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Attention: Chief, Information Management Branch, Division of Program Management

Subject: PWR Owners Group
Evaluation of NRC Questions on the Technical Bases for Revision of the PTS Rule Relative to Their Effects on the Risk Results in WCAP-16168-NP, Revision 1, "Risk-Informed Extension of the Reactor Vessel In-Service Inspection Interval."

References: 1. WOG-06-25, Transmittal of WCAP-16168-NP Rev. 1, "Risk-Informed Extension of Reactor Vessel In-Service Inspection Interval" (MUHP-5097/5098/5099, Tasks 2008/2059), 1/26/2006

On October 11, 2005 the PWROG had a meeting with the Staff to discuss the resubmittal of WCAP-16168-NP. During this meeting, the Staff identified questions that NRR had developed as part of their review of the NRC PTS Risk Reevaluation that were being sent to RES. The Staff requested that the PWROG review these questions and address their impact on WCAP-16168-NP Revision 1, "Risk-Informed Extension of Reactor Vessel In-Service Inspection Interval". In the WCAP-16168-NP Revision 1 submittal letter, the PWROG indicated that they had reviewed the questions and determined that they did not impact the conclusions of the WCAP.

A teleconference was held on May 4, 2006 with the NRC Staff to discuss the submittal and acceptance of WCAP–16168-NP Revision 1. During this call, members of the PWROG agreed to formally transmit their evaluation of the NRR questions to RES on the NRC PTS Risk Reevaluation. This evaluation is included as Attachment 1 to this letter. Also discussed in the May 4, 2006 conference call was the Staff's request for the PWROG to develop an integrated PWR inspection implementation plan. In response, the PWROG commits to provide this plan to the Staff no later than October 31, 2006. The PWROG understands that the completion of the NRC review and approval of WCAP-16168-NP, Revision 1 is contingent upon receiving this plan.

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If you require further information, please contact Mr. Jim Molkenthin in the Owners Group Program Management Office at 860-731-6727.

Very truly yours,

Frederick P. "Ted" Schiffley, II, Chairman
PWR Owners Group

FPS:GCB:las

Attachments (1)

cc: PWROG Steering Committee
PWROG Management Committee
PWROG Licensing Subcommittee
PWROG Materials Subcommittee
PWROG Project Management Office
G. Shukla, USNRC (via Federal Express)
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Evaluation of NRC Questions on the Technical Bases for Revision of the PTS Rule Relative to Their Effects on the Risk Results in WCAP-16168, Revision 1

Westinghouse evaluated the potential effects of the NRC questions on the pressurized thermal shock (PTS) risk analysis methods that were used for revising the Westinghouse Owners Group (WOG) Report, WCAP-16168-NP, Revision 1, as described in Part A and summarized in Table 1-1. These questions were discussed at the meeting of the WOG with the NRC on October 11, 2005, and were included in Attachment 2 of the NRC meeting summary (Attachment 1 Ref. 1). In an e-mail to the PWR Owners Group on March 28, 2006, concerning review of WCAP-16168, NRC also expressed concerns regarding the effects of proposed changes to the FAVOR Code. The FAVOR Code changes that are not addressed in Part A are evaluated in Part B and also included in Table 1-1. The combined effects of all of these NRC questions and FAVOR Code changes is a conservative increase in the change in PTS risk with in-service inspection in Revision 1 of WCAP-16168-NP by no more than a factor of 2.2, which is not considered to be statistically significant. Furthermore, the change in in-service inspection interval proposed in WCAP-16168-NP Revision 1 is based on an acceptable change in risk calculation. The potential increase in PTS risk by a factor of 2.2 would not change the acceptability of the change in risk due to vessel inspection.

