,400	47,400
H5		40,100	81,200
H6		41,400	83,500
H7		60,300	116,000
H8	25	64,300	123,000

Notes:
1. The node numbers indicated correspond to the rebaselined seismic model (Reference 3).
2. The larger of the E-W or N-S moments are indicated.

Table 2.2 Quad Cities Units 1 and 2 Summary of Design Basis OBE Seismic Moments

Horiz. Weld No.	Node No.	Original Design Basis Moment (In.-Kips)	Revised Analysis Moment (In.-Kips)
H1		5,190	6,800
H2		11,600	14,400
H3		12,400	15,300
H4		43,100	50,900
H5		77,200	89,500
H6		79,600	92,100
H7		113,000	128,800
H8	22	119,000	135,900

Notes:

1. The node numbers indicated correspond to the rebaselined seismic model (Reference 4).
2. The larger of the E-W or N-S moments are indicated.

A review of the preliminary analysis for an intact shroud indicates that the primary impact in the seismic response is locally within the elements representing the core shroud. A review of the total mass modeled for the core shroud elements versus the other structural elements (see Table 2.3) indicates that though the change is significant at the core plate location, the magnitude of the change is small in comparison to the total mass of the RPV internals (17%), and insignificant in comparison to the mass of the rest of the RPV and building structures (0.1%). A comparison of the modal frequencies from the rebaselined seismic analyses (with mass discrepancy) versus the revised analysis results (with the corrected mass) is provided in Tables 2.4 and 2.5. These tables illustrate that the effect of this localized mass discrepancy is minimal with respect to the overall seismic response. Note that a comparison of the Quad-Cities modal frequencies produces similar results and thus have not been included in this report.

Table 2.3 Comparison of Total Nodal Mass Dresden Model

Node No.	Elevation (Feet)	Component	Total Mass Slugsx10^3	Total Weight Kips	Remarks
1-3,5-9,11,12	594-532	RPV	130.76	4210.5	
14	574.84	Shroud	2.67	86.0	
17	565.67	Shroud	1.73	55.7	
19	561.92	Shroud	17.30	557.1	Top Guide
20	559.00	Shroud	15.60	502.3	
22	547.96	Shroud	17.73	570.9	Core Plate
24	542.92	Shroud	17.96	570.9	
14,17,19,20, 22,24	575-543	$\sum$Shroud	72.99	2350.3	
26-30	559-539	Fuel & Guide Tubes	15.25	491.1	
31-33	527-519	CRD Housings	5.26	169.4	
37-39	565-540	Shield Wall	44.03	1417.8	
40	517.33	RPV Pedestal	32.16	1035.6	
41-45, 47,49,50	659-517	Reactor Bldg.	6418.02	206,660.2	
52-55	622-561	Turbine Bldg.	2359.15	75,964.6	
Totals			9077.6	292,299.4	

Notes:
1. Values indicated include both the structural mass and the hydrodynamic mass.
2. The elevations and components indicated are an approximate representation of the actual modeling.
3. Values indicated are from Reference 3, Appendix C, with a correction of the mass at node 19. The corresponding Quad Cities values are approximately the same.
4. Only the nodes with lumped mass are included in this table, a complete listing of all nodes is provided in References 3 and 7.

Table 2.4 Comparison of Modal Frequencies - Dresden Units 2 and 3 E-W

Mode	Rebaselined Model Frequency (Hz.)	Revised Model Frequency (Hz.)	Percent Change
1	2.64 - Turbine Bld.	2.64 - Turbine Bld.	0.0%
2	2.73 - Reactor Bld.	2.73 - Reactor Bld.	0.0%
3	4.12 - CRD Housing	4.11 - CRD Housing	0.2%
4	4.36 - Fuel & G. Tubes	4.14 - CRD Housing	N/A
5	5.86 - RPV	5.86 - RPV	0%
6	6.53 - RPV	5.95 - Shroud	N/A
7	7.81 - Shroud	6.72 - RPV	N/A
8	8.51 - Reactor Bld.	8.51 - Reactor Bld.	0%
9	11.58 - Turbine Bld.	11.58 - Turbine Bld.	0%
10	13.92 - RPV	13.90 - RPV	0.1%

