Safety Evaluation Report "Topical Report on ASME Section III Piping and Component Fatigue Analysis Utilizing the WESTEMS™ Computer Code" (WCAP-17577, Revision 2)

1.0 Introduction

This safety evaluation report (SER) provides the U.S. Nuclear Regulatory Commission (NRC) staff's evaluation of the use of the Westinghouse Electric Company (Westinghouse) WESTEMS™ computer code to perform the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PV Code) Section III piping and component design process documented in the topical report (TR) numbered WCAP-17577, Revision 2, "Topical Report on ASME Section III Piping and Component Fatigue Analysis Utilizing the WESTEMS™ Computer Code." The scope of this TR is limited to the ASME B&PV Code Section III, Subsections NB 3200 and NB 3600 design analysis modules of the WESTEMS™ computer code for application to AP1000 ASME Class 1 piping and component design. The online monitoring module of WESTEMS™ is not in the scope of the NRC staff's review of this TR.

To evaluate the technical process internal to the computer code information given in this TR, the NRC staff used the acceptance criteria and guidelines documented in NUREG 0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 3.9.1, "Special Topics for Mechanical Components," Revision 3 (Reference 1), to address ASME Section III NB 3200 and NB 3600 requirements. The staff also reviewed Westinghouse computer software requirements to ensure the software is in compliance with the ASME NQA 1 quality assurance standard.

The WESTEMS™ computer code has the ability to compute a stress history for given piping and components from temperature, pressure, and moment transient input data. Fatigue usage is then evaluated from the stress history. The WESTEMS™ methodology to calculate stress and cumulative usage fatigue (CUF) involves developing transfer functions (stress tensors caused by unit pressure, unit moment, and unit temperature step load increase or decrease) to convert transient data to stress versus time for a given component to address NB 3200 requirements. WESTEMS™ performs one dimensional heat transfer analysis to determine the temperature data for the piping cross section and range of average temperatures for gross structural or material discontinuities to be used in calculating the stress intensity ranges as described in the NB 3653 piping stress qualification.

Westinghouse submitted, by letter dated February 29, 2012, WCAP-17577, Revision 0, "Topical Report on ASME Section III Piping Fatigue Analysis Utilizing the WESTEMS™ Computer Code" (Reference 4). The staff performed an acceptance review and identified specific gaps in the TR. After the NRC staff conveyed these information needs to Westinghouse, the applicant requested by letter dated May 9, 2012, "Withdrawal Request for WCAP-17577 P and –NP," (Reference 5), that Revision 0 of WCAP-17577 be withdrawn from NRC review. The NRC staff confirmed this withdrawal in a letter dated June 1, 2012 (Reference 6). In a letter dated September 28, 2012 (Reference 7), Westinghouse submitted Revision 1 of WCAP-17577 for NRC review. The NRC staff accepted Revision 1 of the TR for review by letter dated November 13, 2012 (Reference 8), identifying the NRC staff's need to understand the circumstances in which WESTEMS™ requires user controlled modification. The staff issued several requests for additional information (RAIs) to ask Westinghouse to address specific technical issues with this TR. To facilitate the staff review and examine detailed documentation not required to be submitted for review, the NRC staff also completed audits in December 2012 and April 2013 (audit reports, References 9 and 10) and held meetings with the applicant on April 25, 2013, and June 3, 2013 (meeting summaries, References 11 and 12, respectively). Westinghouse addressed all RAIs (References 13 through 16) and submitted an updated Revision 2 that reflected all RAI responses by letter dated June 17, 2013 (Reference 17).

2.0 Regulatory Basis

The applicable regulatory requirements for computer codes for piping and component design are as follows:

- Title 10 of the Code of Federal Regulations (10 CFR) 50.55a, "Codes and Standards," which incorporates by reference the ASME Boiler and Pressure Vessel Code Section III, Division 1.

- Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," General Design Criterion (GDC) 1, which requires, in part, that components important to safety be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed.

- Appendix B to 10 CFR Part 50, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," as it relates to the quality of design control.