A. <u>NRC Questions From Meeting on October 11, 2005, Regarding the Proposed WOG Revision to WCAP-16168-NP</u>

The NRC questions on the PTS risk methods were provided in Attachment 2 to the NRC meeting summary (Attachment 1 Ref. 1). The evaluation of each question and the conservative range of factors in Table 1-1 are based upon information from NRC presentations on PTS Risk to the ACRS on November 30 and December 1, 2004, and summary descriptions of the NRC PTS Risk Re-Evaluation Program at the 2005 ASME Pressure Vessel and Piping Division Conference in July 2005 (Attachment 1 Ref. 2) and at the 18th International Conference on Structural Mechanics in Reactor Technology (SMIRT 18) in August 2005 (Attachment 1 Ref. 3). A summary of the PTS Risk Study by NRC is also given in NUREG-1806 (Attachment 1 Ref. 4), which has not yet been issued.

1. Applicability of PTS Risk Results to the PWR Fleet

The NRC proposed statistical approach for generating confidence bounds on 12 data points (3 plants with 4 embrittlement levels each) per component (axial or circ. weld, plate of forging) would not be valid because the sampling and application are not for a homogeneous lot. That is, each of the 69 PWR plant vessels is at a much different point on each of the component trend curves. At the end of life extension (60 years), only one (pilot) plant has a predicted through-wall cracking frequency (TWCF) greater than 10^{-8}/year, which is two orders of magnitude below the PTS risk limit. Approximately half the plants have a predicted TWCF less that 10^{-10}/year due to PTS.

The purpose of the PTS Risk Generalization and Sensitivity Studies, as summarized in NUREG-1806 (Attachment 1 Ref. 4), was to show that the results of the risk analyses for all PWRs with embrittled vessels would not be significantly different that those for the pilot plants at comparable levels of embrittlement. Since the TWCF can be log-linearly correlated for four levels of embrittlement for three different pilot plants (W, CE and B&W designs) with completely different vessel designs and system characteristics for PTS within a factor of 1.6 to 1.7 for the controlling component types shows that the results of the PTS Risk Study (Attachment 1 Ref's. 2-4) are generally applicable. Therefore, no additional margin terms beyond the 1.6 and 1.7 factors applied to the pilot plant PTS risk results are required for evaluation of the remaining PWR fleet. However, for conservatism, a maximum increase in TWCF by a factor of 2 is included in Table 1-1.

2. FAVOR Sampling of Embrittlement Index Bias

The NRC proposed alternative to the current FAVOR sampling scheme would be expected to lower the TWCF by approximately 3 orders of magnitude. This is because the chance of being on the extreme tail of the bias distribution and having a high probability of initiation and failure is reduced from approximately 1 in 10,000 (flaws) per vessel to approximately 1 in 10 (materials) per vessel beltline simulation. For the same risk limit of 10^{-6}/year on the TWCF, the limiting embrittlement index would increase by approximately 100°F. For conservatism and to allow for some potential mitigating effects, the range of reduction factors in Table 1-1 was taken as 0.005 to 0.01 (i.e. a maximum of only 2 orders of magnitude).

3. Plant-Specific vs. Generic Distributions

The plant-specific random variation about the median value is not known for most vessel material properties, with the possible exception of T_0. For T_0, the measure of uncertainty is the shape factor for a Weibull distribution. A number of the Master Curve experts and ASTM have made convincing arguments that the same shape factor of 4 is applicable for all pressure vessel steels. The biggest uncertainty is for the median value, which must come from a generic distribution in order to have a statistically significant number of data points. In the evaluation of uncertainties for the PTS Risk Study by NRC (Attachment 1 Ref's. 2-4), the generic distributions for the critical parameters were chosen so that they would bound the uncertainty distributions in a plant-specific vessel material. Therefore, the net effect is that a more realistic simulation of plant specific uncertainties would be less conservative and the calculated value of TWCF would be lower.

4. Effects of Small Thermal Plumes

Previous FAVOR evaluations by ORNL showed small thermal plumes have an insignificant effect, as summarized in an ASME-PVP Paper. Updates in the current PFM models (FAVOR Code version 04.1 and its input) used for the PTS Risk Study by NRC, such as warm pre-stressing, would make effects of small thermal plumes even smaller.