Table 2.5 Comparison of Modal Frequencies - Dresden Units 2 and 3 N-S

Mode	Rebaselined Model Frequency (Hz.)	Revised Model Frequency (Hz.)	Percent Change
1	2.36 - Reactor Bld.	2.36 - Reactor Bld.	0.0%
2	3.99 - Turbine Bld.	3.99 - Turbine Bld.	0.0%
3	4.12 - CRD Housing	4.11 - CRD Housing	0.2%
4	4.36 - Fuel & G. Tubes	4.14 - CRD Housing	N/A
5	4.98 - Turbine Bld.	4.98 - Turbine Bld.	0%
6	6.10 - RPV	5.94 - Shroud	N/A
7	6.53 - RPV	6.11 - RPV	6.8%
8	7.33 - Reactor Bld.	6.71 - RPV	N/A
9	7.81 - Shroud	7.33 - Reactor Bld.	N/A
10	12.97 - RPV	12.97 - RPV	0.0%

2.2 Quad Cities Unit 2

The seismic analysis used for the design of the core shroud repair hardware (References 5 and 6) is also affected by this discrepancy. Preliminary results using the same seismic modeling techniques with the correction in the top guide mass indicate an increase in the deflections of the upper portion of the shroud and a corresponding increase in the forces in the upper and middle lateral springs. Section 4 of this report provides an explanation of the revised seismic modeling method that is being used to more accurately determine the deflected shape of the core shroud and RPV. Since the loads that act on the core shroud repair hardware are induced by differential seismic displacement (i.e. compression or extension of the springs), any method that more accurately defines the relative displacements will provide more accurate results. Preliminary evaluations have shown that this more refined modeling method will produce results that will be bounded by the previous more conservative analysis.

3.0 Evaluation of the Impact on Dresden Unit 3 and Quad Cities Unit 1

The original seismic design basis results were previously used for the analysis and evaluation of the core shroud flaws identified at the Dresden 3 and Quad Cities 1 Units during the Spring outages of 1994. The core shroud flaw evaluations and safety assessments for these plants were based on the results of the original seismic analysis with this seismic mass discrepancy. The effect of the discrepancy in the mass of the top guide is primarily concentrated in the response of the shroud. This has been determined based on preliminary seismic analysis utilizing the revised seismic model. The change in the seismic response (moments) of the core shroud was summarized in Tables 2.1 and 2.2, and were included in the following evaluations of the critical H5 flaw. The impact of the revised core shroud seismic response has been directly incorporated into this evaluation of the flaw assessments and the safety assessments (References 13-16) which were submitted to the NRC on December 14, 1994.

3.1 Impact on the December 14, 1994 Flaw Evaluation Results

Several assessments were performed as part of the comprehensive core shroud flaw evaluations for the identified cracking at Dresden Unit 3 and Quad Cities Unit 1. These evaluations were reviewed by the NRC and a Safety Evaluation was issued on July 21, 1994 (Reference 10). Updated flaw evaluations were completed and submitted to the NRC on December 14, 1994 (References 14 and 16). These updated flaw evaluations incorporated all of the results of the ComEd efforts to more clearly define the loadings, flaw size and crack growth parameters and thus serve as the basis for this revised flaw evaluation. This evaluation is based on a detailed assessment of the H5 circumferential weld location as it was the location with the most significant amount of cracking discovered during the previous inspections. The same structural margin assessments as previously reported in Table 3.2 of the above referenced reports have been performed for the governing loading cases and are summarized in Tables 3.1 and 3.2 below. The required ligaments and operating time until the allowable depth is reached, were calculated using the same limit load approach as was used for the previous evaluations. These tables provide a direct comparison between the bounding results of the December 14, 1994 flaw evaluation and the revised results with the correction of the mass discrepancy.

Table 3.1 Dresden Unit 3 Summary of Required Ligament at H5

Weld Location	Critical Loading Case	Maximum d/t Ratio	(Revised)Required Ligament (RL) t=2"	(Revised) Time Until Allowable Depth Is Reached (Months)[1,2]	(Previous) Time Until Allowable Depth Is Reached (Months)[1,2]
H5	Normal	1.0000	0.0000"	22.8	22.8
H5	SSE	0.9660	0.0680"	20.8	21.8
H5	MSLOCA	0.9985	0.0030"	22.7	22.7
H5	RRLOCA	0.9988	0.0024"	22.7	22.7
H5	SSE+MSLOCA	0.9636	0.0722"	20.6	21.7
H5	SSE+RR LOCA	0.9648	0.0704"	20.7	21.7