In addition, SRP Section 3.9.1 provides staff guidance in reviewing applications with respect to the requirements of 10 CFR Part 50, Appendix B, and GDC 1. This guidance states that applications should include a list of computer programs to be used in analyses to determine stresses. To determine the applicability and validity of the codes, the NRC staff reviews information about the codes, including the source, version, and facility; a description of the code; the extent and limitation of the code's application; and the solutions of test problems that are demonstrated to be substantially similar to solutions obtained from other specified sources (e.g., hand calculations or benchmark problems).

For quality assurance (QA) programs, the Commission's regulatory requirements are set forth in 10 CFR Part 50, Appendix B. Appendix B establishes QA requirements for the design, fabrication, construction, and testing of the structures, systems and components (SSCs) of the facility. The pertinent requirements of Appendix B apply to all activities that affect the safety related functions of those SSCs and include designing, purchasing, fabricating, handling, shipping, storing, cleaning, erecting, installing, inspecting, testing, operating, maintaining, repairing, refueling, and modifying.

Criterion II, "Quality Assurance Program," of Appendix B to 10 CFR Part 50 establishes QA program requirements. It states, in part, that, "The program shall provide for indoctrination and training of personnel performing activities affecting quality as necessary to assure that suitable proficiency is achieved and maintained."

3.0 Technical Evaluation

3.1 Introduction and Background

Section 1, of WCAP-17577 states that the purpose of this report is to document the use of the WESTEMS™ computer program for performing ASME Section III fatigue analysis on Class 1 piping and components for the AP1000 nuclear power plant, specifically the application of the NB 3600 and NB 3200 modules of the program. Initially, the TR referred only to piping analyses; during a public meeting on April 25, 2013 (Reference 11), the NRC staff noted that ASME Section III NB 3200 can be applied to all components designed by analysis and is not limited to piping only. In addition, it was initially unclear whether the scope of the TR included both the design analysis modules and the online monitoring module. In RAI WSTM-011, dated April 25, 2013 (Reference 18), the NRC staff requested that the applicant address this issue. In its response dated May 10, 2013 (Reference 16), Westinghouse stated that "[t]he revised version of the [TR] will include a statement that specifically excludes the Online Monitoring Module from the scope of this review. It will also clarify that the scope for use of the program is Class 1 piping and components." On the basis that NB 3200, "Design by Analysis," is applied to design analysis for all Class 1 components and that the applicant provided clarification to the review scope by excluding the online monitoring module, the NRC staff determined that this response was acceptable. The NRC staff confirmed that the change has been incorporated in WCAP-17577, Revision 2.

The WESTEMS™ computer program performs stress time history calculations. The alternating stress intensities can be calculated by pairing the stress peaks and valleys from the stress time history. The fatigue usage factor can be calculated using alternating stress intensity. However, the WESTEMS™ computer code does not include algorithms to cover all possible situations in peak and valley selection. The computer code generates redundant peaks that may have to be eliminated to reduce conservatism. This redundant peak elimination is to be determined by the analysts' reasonable engineering decisions. However, without proper procedural guidance, different analysts may make different engineering judgment in determining redundant peaks to eliminate. Therefore, Westinghouse developed a procedure associated with the use of WESTEMS™ to ensure the validity and repeatability of the fatigue analysis results.

In TR Section 1.1, Westinghouse indicated that this computer program is designed to be partially automatic, and user controls over the computer code process are needed. The NRC staff's initial concern from when WESTEMS™ was first discussed in the context of the AP1000 review (References 2 and 3), was that the non-automatic part of the user controls may not produce repeatable results for a specific input, limiting the code's ability to produce a valid solution to a physical problem with user controls. User controls are implemented in the selection of the peak times in the fatigue analysis process. Westinghouse states that the WESTEMS™ program is designed to provide qualified fatigue analysts the necessary tools to perform fatigue analyses commensurate with the degree of conservatism required to demonstrate qualification to ASME Code limits. This includes versatility in inputs, availability of intermediate and final outputs to understand the problem and support qualification documentation, and efficiency of the iterative process that could be required for more complex problems. As described in Section 3.2 below, user controlled decisions for peak selection are documented and reviewed to justify the technical decision made and ensure the validity and repeatability of the fatigue analysis results. The evaluation of the software analysts' decision process is documented in Section 3.3 of this report.