5. RELAP Temperature Uncertainties

The thermal stress is proportional to the difference between the local metal temperature and the bulk average temperature through the vessel wall. Therefore, small systematic differences in temperature, such as 0.67°F during a PTS transient, would have a small effect on the local thermal stress. Even though the rate of water temperature change may be under predicted, the change in metal temperatures would not be affected as much. This is because the metal temperatures respond much more slowly than the water temperatures since the heat flow during PTS transients is typically conduction limited. Previous FAVOR evaluations have shown that the effects of these RELAP uncertainties on the TWCF are not statistically significant. As indicated in Table 1-1, the maximum increase in TWCF would only be approximately a factor of 2. PRA work performed by NRC for the PTS Risk Study (Attachment 1 Ref's. 2-4) has also shown that these uncertainties have a much smaller effect than the uncertainties in operator actions, which are considered in the PTS transient binning process.

6. Gamma Heating Effects

The effects of gamma heating would be maximized at full-power operating conditions where the temperature of the coolant and vessel are nearly identical. However, when the temperature and toughness are lowest near the end of the PTS transient, the effects gamma heating would be insignificant. While gamma heating could affect the thermal stress distribution, the temperatures and toughness are also somewhat higher. Therefore, the net effect on the TWCF would be very small. Decay heat levels, which are also important, are considered in the PTS transient binning process and associated thermal-hydraulic analyses.

7. Distribution of Weld Repairs Through the Vessel Wall

The assumed linear distributions used in the PTS Risk Study by the NRC (Attachment 1 Ref's. 2-4) are consistent with the input from fabrication experts, That is, inspections and repairs are performed throughout the weld fabrication process, not just for the first and last passes near the surfaces. Since the proportion of repair welds is 33% higher than what was measured in the PVRUF vessel (2% vs. 1.5%), changing the flaw density index from a unit volume to a unit area basis should not have a significant effect. This is because the dimensions of the PVRUF vessel are fairly similar to those in the three pilot plants being evaluated in the Study. Based upon PTS risk sensitivity studies performed by the NRC (Attachment 1 Ref's. 2-4), the maximum effect of a non-linear distribution of weld repairs in Table 1-1 would be an increase in the TWCF by factor of 3.

8. Under-clad Cracking of Forgings

The probability of having all of the conditions required to obtain under-clad cracking is much less than the proposed value of 100%, which was shown in a previous informal evaluation of the extremely conservative PNNL assumptions (see Table 1-2). Furthermore, the PWR plants with vessel forgings have significantly less embrittlement than the plants with the highest values of TWCF. Even if their density is assumed to be high, then the under-clad flaws are so shallow that the chance of them initiating during a severe PTS transient would be fairly small. This conclusion is based upon an extensive study by Westinghouse of under-clad cracking and its potential effects that was reviewed and accepted by NRC in 2002 (Attachment 1 Ref. 5)

9. Plants without PORVs

The purpose of the PTS Risk Generalization Studies by NRC, as summarized in NUREG-1806 (Attachment 1 Ref. 4), is to show that the results of the risk analyses for all PWRs with embrittled vessels would not be significantly different that those for the pilot plants at comparable levels of embrittlement. Since stuck-open power operated relief valves

(PORVs) are a source of potential PTS transients in some plants, not having them would reduce the overall TWCF relative to that for the 3 pilot plants that have PORVs.

10. Effects of 10-Year ISI on Assumed Flaws

    All of the domestic PWR plants have performed their 10-year in-service inspection (ISI) of the vessel welds. When the most recent ISI was done per the requirements of USNRC Regulatory Guide 1.150 or Appendix VIII of ASME Section XI, no reportable flaw indications were observed. Furthermore, the PTS risk study on the effects of ISI, including the potential for fatigue crack growth of surface breaking flaws, performed by the WOG and reported in WCAP-16168-NP, Revision 1, has shown that the effects of ISI on the TWCF are not statistically significant.