Table 3.2 Quad Cities 1 Summary of Required Ligament at H5

Weld Location	Critical Loading Case	Maximum d/t Ratio	(Revised)Required Ligament (RL) t=2"	(Revised) Time Until Allowable Depth Is Reached (Months)[1&2]	(Previous) Time Until Allowable Depth Is Reached (Months)[1&2]
H5	Normal	1.0000	0.0000"	22.8	22.8
H5	SSE	0.9625	0.0750"	20.6	20.9
H5	MSLOCA	0.9975	0.0050"	22.6	22.6
H5	RRLOCA	0.9988	0.0024"	22.7	22.7
H5	SSE+MSLOCA	0.9593	0.0814"	20.4	20.7
H5	SSE+RRLOCA	0.9613	0.0774"	20.5	20.8

Notes:

1. The remaining ligament is based on an assumed upper bound crack depth of 1.24 inches with an original wall thickness of 2 inches. The additional ligament provided by the 1" fillet weld has been conservatively neglected for this evaluation.
2. The "Time Until Allowable Depth Is Reached" has been calculated as follows:
   Months = [(2.0"-RL"-1.24")/5.0 E-5 In./Hr.}/666.67 hours/month

3.2 Impact on the December 14, 1994 Safety Assessments

Detailed safety assessments of postulated through wall cracking of the core shroud circumferential welds were prepared for Dresden Unit 2 and Quad Cities Unit 2 (see References 13 and 15) and were submitted to the NRC on December 14, 1994. These safety assessments were reviewed by the NRC and a Safety Evaluation Report (SER) was issued for the continued operation of these units on January 31, 1995 (Reference 9). These safety assessments which were specifically prepared for Dresden Unit 2 and Quad Cities Unit 2 were also applicable for the sister units Dresden Unit 3 and Quad Cities Unit 1. The structural loadings used to perform the previous safety assessment are only marginally affected by this seismic analysis discrepancy as the calculated seismic displacements are not significantly affected. The seismic lifts used are not affected by this discrepancy as the vertical seismic response is based on a uniform seismic input acceleration. The conclusion of these safety assessments was that in the unlikely occurrence of a design basis accident, safe reactor shutdown will be achieved, and the short term and long term cooling requirements will be satisfied. Tables 2.1 through 2.6 of the referenced reports provide a detailed summary of the plants safety features under all of the postulated events, and still remain valid.

3.3 Impact on the NRC Safety Evaluation

The previous NRC SER for the inspected Dresden Unit 3 and Quad Cities Unit 1 (Reference 10), was based partially on an assessment of the critical H5 flaw. This assessment provides the justification that the impact of the identified mass discrepancy on the previous flaw evaluation is minimal and that the conclusions remain valid. The previous NRC SER for the uninspected Dresden Unit 2 and Quad Cities Unit 2 (Reference 9), was based partially on the original seismic design basis analysis. The effect of the mass discrepancy on the previous SER is minimal and the overall impact on the core shroud response does not change the conclusions of the previous safety assessments.

4.0 Evaluation of the Impact on Quad Cities Unit 2

The impact of the discrepancy in the mass at the top guide location, with respect to RPV internals and the core shroud repair hardware has been evaluated using the preliminary results of the reanalysis. This evaluation shows that the shroud and shroud repair hardware stresses are below the design allowable stresses, and that the existing design remains valid.

4.1 Stress Margins in the Existing Hardware Design

The stress margins in the shroud and shroud repair hardware for Quad Cities Unit 2 using the seismic analysis which includes the mass discrepancy, (References 5 and 6) are presented in Table 4.1. This table provides a summary of the repair hardware critical stress given as a percent of the allowable stress limit for each loading condition. A review of this table illustrates that the existing hardware design includes a significant design margin.

