FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-12472-P/WCAP-12472-NP, ADDENDUM 4, REVISION 0,

"BEACON^{TM} CORE MONITORING AND OPERATION SUPPORT SYSTEM, ADDENDUM 4"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By application dated December 10, 2010 (Reference 1), Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-12472-P/WCAP-12472-NP, Addendum 4, Revision 0, "BEACON^{TM} Core Monitoring and Operation Support System, Addendum 4," for U.S. Nuclear Regulatory Commission (NRC) review and approval. WCAP-12472-P/WCAP-12472-NP, Addendum 4 provides information on an improved analysis for evaluating thermocouple behavior and uncertainties for the BEACON core monitoring system.

The BEACON system was developed by Westinghouse to improve operational support for pressurized water reactors (PWRs) (Reference 2). It is a core monitoring and support package that uses Westinghouse standard instrumentation in conjunction with an analytical methodology for online generation of three-dimensional power distributions. The system provides core monitoring, core measurement reduction, core analysis, and core predictions.

The updated thermocouple uncertainty evaluation method presented in the submitted TR is based on the licensed methodology in the BEACON TR, but uses the current plant/cycle data in the evaluation process to generate cycle specific uncertainty constants. There are no new methods being developed for the BEACON system; this update is a change in the application of the approved method. Westinghouse stated in the submittal, that this thermocouple uncertainty methodology is only applied to plants with movable in-core detectors. These plants use thermocouples to determine the measured power distribution as described in WCAP-12472-P-A, "BEACON: Core Monitoring and Operations Support System" (Reference 2) and the request for additional information (RAI) responses provided in Reference 3.

The purpose of the Addendum 4 to WCAP-12472-P/WCAP-12472-NP is to: a) Provide the information needed to review and approve the updated thermocouple uncertainty analysis process that will be applied in the BEACON on-line core monitoring system, b) Affirm the continued use of the NRC approved Westinghouse design model methodology, currently PHOENIX-P/ANC, PARAGON/ANC, and NEXUS/ANC, in the BEACON system, and c) Affirm that uncertainties applied to power distribution monitoring using fixed in-core detectors are valid using higher order polynomial fits of the detector variability and fraction of inoperable detectors than provided in Reference 4. Westinghouse alluded to in the current submittal that this methodology can be updated in the future without making a separate BEACON addendum. The staff requested clarification through the RAI process. Westinghouse responded by stating that the methodology change specified on page 1-1, last paragraph, refers to the neutronic methods licensed through the Westinghouse design codes (e.g., NEXUS/ANC, etc) which are used in the BEACON system. This is the methodology used to generate cross-sections and perform the core model neutronics solution.

2.0 TECHNICAL EVALUATION

2.1 BEACON Monitoring Methodology

The BEACON core monitoring system was developed by Westinghouse to improve the operational support for PWRs. It is a core monitoring and support package that uses Westinghouse standard instrumentation in conjunction with an analytical methodology for on-line generation of three dimensional power distributions. The system provides core monitoring, core measurement reduction, core analysis, and core predictions.

The BEACON core monitoring power distribution methodology with movable in-core detectors consists of three distinct steps.

2.1.1 Step 1: Calibration Factor Update by In-core Flux Map

The BEACON code uses in-core maps to determine calibration factors for the nodal code, thermocouples, and the excore detectors. The calibration factors are defined as the ratio of measured to predicted reaction rate in the in-core detector. Then the best estimate power distribution is determined by multiplying the predicted power distribution by the model calibration factors. These calibration factors are extended to the non-instrumented assemblies using a surface spline fit method. The NRC staff requested additional information regarding the “best estimate” value of the power distribution. Westinghouse responded by stating that what is referred to as the best estimate is the predicted power distribution corrected by the model calibration factors which are the ratio of the measured to predicted reaction rates generated from the flux map. At the time of the flux map calibration the best estimate and the actual “measured” power distribution are the same. During core operation after the flux map calibration, if no additional measurement information is provided or used (e.g., excore, thermocouple), then this would be the “best” expectation of the current measured power distribution. The product of the predicted power distribution and the model calibration factors from the flux map would result in a more accurate representation of the current core power distribution than the predicted power distribution alone.

Next the thermocouple calibration factors (sometimes referred to as mixing factors) are determined as the ratio of the estimated power to the relative enthalpy rise measured by the assembly outlet temperature. Finally, the excore detector calibration factors are defined to relate the axial offset and power level of the assemblies near the excore detectors to the excore detector readings. The best estimate core axial behavior is obtained from the calibrated nodal code calculation.

2.1.2 Step 2: Nodal Model Update

The 3D nodal model is updated frequently by following the core operation history. The model is adjusted to reproduce the axial offset measured at this condition. The model calibration factors determined in Step 1 are then applied to the calculated 3D power distribution. The radial power distribution is further corrected by core exit thermocouple measurement. The corrections are extended to non-instrumented assemblies, again using the surface spline fit. This correction is necessary because the real reactor condition may or may not be the same as the input reactor condition to the calculation model. This power distribution will serve as a reference for the frequent power distribution updating in Step 3.