The TR emphasizes the use of user controls in the application of WESTEMS™ to ensure that ASME Code and regulatory requirements are met. These controls include QA policies for the development and validation of software, procedures for using the software and documenting the analysis process, training and qualification requirements for individuals, and benchmarking of the analysis process.

The staff reviewed the QA policies and programs for the WESTEMS™ computer code, as documented in Section 3.3 of this report.

3.2 Resolution of Regulatory Concerns with Fatigue Analysis Software and Process

In NUREG 1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design," Supplement 2, Volume 1, dated September 2011, (Reference 19), the NRC staff documented initial review and discussion of the WESTEMS™ computer code in the context of the AP1000 design certification review. The WESTEMS™ computer code was later removed from the scope of the design certification. However, Sections 1.2 and 2.1 of the TR include those technical issues previously identified by the staff in its initial review of the WESTEMS™ computer code, as documented in NUREG-1793.

First, the NRC staff noted that the algebraic summation of three orthogonal moment components is mathematically incorrect and physically meaningless and requested the applicant to provide technical justification for this option in selecting peak and valley times for the fatigue evaluation. This concern was not addressed at that time because WESTEMS™ was removed from the scope of the design certification. In Section 2.1 of WCAP-17577, Westinghouse indicates that the user controlled option on peak selection with algebraic summation of the three orthogonal moments has been eliminated and the modified peak selection process, which is based on stress ranges using ASME Section III equations 10, 11, and 14 always uses the square root of the sum of the squares (SRSS) ranged orthogonal moment components. In audits performed in the context of the review of WCAP-17577, the NRC staff reviewed the user manual, software design specification, and validation package of WESTEMS™ Version 4.5.6 to confirm the computer code has been revised to address this concern. On the basis that the peak selection option using SRSS of three moment component ranges to determine the moment stress is consistent with the requirement in ASME Section III NB 3653, the NRC staff found this resolution acceptable.

Second, the NRC staff identified that the WESTEMS™ option allowing the elimination of peak and valley points would necessitate review of configuration control and limitations of the program for this option. This additional information would enable the staff to conclude that the process and results are valid and repeatable. In Section 2.1 of the TR, the applicant provided its resolution of this issue. The applicant identified that there are two primary aspects to this concern. The first is with respect to ASME's Quality Assurance Requirements for Nuclear Facility Applications (NQA 1)—requirements that the results of safety related computer software are valid and repeatable. The second aspect focuses on quality control of the analyst performing the fatigue evaluation with specific regard to the editing of the input peak and valley set in a restart file.

The applicant stated that the Westinghouse software development process implemented in the development and maintenance of the WESTEMS™ computer program is fully in compliance with NQA 1 requirements, and validation and verification of the WESTEMS™ program show that the software produces valid and repeatable results for a given set of inputs. The applicant considers WESTEMS™ fatigue analysis as a two phase process. The first phase is an initial analysis, in which the program performs stress history calculations, selects peak and valley times, and calculates fatigue results from the parameters associated with initial peak and valley times selected. The second phase includes an optional step for editing of the input peak and valley set based on the identified conservatisms. If the peak and valley set is modified to reduce conservatism, then the final analysis is performed in the second phase of the fatigue analysis. The edited set of stress peaks is considered to be a new user input as provided in a restart file. Each phase is an independent analysis that produces consistent output for a given set of inputs. The complete fatigue analysis—including inputs, methodology, results of the initial and final evaluation phases, and associated engineering justification—is fully reviewed by an independent verifier. By this separation of the fatigue analysis process into two distinct phases, Westinghouse indicates that there is one set of input for each phase, which does not constitute producing different output for the same analysis inputs. The initial analysis has one set of inputs and always produces consistent and repeatable outputs. The final analysis is based on initial analysis, but it also considers an independent set of revised user inputs. The applicant states that the final analysis phase will also produce conservative and acceptable results; the staff's evaluation of the acceptability of the results is documented in Section 3.5 of this report.

