March 7, 2000

Carl Terry, BWRVIP Chairman
Niagara Mohawk Power Company
Post Office Box 63
Lycoming, NY 13093

SUBJECT: SUPPLEMENT TO FINAL SAFETY EVALUATION OF THE BWR VESSEL AND INTERNALS PROJECT BWRVIP-05 REPORT (TAC NO. MA3395)

Dear Mr. Terry:

By letter dated September 28, 1995, as supplemented by letters dated June 24 and October 29, 1996, May 16, June 4, June 13, and December 18, 1997, and January 13, 1998, you submitted the Electric Power Research Institute (EPRI) proprietary report TR-105697, "BWR Vessel and Internals Project [BWRVIP], BWR Reactor Pressure Vessel Shell Weld Inspection Recommendations (BWRVIP-05)." The BWRVIP-05 report, as modified, proposed several actions, including reducing the scope of inservice inspections of the BWR reactor pressure vessel (RPV) shell welds from essentially 100 percent of all RPV shell welds to essentially 100 percent of the RPV axial shell welds and essentially zero percent of the circumferential RPV shell welds, except for the intersections of the axial and circumferential welds. This proposal was evaluated by the NRC staff and approved in a safety evaluation (SE) dated July 28, 1998. The SE stated that the NRC staff had concluded that a near-term safety concern did not exist due to various conservatisms in the calculations for axial welds, including the use of peak end-of-license (EOL) fluence levels for all postulated flaws and the assumptions of flaw density and flaw location.

However, the NRC staff identified a need to further evaluate the high conditional failure probability levels for axial welds in BWR RPVs determined in the staff's SE. In a request for additional information (RAI) dated June 8, 1998, the staff requested that BWRVIP provide a plan for follow up analyses to determine, on a more realistic basis, the potential for axial weld failures due to cold over-pressure events and appropriate technical approaches for addressing this concern, as necessary. Further, the staff requested that BWRVIP provide the failure frequency of axial welds in BWRs (from the results of probabilistic fracture mechanics evaluations) using specific staff recommendations on input variables and a risk assessment of the impact of inspection, operating procedures, training, etc., on the results of the failure frequency evaluations and the guidance of Regulatory Guide (RG) 1.174.

BWRVIP provided the results of its evaluations on axial weld failure frequency by letter dated December 15, 1998. In a letter dated April 29, 1999, the NRC staff concluded that the BWRVIP response was deficient and provided several options for additional evaluations by BWRVIP. By letter dated November 12, 1999, BWRVIP provided the results of its revised evaluations, which the staff has reviewed in the attached SE.

The staff has determined, based on its evaluation of the information provided, that the RPV failure frequency due to failure of the limiting axial welds in the BWR fleet are below 5×10^{-6} per reactor-year, consistent with RG 1.154, given the assumptions described in the attached SE.

Note that these results apply only for the initial 40-year license period of BWR plants, and that consideration of BWR axial welds for license renewal would require a plant-specific treatment by the license renewal applicant. The staff is presently reviewing the “BWR Reactor Pressure Vessel Inspection and Flaw Evaluation Guidelines (BWRVIP-74),” dated September 21, 1999, to determine the applicability for the extended operating period.

The NRC is conducting an expert elicitation to provide improved guidance on flaw density, distribution and location for RPVs. Thus, the results of this evaluation for axial welds should be considered interim pending the results of the expert elicitation. Should the results of the expert elicitation be more conservative than the assumptions used here, then BWRVIP would be required to re-evaluate BWR axial welds using the results of the expert elicitation.

Also, the staff is enclosing a revised Table 2.6-4, “Summary of Results of NRC Staff and BWRVIP Limiting Plant-Specific Analyses (32 EFPY),” page 28 of the staff’s July 28, 1998, “Final Safety Evaluation of the BWR Vessel and Internals Project BWRVIP-05 Report.” Specifically, the chemistry factor (CF) for the CB&I circumferential flaw orientation was erroneously reported as 109.5. The correct value is 134.9, as noted in bold in the attached, revised Table 2.6-4. This errata correction reflects an intermediate calculation value and does not change any conclusion in the original SE.