2.1.3 Step 3: Power Distribution Update by Thermocouple and Excore Detector

2.1.3.1 Current Method

The reference power distribution in Step 2 is adjusted to the current reactor condition as measured by the core exit thermocouples for the radial power distribution adjustment and excore detectors for the axial power distribution adjustment. The radial power distribution is adjusted such as to reproduce the assembly-wise enthalpy rise measured by the thermocouple, assuming the mixing factors retain their same values as under the Step 2 conditions. Again an interpolation process is used to determine the adjustment for the non-instrumented assemblies. The axial power distribution is adjusted by adding a sinusoidal harmonic term to preserve the axial offset measured by the excore detectors.

The power distribution monitoring process is depicted in Figure 1 of the submitted TR. In the BEACON system, the power distribution updating by thermocouples and excore detectors (Step 3) is performed on a continuous basis without any interruption. Generation of a new reference power distribution (Step 2) is performed as a parallel operation without hindering Step 3 operation. As soon as generation of the power shape of Step 2 is completed, the reference power distribution is replaced.

2.1.3.2 Thermocouple Uncertainty Methodology

As mentioned in the submittal, a key component in the BEACON TR is the methodology to apply uncertainties to the BEACON measured powers. The measured power uncertainty methodology for BEACON has been described in Section 5 of Reference 2, for plants using movable in-core detectors. A component of the measurement uncertainty is the variability of the thermocouple calibration factors (mixing factors). The components of the thermocouple mixing factor uncertainty are described in Section 4.3 of Reference 2, and are summarized below.

Thermocouple calibration accounts for the power dependence of the mixing factor standard deviation. It does so by accounting for two effects independently. These effects are: (1) the increased percentage of variability in the thermocouple measured power due to the decreased temperature difference at lower powers and (2) the changes in the cross flow patterns as the power is reduced. This is generically expressed in the equation 4-1 of Section 4.3.1 of Reference 2 and is reproduced in this submittal.

Westinghouse pointed out, and the NRC staff concurs that the uncertainty methodology described in Section 4 of the WCAP-12472-P-A TR is based on the average thermocouple deviation at hot full power (HFP) which is based on past performance of the thermocouples. This approach results in some limitations in determining accurate thermocouple uncertainties. This is because hardware thermocouple connections are disrupted, that is disconnected and reconnected resulting in a possible loose connection. Any of these possibilities can lead to a change in the thermocouple response signal and statistical behavior, the overall behavior and characteristics of the thermocouple set would remain applicable. But, this could lead to individual thermocouples having changed behavior.

2.2 UPDATED METHOD

To address these issues stated in Section 2.1.3.2 above, Westinghouse updated the thermocouple evaluation process by having the thermocouple assess temperature and power data from the current cycle. The data is collected during the initial startup power ascension following refueling. Any planned or unplanned changes to the characteristics of the thermocouple behavior are in place and measured during the initial power ascension.

Both the analysis of the thermocouple mixing factors and the use of power dependent mixing factor data were discussed in the NRC approved WCAP-12472-P-A TR. By collecting and evaluating power dependent thermocouple mixing factor data from a long power ramp, such as during startup, the two effects of the power dependence on the mixing factor standard deviation are captured simultaneously in one function, eliminating the independent treatment. The core average mixing factor standard deviation is the average value over all of the thermocouples at a given core power.

Equation 2 in Reference 1 represents the plant/cycle-specific power dependent thermocouple deviation, while equation 1 represents the plant-specific HFP average thermocouple deviation with an independent, conservative power dependent cross flow deviation term added.

Both of the thermocouple standard deviation functions (equations 1 and 2) can provide the same behavior trends, which demonstrate that the components of the thermocouple mixing factor uncertainty described in Section 4.3 of WCAP-12472-P-A and generically expressed in equation 4-1 in Reference 2 are also reproduced as equation 2 in the submitted TR.

The uncertainty on radial assembly power is discussed in Section 5.3.4 of WCAP-12472-P-A and is calculated using equation 5-7 of WCAP- 12472-P-A which includes the power dependent thermocouple deviation function defined in equation 1 as shown below.

In the updated thermocouple evaluation process, equation 2 is used in the equation 3 instead of equation 1, and the radial assembly uncertainty function is a function of the average thermocouple deviation which is a function **[ ]**

In this form the radial assembly uncertainty is a function of the plant/cycle-specific power dependent thermocouple deviation. At full power conditions the average thermocouple deviation will be equal to the average deviation for the thermocouples, if it were calculated from multiple flux maps near HFP conditions at the start of the current cycle.