The second aspect of the NRC staff's concern focuses on quality control of the analyst performing fatigue evaluation with specific regard to the editing of the input peak and valley set between the two phases of WESTEMS™ evaluations. This is not an aspect of the software, and cannot be controlled through software specifications and validation analyses. Westinghouse developed a fatigue analysis procedure to serve as the quality control to ensure that decisions made by the analyst are justified, documented, verified, and repeatable. Both the procedure and user manual provide discussion of the potential causes for conservative (redundant) peaks and valleys that may be included in the initial analysis. The procedure also provides the analyst the guidelines for identifying instances of these noncontrolling redundant peak and valley times that are considered conservative and unnecessary. Westinghouse stated that all analysts who intend to use the WESTEMS™ computer program are required to review the procedure and document this review in a training record in accordance with the Westinghouse training process.

The NRC staff noted that WESTEMS™ TR is also applied to ASME Section III NB 3200 fatigue analysis, and the NB 3200 analysis also requires user controlled elimination of redundant peaks/valleys. The staff issued an RAI (WSTM-006) to ask Westinghouse to provide an NB 3200 fatigue procedure. In its response dated March 4, 2013 (Reference 15), the applicant provided an additional NB 3200 fatigue analysis procedure to address this RAI. The evaluation of this procedure is documented in Section 3.4 of this report.

The NRC staff reviewed the two phase procedure documentation and user manual during an audit. The NRC staff determined that this approach is acceptable for yielding a result that is valid and repeatable. The evaluation of the procedure and process is documented in Section 3.4 of this report.

3.3 General Software Requirements

In TR Section 3, Westinghouse provides its computer software development and validation process and requirements. The computer software developed for safety related design and analysis must meet a series of requirements defined in Westinghouse quality and procedure documents that ensure the software is in compliance with ASME NQA 1 QA standards. In line with the policies pertaining to software development are Westinghouse policies and procedures governing the design and analysis process for the AP1000.

At Westinghouse, the Quality Management System (QMS) serves as a directive for all functions in establishing necessary policies and procedures that comply with requirements of ISO 9001; and in addition, as applicable for safety related activities, Appendix B to 10 CFR Part 50, and ASME NQA 1. Software development at Westinghouse is performed in accordance with documented policies and procedures that implement QMS and conform to NQA 1. These procedures explicitly apply to safety related software, and software used in the design and analysis of safety related systems, structures, and components (e.g., the WESTEMS™ analysis software). As noted in NUREG 1793, the NRC staff previously approved Revision 5 of the QMS in a letter dated September 13, 2002. Furthermore, the NRC staff concluded in Section 17.3.3 of NUREG 1793 that the QMS, as described in the AP1000 design control document, Revision 17, meets the criteria of 10 CFR 52.63(a)(1)(vii) and Appendix B to 10 CFR Part 50 and is, therefore, acceptable.

The NRC staff reviewed the software design specification and design specification changes from version 4.5 to version 4.5.6 during an audit in December 2012. The staff determined that all required documentation is available. The validation of the software for reliability and repeatability is evaluated and documented in Section 3.5 of this report.

In Section 3.2 of the TR, Westinghouse indicates that regardless of the software and engineering tools used and the qualification of the analyst, the analyst is required to satisfy all requirements identified in Westinghouse policy NSNP 3.2.6 in performing and documenting a design analysis. This is intended to ensure that the design analysis meets all defined acceptance criteria. In addition, all calculations performed with or without a computer code are independently verified in compliance with NSNP 3.3.7.

In TR Section 3.3, Westinghouse provided applicability limits of the WESTEMS™ software. The staff reviewed these limitations and focused on the limits of the automatic processing of calculation input (i.e., user controlled activities). This evaluation is documented in Section 3.4 of this report.

Quality Assurance Program

Section 1.5, “Summary,” of Chapter 1, “Introduction,” of WCAP-17577-P states, in part, that:

> The development of safety related computer software and the requirements for performing design analysis are governed by Westinghouse quality policies and procedures that ensure compliance with NQA 1 quality controls.

Chapter 3, “General Software Requirements,” notes that:

> Computer software developed for safety related design and analysis must meet a series of requirements defined in Westinghouse quality policy and procedure documents that ensure the software is in compliance with ASME NQA 1 quality assurance standards. These documents identify the responsibilities for developing a computer code, validating the software functionality, maintaining configuration control, documenting errors and their resolution, and updating controlled software.