The staff requests that BWRVIP review the enclosed SE, and incorporate the staff’s conclusions into a revised BWRVIP-05 report. Please inform the staff within 90 days of the date of this letter as to your proposed actions and schedule for such a revision.

Please contact C. E. (Gene) Carpenter, Jr., of my staff at (301) 415-2169 if you have any further questions regarding this subject.

Sincerely,

/RA/

Jack R. Strosnider, Director
Division of Engineering
Office of Nuclear Reactor Regulation

Project No. 704

Enclosure: Initial Safety Evaluation Report

cc: See next page

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Enclosure: Initial Safety Evaluation Report
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U.S. NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REACTOR REGULATION

SUPPLEMENTAL SAFETY EVALUATION OF EPRI TOPICAL REPORT TR-105697 "BWR VESSEL AND INTERNALS PROJECT, BWR REACTOR PRESSURE VESSEL SHELL WELD INSPECTION RECOMMENDATIONS (BWRVIP-05)"

1.0 INTRODUCTION

1.1 Background

By letter dated September 28, 1995, as supplemented by letters dated June 24 and October 29, 1996, May 16, June 4, June 13, and December 18, 1997, and January 13, 1998, the BWR Vessel and Internals Project (BWRVIP) submitted the Electric Power Research Institute (EPRI) proprietary report TR-105697, "BWR Vessel and Internals Project, BWR Reactor Pressure Vessel Shell Weld Inspection Recommendations (BWRVIP-05)." The BWRVIP-05 report, as modified, proposed several actions, including reducing the scope of inservice inspections of the BWR reactor pressure vessel (RPV) shell welds from essentially 100 percent of all RPV shell welds to essentially 100 percent of the RPV axial shell welds and essentially zero percent of the circumferential RPV shell welds, except for the intersections of the axial and circumferential welds. This proposal was evaluated by the NRC staff and approved in a safety evaluation (SE) dated July 28, 1998, which stated that the NRC staff had concluded that a near-term safety concern did not exist due to various conservatisms in the calculations for axial welds, including the use of peak end-of-license (EOL) fluence levels for all postulated flaws and the assumptions of flaw density and flaw location.

The NRC staff identified a need to further evaluate the high conditional failure probability levels for axial welds in BWR RPVs, which were described in the staff's SE. In a request for additional information (RAI) dated June 8, 1998, the staff requested that BWRVIP provide a plan for follow-up analyses to determine, on a more realistic basis, the potential for axial weld failures due to cold over-pressure events and appropriate technical approaches for addressing this concern, as necessary. Further, the staff requested that BWRVIP provide the failure frequency of axial welds in BWRs (from the results of probabilistic fracture mechanics evaluations) using specific staff recommendations on input variables and a risk-informed assessment of the impact of inspection, operating procedures, training, etc., on the results of the failure frequency evaluations and using the guidance of Regulatory Guide (RG) 1.174.

The BWRVIP provided the results of its evaluations on axial weld failure frequency by letter dated December 15, 1998. In a letter dated April 29, 1999, the NRC staff concluded that the BWRVIP response was deficient and provided several options for additional evaluations by the BWRVIP. By letter dated November 12, 1999, the BWRVIP provided the results of its revised evaluations.

ENCLOSURE

1.2 Organization of the Report

Because the BWRVIP-05 report, as supplemented with the revised evaluations, is proprietary, this supplemental safety evaluation (SE) was written to ensure that proprietary information was not compromised. The staff's July 28, 1998, SE, gives a brief summary of the general contents of the BWRVIP-05 report, and that synopsis is not repeated here. Section 2.0 provides a detailed evaluation of the supplemental material provided by the BWRVIP. Because of proprietary information concerns, this SE does not discuss in any detail the provisions of the BWRVIP's revised evaluations, nor the parts of the revised evaluations that the staff finds acceptable.