B. <u>Recent NRC Concerns on Latest FAVOR Changes (Version 04.1 to 06.1)</u>

The proposed changes to FAVOR 06.1 were discussed at an NRC meeting on March 29, 2006 (Attachment 1 Ref. 7). One change to correct an error discovered in the industry verification and validation of FAVOR 04.1 does not need to be considered because the PTS risk calculations that support Revision 1 of WCAP-16168 were performed with version 05.1, which corrected that error. A number of other changes were made to FAVOR to address the NRC questions that were discussed in Part A. Two additional changes to FAVOR that could potentially affect the WCAP results were also discussed at the NRC meeting on March 29, 2006 (Attachment 1 Ref. 6). These FAVOR 06.1 changes, which were recently added to Table 1-1, are discussed below.

1. Correction of the Error in the Treatment of Thermal Expansion

   When temperature dependent material properties, including the coefficient of thermal expansion for the vessel and its cladding, were added to the FAVOR Code, the calculation of thermal expansion with respect to the stress-free temperature and the resulting thermal stress was not correct. As discussed at the recent NRC meeting (Attachment 1 Ref. 6), correcting this error increases the TWCF due to PTS by a maximum factor of approximately 2.

2. New Embrittlement Trend Curves

   The latest NRC trend curves for the change in embrittlement index (RT_{NDT}), as proposed for Revision 3 of Regulatory Guide 1.99, were evaluated by industry (Attachment 1 Ref. 6). The maximum / average change in index for PWR / BWR plant vessels was estimated to be approximately 25°F for the conditions evaluated in the WCAP. Using the correlations for the TWCF in the SMIRT-18 Paper (Attachment 1 Ref. 3) resulted in a maximum increase of approximately a factor 4.5.

   PTS risk analyses, including the effects of surface breaking flaw growth due to fatigue and in-service inspection, in Revisions 0 and 1 of WCAP-16168-NP were performed using FAVOR versions 02.4, 03.1 and 05.1. While the calculated values of the TWCF at 60 EFPY were different, the conclusion that the effect of inspection is not risk significant did not change. It is therefore concluded that results calculated with FAVOR version 06.1 would also show that the effect of inspection is not risk significant.

C. Attachment 1 References

1. NRC Letter from Girija Shukla to Daniel S. Collins dated October 26, 2005, Summary Of Meeting Held On October 11, 2005 With The Westinghouse Owners Group To Discuss Resubmittal Of WCAP-16168-NP, "Risk-Informed Extension Of Reactor Vessel Inservice Inspection Interval," ADAMS Accession No. ML052910148.

2. Paper PVP2005-71638, "An Overview of the Pressurized Thermal Shock Re-evaluation Project," by T. L. Dickson and M. T. EricksonKirk, in Proceedings of the 2005 ASME Pressure Vessel and Piping Division Conference, July 2005.

3. Paper SMIRT18-D06-4, "Technical Basis for Revision of the Pressurized Thermal shock (PTS) Screening Limit in the PTS Rule (10CFR50.61)," by Mark T. EricksonKirk, Nilesh Chokshi, Roy Woods, Mike Junge, Shah Malik and David Besssette, in Proceedings of the 18th International Conference on Structural Mechanics in Reactor Technology, August 2005.

4. NUREG-1806, "Technical Bases for Revision of the Pressurized Thermal Shock (PTS) Screening Limit in the PTS Rule (10CFR50.61): Summary Report," by Mark T. EricksonKirk and others, U. S. Nuclear Regulatory Commission, to be published for public review and comment in 2006.

5. WCAP-15338-A, A review of Cracking Associated with Weld Deposited Cladding in Operating PWR Plants, Warren Bamford and R. D. Rishel, Westinghouse Electric Company LLC, October 2002.