Section 3.1, “Development and Validation of Computer Codes,” of the above section further states that:

> Activities affecting the quality of items and services are performed at Westinghouse in accordance with the Quality Management System (QMS). The QMS serves as a directive for all functions in establishing necessary policies and procedures that comply with the requirements of ISO 9001; and in addition, as applicable for safety related activities, 10 CFR 50, Appendix B; ASME NQA 1. Software development at Westinghouse is performed in accordance with documented policies and procedures that implement the QMS and conform to NQA 1. These procedures explicitly apply to safety related software (e.g., plant operational control), and software used in the design and analysis of safety related systems structures, and components (e.g., the WESTEMS analysis software).

The staff notes that WCAP-17577-P, Revision 2, references the Westinghouse Quality Management System (QMS). By letter dated February 24, 2011 (Reference 20), the NRC staff found that Revision 6 to the Westinghouse QMS meets the requirements of Appendix B to 10 CFR Part 50 and is, therefore, acceptable.

<u>Training</u>

The staff issued RAI WSTM-010 on January 28, 2013, requesting that the applicant specifically address indoctrination and training and requirements for the fatigue analysts that perform fatigue analyses to demonstrate qualifications to ASME Code limits using the WESTEMS™ computer code.

In a letter response to WSTM-010, dated February 18, 2013, the applicant describes how the Westinghouse Quality Program defines how the company meets customer and regulatory requirements. The applicant provides additional details regarding its training program for the WESTEMS™ analysis covering two areas: (1) The level 3 WESTEMS™ Fatigue Procedure PSDR QP 4.7 and (2) correct use of WESTEMS™ version 4.5.6.

The applicant notes that:

> The WESTEMS™ training consists of four training module presentations and completion of a test problem which is submitted for demonstration of understanding. In addition, a mentoring relationship (on the job training) is established until the analyst has demonstrated sufficient understanding by producing an acceptable analysis which has been determined to be correct.
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> (…)
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> Individual training for each analyst is documented in each analyst's training records and is summarized in a qualification and training matrix, which is maintained by the group manager in accordance with Westinghouse level 2 procedure WEC 2.6, Training. The qualification matrix is used to determine who is qualified to perform fatigue analysis using WESTEMS™ and who is qualified to verify the WESTEMS™ fatigue analysis.

The staff determined that users of the WESTEMS™ software are required to be adequately trained in accordance with Westinghouse's QA program. The staff found the applicant's response meets the training requirements of Appendix B to 10 CFR Part 50.

3.4 Overview of WESTEMS™ Fatigue Analysis

The WESTEMS™ design analysis module calculates the stresses required by ASME Section III, Subsections NB 3200 and NB 3600, and provides a comparison of the calculated results to those allowed under the ASME Code. Westinghouse provided the general steps for the fatigue analysis calculation as follows:

(1) Calculate primary plus secondary stress intensity ranges.

(2) Calculate Simplified Elastic Plastic penalty factors (Ke) for each stress range pair.

(3) Calculate total stress intensity ranges.

(4) Calculate alternating stress intensity (Sa) including Ke required by the code.

(5) Calculate fatigue usage factors using the Sa value and corresponding cycles.

(6) Calculate thermal stress ratchet requirements.

The staff reviewed the calculation process and found that it meets the ASME Code requirements and that the steps are in the right order. Accordingly, the staff found this process acceptable.

3.4.1 NB 3600 Analysis Review

NB 3600 thermal stress analyses are based on heat transfer temperature solutions and stress formula. WESTEMS™ uses a finite difference technique to calculate the temperature solutions. The ASME Code stress intensity range calculation is based upon the effect of changes in mechanical or thermal loadings that take place as the system goes from one load set, such as pressure, temperature, moment, and force loading, to any other load set that follows it in time. The process flowchart for this calculation is in Figure 4-1, the equations used to determine the stress intensity ranges are in Figure 4-3, and the NB 3600 peak selection method is in Figures 4-2 and 4-4.