Table 4.1 Summary Of Existing Design Margins
(Percent of Stress Limit)

Component	Normal & Upset	Emergency	Faulted
Shroud	49%	45%	45%
Upper Spring	57%	75%	56%
Long Upper Support	38%	71%	67%
Bracket Yoke	37%	74%	74%
Middle Spring	73%	97%	73%
Lower Spring	70%	93%	70%
Tie Rod	41%	82%	81%

4.2 Refined Representation of Weld-Crack Interface and Tie Rod Stiffness

The conservative bounding "pinned" and "roller" shroud weld-crack connectivity conditions are replaced by single "pinned" connectivity conditions in conjunction with rotational springs. The improved configuration is more representative of the actual three-dimensional, cracked shroud continuum and will enable the cracked shroud, in the primary structure beam element seismic model, to transfer part of the fuel horizontal inertia loads to the RPV wall during seismic/dynamic excitation.

The improved representation of the weld-crack interface connectivity is based on the fact that the three-dimensional geometry of the cracked shroud has a significant capacity to transmit moment across each weld-crack interface plane. This inherent capability is not accounted for in the bounding "pinned" and "roller" weld-crack shroud connectivity conditions currently utilized.

The tie-rods are attached to the shroud head support ring at the upper end and to the shroud support plate at the lower end. The tie rods act as axial members and can transmit only vertical loads. Consequently, in the seismic horizontal beam element model, the only elastic coupling between the plane of the shroud head support ring and that of the shroud support plate, due to the tie rods, is rotational. Due to differential elongation, the tie rods give rise to a restoring moment between the shroud flange plane and that of the shroud support plate if, and only if, there is relative rotation between the two planes. No restoring moment develops between the two planes if there is no relative rotation. The restoring moment is due to tie rod differential elongation and is independent of whether or not the shroud compressive load, due to the tie rod preload is relieved during seismic/dynamic excitation. Additional extension of the tie rod due to rotation of an intermediate section of shroud between circumferential weld cracks does not change the tie rod rotational stiffness between the planes of the shroud flange and the shroud support plate.

The tensile loads which develop in the vertical tie rods, as a result of rotation of the shroud three-dimensional geometry, are applied to calculate equivalent rotational stiffness at the circumferential weld-crack in the horizontal seismic model. The equivalent rotational stiffnesses impede opening of the weld-crack and enables the shroud to transfer horizontal shear loads.

The initial preload in the tie rod (mechanical plus thermal) and the restoring moment due to dead weight are conservatively neglected in the calculation of the rotational stiffness. These effects will, however, be included when calculating the tie rod maximum loads.

Because of the three dimensional geometry of the "shroud/tie rod" assembly, any rotation of the plane containing the tie rod upper supports relative to the shroud support plate will elongate the tie rods. Also, the rotation of any shroud section with circumferential weld cracks at the top and bottom will have the same effect. The elongation of the vertical tie rods can be modeled as equivalent rotational springs in the horizontal seismic model at weld cracks since they tend to impede opening of the weld cracks.

The rotational stiffnesses used in the new seismic analysis are:

Tie rods - $2(AE/L)r^2$

At the shroud welds - $4(AE/L)r^2$

where: AE/L = axial stiffness of tie rod from FEA

r = radius of tie rod location

4.3 Overview of Results Using the New Analysis Approach

A preliminary seismic analysis of the shroud with the repair hardware installed was performed for the Dresden plant. The results of this analysis show a reduction in all of the loads on the repair hardware, the horizontal spring loads and the tie rod loads, for the upset, emergency and faulted loading conditions. The loads on the upper spring were reduced by approximately 30%, on the middle spring they were reduced by about 15%, on the lower spring by about 80%. The loads on the tie rods were reduced by about 5%. This preliminary assessment of the Dresden design provides an analogous example for the Quad Cities design.

4.4 Overview of Results Using the New Analysis Approach

The current plan is to revise the Primary Structural Seismic Model reports, References 3 and 4, and then revise the Shroud Repair Seismic Analysis reports, References 5 and 7. The revised reports will show that the loads on the shroud and the shroud repair hardware is less than what was previously used to evaluate them.

5.0 Summary and Conclusions

Preliminary evaluations on the inspected Units (Dresden Unit 3 and Quad Cities Unit 1) have shown that the effect of this discrepancy on the shroud seismic response will not invalidate the conclusions of the existing flaw evaluations (References 14 and 16). The identified safety margins for the critical H5 flaw are sufficient to account for this discrepancy in the seismic analysis and to demonstrate adequate margin to continue to operate these units. Preliminary evaluations of the Quad Cities Unit 2 core shroud repair hardware, show that other conservatism in the shroud seismic modeling and hardware stress analysis can be reevaluated and will demonstrate that the existing core shroud repair design is adequate with the correction of this discrepancy. The results presented in this report in conjunction with the original safety assessment for a fully cracked core shroud (References 13 and 15), clearly demonstrate that the effect of this discrepancy will not change the conclusions of the previous assessments performed by both ComEd (References 13-16) and the NRC (References 9-12).