2.0 EVALUATION

2.1 Probabilistic Fracture Mechanics Evaluations by BWRVIP

Input Parameters

Limiting Plants: Consistent with the approach taken in the BWRVIP-05 report and the staff evaluation of the failure frequency for RPV axial and circumferential welds, BWRVIP identified two limiting plants from the fleet of BWR plants, from the standpoint of irradiation embrittlement of the axial welds. More specifically, BWRVIP identified the two plants which have the axial welds with the highest mean RT_{NDT} levels at EOL conditions, where mean RT_{NDT} does not include margin terms (M) described in RG 1.99, Revision 2 and the PTS Rule (10 CFR 50.61). The identified plants, Clinton and Pilgrim, have RPVs which were fabricated by Chicago Bridge and Iron (CB&I) and Combustion Engineering, respectively. The material property information used by BWRVIP to define the EOL fracture toughness of each of these plants is summarized in Table 1. Note that the peak RPV fluences at EOL do not correspond to the axial weld locations, with the peak EOL fluences for the axial welds at Pilgrim much below the peak for the overall RPV.

Table 1: Material Property Data for Limiting BWR Axial Welds (BWVIP Data)

Plant Name	Initial RT_{NDT} (°F)	Chemical Composition (Wt. %)		Peak RPV EOL Fluence (10^{19} n/cm^2)	EOL Mean RT_{NDT} (°F)
		Copper	Nickel		
Clinton	-30	0.10	1.08	0.69*	91
Pilgrim	0	0.219	0.996	0.2 **	116

* The peak axial weld fluence is 0.676 x 10^{19} n/cm^2.
** The peak axial weld fluence is 0.148 x 10^{19} n/cm^2.

Fluence Maps: For the Clinton plant, the beltline portion of the RPV is a single shell course consisting of three axial welds. For the Pilgrim plant, the beltline portion of the RPV contains a circumferential weld, and hence there are a total of six axial welds. For each plant, the EOL fluences were determined for 24 regions of the axial welds, with the mean fluence of each region used to define the fluence for that region.

Flaw Density, Distribution, and Location: These parameters relate to the number, size and position (through the weld thickness) of flaws postulated in probabilistic fracture mechanics (PFM) calculations. As specified by the staff, the BWRVIP calculations used a density of 3 flaws per vessel, with the size distribution of flaws given by the “PVRUF Flaw Depth Distribution.” All of the flaws were assumed to be surface-breaking in the PFM evaluation.

VIPER Computations

The VIPER code was used to perform the PFM evaluations by BWRVIP. The application of this code assumed that a single low-temperature over-pressure transient occurred each year of the simulated 40-year lifetime of each RPV. The cumulative number of failures for the 40-year period was used to determine the conditional failure probability for each RPV.

BWRVIP Results

The results from the BWRVIP evaluation are provided in Table 2. The “conditional failure probability,” or P(F|E), is the probability that the vessel will fail, assuming that the transient occurs. The “LTOP frequency” is the frequency of the transient occurring, determined as 10^{-3} per reactor-year in the evaluation of the BWRVIP-05 report. Therefore, the “vessel failure frequency” is the product of the conditional failure probability and the LTOP frequency. The resultant vessel failure frequencies for the limiting BWR axial welds are below 5×10^{-6} per reactor-year, consistent with Regulatory Guide (RG) 1.154, “Format and Content of Plant-Specific Pressurized Thermal Shock Safety Analysis Reports for Pressurized Water Reactors,” dated January 1987, throughout the 40-year license period.