The NRC staff reviewed the process flowchart and determined that WESTEMS™ process follows ASME Code stress intensity range calculation for each pair, including the peak and valley time selection. In addition, the NRC staff confirmed that WESTEMS™ version 4.5.6 does address the previously identified algebraic summation of three orthogonal moments (as mentioned above, this option has been eliminated by Westinghouse). Therefore, the NRC staff concludes that Figure 4-3 is consistent with ASME Section III, Subsection NB 3653, and that the methodology documented in Figures 4-2 and 4-3 is acceptable.

In addition, the staff observed that Figure 4-1 and Section 4.1.1 indicate that [ ] (optionally) at the first step as an alternative to an enveloping moment stress range. The applicant provided clarification specific to this option in a teleconference on June 25, 2013, noting that the details of this step are documented in the analysis procedure (Section 5.1.2.2, as Figure 4-6 notes) and user manual (Section 10.2 of Volume 2), both of which the staff previously audited (References 9 and 10). These documents clarify that the general approach is to use moment stress ranges, but the analyst may choose to use moment component histories in certain cases. The NRC staff observes that a thermal analysis would first need to be completed to develop the timing of temperature peaks identified in the procedure. The piping moment component histories are functions of the piping global temperature histories. If the moment component histories are used, the input considers the relative timing of temperature and pressure peaks and valleys to result in a conservative range of combined stress, and the calculation package documents the justification for and adequacy of the input. The NRC staff concludes that this approach is sufficient to provide conservative moment inputs to the calculation.

TR Figure 4-4 shows that a peak exclusion time constant check is used to eliminate redundant peaks and valleys. The staff issued RAI WSTM-07 to ask the applicant to clearly define how the time constant is determined and provide clear justification for this elimination.

In its response dated February 18, 2013, the applicant stated that the WESTEMS™ [

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The staff asked a followup question, RAI WSTM-007, to clarify the determination of the time constant value. In its response dated May 10, 2013, Westinghouse updated part of the previous response as follows:

> [
>
>]

The staff reviewed the response. On the basis that the time constant value can remove the identified redundant peak and that the procedure requires review by the analyst and independent verifier to ensure that this process does not eliminate actual peaks, the NRC staff found this acceptable.

TR Figure 4-4 shows that a stress filter check is used for the peak selection process. The NRC staff issued RAI WSTM-009 to ask the applicant to explain the process to ensure the critical (maximum stress for peak, minimum stress for valley) points are retained for both NB 3600 and NB 3200. In its response dated February 26, 2013, the applicant provided examples to explain the stress filter check process and also provided guidelines of the NB 3600 fatigue analysis procedure. The applicant stated that WESTEMS™ always retains the maximum and minimum stress states that contribute to the greatest alternating stress within a transient and these values cannot be eliminated by the application of the stress filter. WESTEMS™ procedural guidelines require that the analyst and independent verifier review peaks following the application of the stress filter to ensure that a peak is included for each sub cycle load excursion. Because the critical values cannot be eliminated by the stress filter, the NRC staff found this acceptable.

In TR Figure 4-5, Westinghouse presents a process flowchart for WESTEMS™ NB 3600 peak review and editing. The staff reviewed Figure 4-5 and identified two critical decision points in the flowchart for which the process flowchart does not provide justification or criteria.

- The process flowchart indicates that “if peak does not correspond to a load excursion, eliminate this peak.” The applicant did not provide technical justification for why this peak is redundant.

- The flowchart indicated that “if two or more peak times exist for the same load excursion, then eliminate redundant peak ‘A’ and ‘B’.” The applicant did not provide technical justification for the elimination.

The staff issued RAI WSTM-008 to ask Westinghouse to address this issue. In its response dated February 26, 2013, Westinghouse provided examples in which peaks occur due to stress phasing differences or due to small fluctuation of applied loading. The staff reviewed the response and determined that a followup question was needed to clarify the technical justification from the examples. The example indicated that if time points P1 and P2 are selected by the automated process and represent the same state, P2 may be deleted. The condition for eliminating P2 is under the flow path “Does peak correspond to a load excursion? → NO → Eliminate conservative peak using the WESTEMS™ peak editing tool.” The staff asked whether the same principle can be applied to delete peaks A and B. The staff asked the applicant to define which peaks correspond to load excursion.