Hence, if assuming only full power conditions, equations 3 and 4 of the current submittal would be equivalent. At reduced power levels the trends of the thermocouple mixing factor standard deviations and the radial assembly uncertainties will be different [

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2.3 APPLICATION OF THE UPDATED METHOD

The updated BEACON method of analyzing the thermocouple mixing factor data is unchanged from the licensed method described in the approved WCAP-12472-P-A TR. What has changed in the update is the use of current plant/cycle thermocouple data in the analysis to generate a plant/cycle specific power dependent thermocouple deviation function that replaces the function defined in equation 4-4 of WCAP-12472-P-A.

Westinghouse has provided a methodology for implementing an updated thermocouple uncertainty analysis process in the submitted TR. [

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Westinghouse also provided an example of the results of implementing the updated methodology in Table 1 from Plant X. These results are from a Westinghouse 4 loop plant with 193 fuel assemblies and 57 thermocouples.

The average thermocouple mixing factor standard deviation at HFP conditions was determined and indicated a very good thermocouple behavior at full power conditions. The fitting coefficients determined for the thermocouple deviation function, equation 2, were also determined.

Table 1 also provides a comparison of the thermocouple power dependent deviations and uncertainties using the original method of WCAP-12472-P-A and the updated method discussed above. Columns 2 and 3 of the table show the power dependent average thermocouple deviation results using equation 1 (equation 4-4 of Reference 2 and results from the analysis based on using equation 2 to determine the deviation for each thermocouple then averaging for the core value. The radial assembly uncertainty results from using equation 3 and using the updated equation 4 are also shown in the table in columns 5 and 6. The difference between the original method and the updated method for the average standard deviation and assembly uncertainty is shown in columns 4 and 7, respectively. [

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A second example of results from an on-line analysis is shown in Table 2 for Plant Y, with greater variability in the thermocouple behavior. These results are from a Westinghouse four loop plant with 193 fuel assemblies with 65 thermocouples. The average thermocouple mixing factor standard deviation at HFP conditions was determined to be [ ] which is larger than plant X, indicating greater variability in the thermocouple behavior at full power conditions. The fitting coefficients determined for the thermocouple deviation function (equation 2) were determined to be satisfactory. Equation 2 in the submittal is a second order (degree) polynomial. The NRC staff asked Westinghouse why a second degree polynomial was adequate. Westinghouse responded by stating that the **[**

] Second, evaluation of the mixing factor behavior in Chapter 6 of WCAP-12472-P-A demonstrated that the quadratic function shown in equation 1 of the Addendum 4 appropriately represents the physical behavior of the power dependent thermocouple data. This quadratic function can nearly be exactly reproduced with the second order polynomial. Going beyond a second order polynomial would introduce a significant risk that in some cases the fit could bend to non-physical or non-conservative directions at lower power levels. The resulting function would then not be representative or consistent with equation 1. To avoid this risk the fit is limited to a second order polynomial.

Table 2 also provides the same comparison of the thermocouple power dependent deviations and uncertainties using the original method of WCAP-12472-P-A and the updated method discussed above. Columns 2 and 3 of the table show the power dependent average thermocouple deviation results using equation 1 (equation 4-4 of WCAP-12472-P-A) and results from the analysis based on using equation 2 to determine the deviation for each thermocouple then averaging for the core value. The radial assembly uncertainty results from using equation 3 and using the updated equation 4 are also shown in the table in columns 5 and 6. The difference between the original method and the updated method for the average standard deviation and assembly uncertainty is shown in columns 4 and 7, respectively.

These results clearly show that the benefit from the updated analysis process is plant/cycle specific and can be relatively small depending on the cycle specific thermocouple behavior. The total peaking factor uncertainty values resulting from using either equation 3 or 4 of the updated method does not impact the reload safety analysis because valid ranges of the on-line surveillance uncertainties are considered in the plant specific safety analysis using approved methodologies.

3.0 CONCLUSION

The NRC staff has reviewed the Westinghouse submittal TR WCAP-12472-P/WCAP-12472-NP, Addendum 4, Revision 0, and found the updated thermocouple methodology, the use of approved Westinghouse design model methodology, and the use of higher order polynomial fits for FID uncertainties provided in the TR acceptable. The basis for acceptance is due to the provided qualitative and quantitative technical material contained in the TR.

The NRC staff has concluded, based on the considerations discussed above, that:
(1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

4.0 REFERENCES

1. Letter from J.A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, dated December 10, 2010, “The Westinghouse Electric Company TR WCAP-12472-P/WCAP-12472-NP, Addendum 4, Revision 0, ‘BEACON^{TM} Core Monitoring and Operation Support System, Addendum 4,’” ML1035100670.

2. WCAP-12472-P-A, “BEACON- Core Monitoring and Operations Support System,” August 1994.

3. Letter from J.A. Gresham, Manager, Regulatory Compliance, Westinghouse Electric Company, dated October 28, 2011, “Responses to the NRC Request for Additional Information on WCAP-12472-P/WCAP-12472-NP, Addendum 4, "BEACON™ Core Monitoring and Operation Support System, Addendum 4,” ML11308B387.

4. WCAP-12472-P-A, Addendum 1-A, “BEACON- Core Monitoring and Operations Support System,” January 2000.

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