Table 2: Results of BWRVIP Evaluations for Limiting BWR Axial Welds

Plant Name	Conditional Failure Probability P(F|E)	LTOP Frequency	Vessel Failure Frequency
Clinton	1.52E-3	1E-3	1.52E-6
Pilgrim	1.55E-3	1E-3	1.55E-6

2.2 Staff Evaluation

Input Parameters

Limiting Plants: To ensure that the BWR plants identified by BWRVIP are limiting for the entire BWR fleet, NRC staff reviewed information in the Reactor Vessel Integrity Database (RVID). The axial welds identified by RVID as having the highest mean RT_{NDT} are:

- Oyster Creek (Heat 86054B): 114°F
- Millstone 1 (Heat W5214): 98°F
- Clinton (Heat 76492): 91°F
- Browns Ferry 2 and 3: 84°F

Review of the data for Oyster Creek indicated that the data contained in the RVID represents the docketed, licensing information, provided by the licensee, for the welds in the plant. However, the latest chemical composition data for Combustion Engineering welds (Heat 86054B) indicates substantially lower copper and nickel contents of this weld, such that the EOL mean RT_{NDT} for Oyster Creek is actually less than 70°F.

Millstone 1 was excluded from consideration since the licensee has discontinued operation of the plant.

Pilgrim was not identified within the RVID as one of the limiting plants because the initial RT_{NDT} docketed in the RVID is -48°F, as opposed to 0°F, which was used by the BWRVIP. In addition, the peak EOL fluence reported in the RVID is 0.138 x 10^{19} n/cm^2, as opposed to 0.148 x 10^{19} n/cm^2 used by the BWRVIP. As a result, the RVID value of mean RT_{NDT} for Pilgrim is 64°F instead of the 116°F determined from the BWRVIP input values.

Therefore, the axial welds for the Clinton plant are the limiting welds for the BWR fleet, and vessel failure probability calculations determined for Clinton should bound those for the BWR fleet. Note that the mean RT_{NDT} for Pilgrim used by BWRVIP also bounds that for all of the axial welds in BWR plants, but in this case the Pilgrim data used by BWRVIP are over-conservative in comparison to the overall BWR fleet.

Flaw Density, Distribution, and Location: The staff evaluation of the BWRVIP-05 report used the results of an examination of the welds in the Pressure Vessel Research Users Facility (PVRUF) vessel at Oak Ridge National Laboratory. This RPV is from a canceled plant and was fabricated by Combustion Engineering. The results from the examination of the PVRUF welds indicated a density of 994 flaws/m^3. However, none of these flaws were surface-breaking flaws, even using the proximity rules of the ASME Code. Since surface-breaking flaws dominate vessel failure determinations, the staff decided to remove one conservatism by considering only surface-breaking flaws in evaluations for axial welds. Given the results of no surface-breaking flaws with inspection of 800 feet of PVRUF welds, the 95 percent upper confidence bound for the frequency of a surface-breaking flaw is determined as three per 800 feet, or three per vessel.

Note that this flaw density of three flaws per RPV is intended as an interim assumption only to help reduce unnecessary conservatism in the PFM evaluation for BWR axial welds. The NRC has initiated an expert elicitation to provide guidance on the density and distribution of flaws in RPVs. Should the results of that expert elicitation be more conservative than the assumptions used in these calculations, then reconsideration of these results would be necessary.

The sizes of the flaws found in the PVRUF were used to construct the "PVRUF Flaw Depth Distribution," which was used by BWRVIP in its evaluation for axial welds and in previous staff evaluations for the BWRVIP-05 report.

Fluence Maps: The fluence maps provided by BWRVIP were used in calculations for both the Clinton and Pilgrim RPVs.

FAVOR Code

The staff performed independent calculations for Clinton and Pilgrim using the FAVOR code developed by the Oak Ridge National Laboratory. These calculations used the EOL fluence maps for each plant. Using the information relevant to the Pilgrim plant, calculations were made using both the BWRVIP input initial RT_{NDT} of 0°F and the RVID docketed value of -48°F.