In its response dated May 10, 2013, Westinghouse stated:

> The intent of the procedure is to [ ]. To better clarify the intent, the wording “corresponding to a load excursion” will be changed in the flow chart in the TR and procedure to be more explicit, as shown in the topical report markup section of this response.

In Revision 2 of the TR, the wording of this item was changed from “Does peak correspond to a load excursion” to “Is peak a sub cycle peak due to [ ]?” On the basis that this would be a redundant peak that can be appropriately eliminated, the NRC staff found this change acceptable and the issue resolved. TR Section 1.1 indicates that “[t]he effort to develop algorithms to cover all possible conceived problem dependencies is not practically justified compared to the effort for analysts to make reasonable engineering decisions about the inputs for known problems.” The NRC staff issued RAI WSTM-005 to request the applicant to identify all reasonable engineering decisions for the removal of the redundant peaks with corresponding engineering criteria and to clarify whether these are all included in the procedure. Specifically, the applicant was asked to address under what situation, if any, the peak elimination process criteria could not be included in the procedure. The NRC staff observed that TR Section 4.1.2 stated that “[i]n addition to the peak selection controls, the analyst has the ability to refine the fatigue analysis restart file to manually eliminate peak times justified to be redundant and conservative and to perform fatigue reanalysis with the restart file.” The NRC staff asked the applicant to clarify this situation with examples.

In a letter dated March 4, 2013 (Reference 15), the applicant responded to the RAI and provided the potential sources of the redundant peaks in WESTEMS™ NB 3600 analysis with three scenarios:

(1) [ ]

(2) [ ]

(3) [ ]

Redundant peaks could occur in the NB 3200 analysis in two scenarios:

(1) [ ]

(2) [ ]

The response also stated that all those scenarios have been described in the user manual and procedure and there are no additional situations presently known that can be described. The staff found this acceptable. However, the NRC staff issued a supplemental question to RAI WSTM-005 requesting that the applicant revise the sentence mentioned above that appeared to grant the analyst the ability to manually eliminate peak times. In its response dated May 10, 2013, Westinghouse stated that it would revise the TR to state that no other redundant peaks can be credited, aside from those defined in Section 4.1.5 for NB 3600 analysis and in Section 4.2 for NB 3200 analysis, without prior NRC approval. The NB 3600 and NB 3200 procedures will be revised, as necessary, to reflect this change to the TR. The applicant also provided its TR markup for Sections 4.1.5 and 4.2 to address this issue, and the staff confirmed that these changes were incorporated in Revision 2 of the TR. On the basis that the applicant correctly addressed this concern and limited the peak selection criteria to these five defined instances, the NRC staff found this acceptable.

3.4.2 NB 3200 Review

As noted in Section 1.1 of the TR, proper incorporation of the user controls for elimination of the redundant peaks and valleys has been the subject of previous interaction with the NRC staff. To address this concern, the applicant proposed to use a fatigue analysis procedure. WESTEMS™ is also applied to NB 3200 fatigue analysis. On the basis that the NB 3200 fatigue analysis also requires user controlled elimination of redundant peaks and valleys, the NRC staff issued RAI WSTM 006 to request the applicant to provide the criteria and procedure for NB 3200 fatigue analysis. In its response dated March 4, 2013, Westinghouse stated:

> The procedure for NB 3200 fatigue analysis is being added as a new Section 8.1.13 in the WESTEMS™ User Manual Volume 2 for Design Analysis. The procedure will reference an updated Section 8.1.13 in the manual that provides expanded criteria and guidelines for peak selection control and peak editing in NB 3200 (ASN) analysis.

The applicant also provided the WESTEMS™ User Manual Volume 2 markups. The NRC staff reviewed this information related to the NB 3200 procedure and found that additional information was needed related to the use of a time constant to eliminate peaks. The staff issued supplemental RAIs WSTM-006 and WSTM-007 to address this topic. In its response dated May 10, 2013, Westinghouse provided its response to RAI WSTM-006 as follows:

(1) The wording in the NB 3200 user's manual markup, attached to the RAI response, will be revised to change "no greater than" to "less than" in the last paragraph before Figure 1 in the section on time constant input. [

]

(2) [

]

(3) The TR defines redundant peaks as [

]. In addition, contextual use of the term will be made to be consistent with the definition in the revised version of the TR."