6. NRC Memorandum from Mark Kirk to Jennifer L. Uhle dated April 11, 2006, Summary Of Meeting Between The Nuclear Regulatory Commission (NRC) Staff And Industry Representatives On Performing Research In Support Of The Goal Of Risk Informing 10CFR50 Appendix G And 10 CFR 50.61, ADAMS Accession No. ML060950059.

Table 1-1

Estimated Effects of NRC Questions on the Results in WCAP-16168-NP, Revision 1

Question Number	Description of PTS Risk Topic	Minimum Factor	Maximum Factor
1	Applicability of Risk Results to the PWR Fleet	1.0	2.0
2	FAVOR Sampling of Embrittlement Index Bias	0.005	0.01
3	Plant-Specific vs. Generic Distributions	0.5	1.0
4	Effects of Small Thermal Plumes	1.0	1.4
5	RELAP Temperature Uncertainties	1.0	2.0
6	Gamma Heating Effects	1.0	1.4
7	Distribution of Repairs Through the Vessel Wall	1.0	3.0
8	Under-clad Cracking of Forgings	1.0	1.0
9	Plants without PORVs	1.0	1.0
10	Effects of 10-Year ISI on Assumed Flaws	1.0	1.0
FAVOR Ver. 06.1	Correction of Error in Thermal Expansion	1.0	2.0
	New Embrittlement Trend Curve (+25°F)	1.0	4.5
	Total Combined Effects on PTS Risk (TWCF)	**0.0025**	**2.16**

Table 1-2

Results of the Westinghouse Informal Review of the PNNL Report on PTS Sensitivity to Under-Clad Cracking (Subclad Flaws)

No.	Comment on April 2005 Draft
1	Looking at Fig. 1 of the PNNL report on subclad flaws, only approximately 11.5% ($\pm$3.9%) of the area (or volume) has the high flaw density. In Fig. 6 of the Horiya Paper, only 7.6% of the area in the photo has the high density of subclad flaws. Assuming that the high density applies to 100% of the area or volume is extremely conservative
2	In these same figures, the subclad flaw lengths appear to be fairly constant, especially in Fig. 6. This variation is much smaller than that shown in the output of PNNL's computer program for generating the flaw input files for FAVOR, which is a uniform distribution in L/a from 1.0 to 5.0 with a constant depth a.
3	Of the 29 plants in Table 9.4 of the draft NUREG Report (Attachment 1 Ref. 4), only 5 have a forging as the limiting component. Of these 5 plants, it is not clear how many of them would actually have all the conditions necessary for subclad cracking: the class 2 forging material, at least 2 layers of strip cladding (vs. weld deposited cladding) with NO heat treatment between the first two layers. A reasonable probability that all of the necessary conditions are present for generating subclad flaws needs to be determined and applied to the results.
4	Even with all of the extremely conservative assumptions and no consideration of the likelihood of their occurrence, the effect of subclad flaws at 60 EFPY reduces the TWCF by approximately a factor of 5. Only at 100 EFPY, did it increase the TWCF by a factor of 10.
5	In Table 9.4 of the draft NUREG (Attachment 1 Ref. 4), the 40-year RT_{NDT} values for the highest ranked forging plants (#9, Sequoyah 1 and #10 Watts Bar 1) were 27°F to 31°F lower than that for the limiting Beaver Valley 1 (BV1) plates, whose embrittlement properties were used in the subclad flaw sensitivity study. In the FAVOR 0.41 results for the draft NUREG Report (Attachment 1 Ref. 4) in Table A1 of ORNL/NRC/LTR-04/18, the change in RT_{NDT} from 60 EFPY to 100 EFPY for the BV1 plates ranged from 25°to 31°F. Therefore, for the two worst forging plants at 100 EFPY, the BV1 results at 60 EFPY would be much more applicable than the BV1 results at 100 EFPY.
6	ORNL has indicated that they have developed a version of FAVOR with a random variation of subclad flaw depth, which would be much more realistic. Check runs with this new version seem to reduce the effects on the TWCF substantially relative to those with a constant flaw depth used in the PNNL sensitivity study.