Staff Results

Results from the staff calculations are provided in Table 3. The staff calculations used the basic input information for Pilgrim, with three different assumptions for the initial RT_{NDT}. The calculations of the actual Pilgrim condition used the docketed initial RT_{NDT} of -48°F and a mean RT_{NDT} of 68°F. A second calculation, listed as “Mod 1" in Table 3, is consistent with the BWRVIP calculations, with an initial RT_{NDT} of 0°F and a mean RT_{NDT} of 116°F. A third calculation, with an initial RT_{NDT} of -2°F and a mean RT_{NDT} of 114°F, was chosen to identify the mean value of RT_{NDT} required to provide a result which closely matches the RPV failure frequency of 5 x 10^{-6} per reactor-year.

Table 3: Comparison of Results from Staff and BWRVIP

Plant	Initial RT_{NDT} (°F)	Mean RT_{NDT} (°F)	Vessel Failure Freq.	
			Staff	BWRVIP
Clinton	-30	91	2.73E-6	1.52E-6
Pilgrim	-48	68	2.24E-7	-------
Mod 1 *	0	116	5.51E-6	1.55E-6
Mod 2 **	-2	114	5.02E-6	-------

* A variant of Pilgrim input data, with initial RT_{NDT} = 0°F.
** A variant of Pilgrim input data, with initial RT_{NDT} = -2°F.

The staff calculations tend to give somewhat higher failure frequencies than those reported by BWRVIP. However, both BWRVIP and the NRC staff calculations indicate that the vessel failure frequency due to failure of the axial welds is below 5 x 10^{-6} per reactor-year for each BWR.

3.0 STAFF CONCLUSIONS

The results of these calculations indicate that the RPV failure frequency due to failure of the limiting axial welds in the BWR fleet are below 5 x 10^{-6} per reactor-year, given the assumptions on flaw density, distribution and location described previously. Note that these results apply only for the initial 40-year license period of BWR plants, and that consideration of BWR axial welds for license renewal would require a plant-specific treatment by the license renewal applicant.

As described previously, the NRC is conducting an expert elicitation to provide guidance on flaw density, distribution and location for RPVs. The results of this evaluation for axial welds should be considered interim pending the results of the expert elicitation. Should the results of the expert elicitation be more conservative than the assumptions used here, then BWRVIP would be required to re-evaluate BWR axial welds using the results of the expert elicitation.

TABLE 2.6-4
SUMMARY OF RESULTS OF NRC STAFF AND BWRVIP LIMITING PLANT-SPECIFIC ANALYSES (32 EFPY)

FLAW ORIENT.	GROUP	Cu	Ni	CF	FLUENCE (10^{19} n/cm^2)	ΔRT_{NDT} (°F)	$RT_{NDT(U)}$ (°F)	MEAN RT_{NDT} * (°F)	P(F|E)	
									STAFF	BWRVIP
AXIAL	CE (VIP)[a]	0.26	1.20	276.0	0.15	138.8	-20	118.8	2.94 E-1	1.37 E-2
	CE (CEOG)[b]	0.219	0.996	231.1	0.20	131.6	0	131.6	4.37 E-1	-----
	CB&I	0.10	1.08	135.0	0.69	121.0	-30	91.0	1.42 E-1	1.55 E-2
	B&W	0.25	0.35	142.5	0.125	66.0	10	76.0	5.98 E-2	8.12 E-3
CIRC.	CE (VIP)[a]	0.13	0.71	151.7	0.20	86.4	0	86.4	2.81 E-5	NF (10^6) [c]
	CE (CEOG)[b]	0.183	0.704	172.2	0.20	98.1	0	98.1	6.34 E-5	-----
	CB&I	0.10	0.99	**134.9**	0.51	109.5	-65	44.5	2 E-7	1 E-6
	B&W	0.31	0.59	196.7	0.095	79.8	20	99.8	8.17 E-5	1 E-6

[a] Chemistry information reported in BWRVIP-05.
[b] Chemistry information reported in CEOG report.
[c] No failures in the indicated number of vessel simulations.
* Mean RT_{NDT} was determined using the peak neutron fluence for the limiting weld.