6.0 References

1. GE Report 257HA718, Revision 0, "Seismic Analysis for Reactor Internals for Dresden II and Millstone Plants", December 24, 1968.
2. GE Report 257HA925, DAR 93, Revision 1, "Seismic Response of Quad Cities Reactor Pressure Vessel and Internals", February 1970.
3. GENE-523-A181-1294, Revision 0, "Dresden Units 2 & 3 - Primary Structure Seismic Models", December 1994.
4. GENE 523-A169-1194, "Commonwealth Edison Company Quad Cities Nuclear Power Station, Units 1 & 2, Primary Structure Seismic Models", November 16,1994.
5. GENE 771-71-1094, Revision 1, "Quad Cities Units 1 and 2 - Shroud Repair Seismic Analysis", January 5, 1995.
6. GENE 771-72-1091, Revision 1, "Quad Cities Units 1 & 2 Shroud Repair Seismic Analysis Backup Calculations", January 5, 1995.
7. GENE-771-84-1194, Revision 2, "Dresden Units 2 & 3, Shroud Repair Seismic Analysis", May 1, 1995.
8. GENE 771-85-1194, Revision 2, "Dresden Units 2 & 3, Shroud Repair Seismic Analysis Backup Calculations", May 1, 1995.
9. U. S. Nuclear Regulatory Commission Letter, John F. Stang - Senior Project Manager, To D. L. Farrar - Manager, Nuclear Regulatory Service ComEd, Subject - Resolution of Generic Letter 94-03, Intergranular Stress Corrosion Cracking of Core Shrouds in Boiling Water Reactors at Dresden, Units 2 and 3, and Quad Cities , Units 1 and 2 (TAC NOS. M90088, M90089, M90109, and M90110), dated January 31, 1995.
10. U. S. Nuclear Regulatory Commission Letter, John F. Stang - Project Manager, To D. L. Farrar - Manager, Nuclear Regulatory Service ComEd, Subject - Resolution of Core Shroud Cracking at Dresden, Units 3, and Quad Cities , Units 1 (TAC NOS. M89871, and M89493), dated July 21, 1994.
11. U. S. Nuclear Regulatory Commission Letter, Robert M. Pulsifer - Project Manager, To D. L. Farrar - Manager, Nuclear Regulatory Service ComEd, Subject - Quad Cities Nuclear Power Station, Units 1 and 2, Safety Evaluation Regarding Core Shroud Repair (TAC NOS. M91301, and M91301), dated June 8, 1995.
12. U. S. NRC Letter, Mr. John Stang, to Mr D.L. Farrar - ComEd , Subject - Request for Additional information - Core Shroud Repair (TAC NOS M91301 and M91302), Dated July 26, 1995.
13. ComEd Letter, P. Piet to the U.S. NRC Document Control Desk, Subject - Response to NRC for request for additional information concerning Generic Letter 94-03, Dated December 14, 1994, Attachment B - "Safety Assessment of Horizontal Core Shroud Weld H1 through H7 for Cycle 14 Operation of for Dresden Unit 2".

14. ComEd Letter, P. Piet to the U.S. NRC Document Control Desk, Subject - Response to NRC for request for additional information concerning Generic Letter 94-03, Dated December 14, 1994, Attachment D - "Final Evaluation of the Core Shroud Flaws at the H5 Horizontal Weld For Dresden Unit 3".
15. ComEd Letter, P. Piet to the U.S. NRC Document Control Desk, Subject - Response to NRC for request for additional information concerning Generic Letter 94-03, Dated December 14, 1994, Attachment C - "Safety Assessment of Horizontal Core Shroud Weld H1 through H7 for Cycle 13 Operation of for Quad Cities Unit 2".
16. ComEd Letter, P. Piet to the U.S. NRC Document Control Desk, Subject - Response to NRC for request for additional information concerning Generic Letter 94-03, Dated December 14, 1994, Attachment E - "Final Evaluation of the Core Shroud Flaws at the H5 Horizontal Weld For Quad Cities Unit 1".