(4) Item 3 of the time constant input for the NB 3200 procedure markup will be updated as follows:

[

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The applicant also provided its response to RAI WSTM-007 as follows:

[

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The applicant also provided its TR markups to incorporate the changes, and the NRC staff verified that these changes were incorporated in Revision 2 of the TR. On the basis that the applicant clarified how to determine the time constant used in peak selection, as well as how to determine redundant peaks using this time constant, the NRC staff found this response acceptable.

As described above, the staff issued RAI WSTM-005 to request the applicant to identify all reasonable engineering decisions for the removal of the redundant peaks with corresponding engineering criteria and clarify whether these are all included in the procedure. The staff also issued RAI WSTM-009 to ask the applicant to explain the process to ensure the critical (maximum stress for peak, minimum stress for valley) points are retained for both NB 3600 and NB 3200. As documented in Section 3.4.1 of this report for the NB 3600 analysis, the staff found the applicant's response acceptable and considers this issue closed with Revision 2 of the TR.

3.5 Validation of the Revised WESTEMS™ Program

Section 2.1 of the TR discusses the applicant's resolution of regulatory issues that were raised in previous NRC audits. Of note, in response to an original question in SRP Section 3.9.1 EMB 07 issued during the review of the AP1000 design certification, discussed on Page 2-1 of the report, the application states that the WESTEMS™ computer code consists of a two phased fatigue analyses. The first phase was performed to calculate stress time history for each individual transient, select peak and valley times, and calculate fatigue results from all transient pairs associated with the selected peak and valley times. The second phase includes a user's controlled modification of redundant peaks and valleys for input to the reanalysis.

The NRC staff noted that the user's controlled modification is part of the application of the computer code as it is included in the program user's manual and that it is considered necessary by Westinghouse for using WESTEMS™ computer program. It is noted that no user's controlled modification will be required if there exist no redundant peaks from the computer run. As such, in RAI WSTM-001, the NRC staff requested that Westinghouse provide the root cause of generating the redundant and additional peaks and valleys that the program users need to eliminate during the manual modification. The staff also requested that Westinghouse confirm whether the additional redundant times could be created because of deficiencies in certain program algorithms and whether there are transient cases other than those stated in Section 4.1.5.

In its response dated February 26, 2013 (Reference 14), the applicant attributed the "root cause" of redundant peaks to three potential sources stated in Section 4.1.5 of the topical report (WCAP-17577) for an NB 3600 fatigue analysis in WESTEMS™:

(1) [
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(2) [
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(3) [
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The first "root cause" of redundant peaks is attributed to transient definitions. The transient definitions may inherently include redundant extreme stress states, such that a final stress state for one transient may represent an initial stress state of another transient (e.g., heatup and cooldown design transients in which cooldown begins at the same state that heatup ends and heatup begins at the same state that cooldown ends).

The second "root cause" of redundant peaks is attributed to phasing of primary plus secondary stress (Sn) and total stress (Sp) for a transient load excursion. ASME Code fatigue usage is based on alternating stress (Sa), which is determined from the total stress range and the Ke penalty factor. The Ke penalty factor is a function of the Primary plus Secondary stress range. Therefore, the [

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The applicant asserted these potential redundant sources to be the only cases where the redundant peaks can be generated by WESTEMS™ computer code. The analysts will select redundant peaks for elimination only in the above three cases and document the justification in the calculation notes.

Regarding the root causes related to computer programming algorithmic deficiencies, the applicant stated that the creation of redundant peaks is intentionally coded into WESTEMS™ to conservatively account for all possible peaks, and that these are not the result of any algorithmic deficiencies. For instance, the operation of the program is to [

] for the through wall temperatures to return to steady state conditions. Also, the program operation will conservatively allow both times to be included in the initial fatigue evaluation. This allows for any dominant effects of Ke at the Sn peak time to produce a higher alternating stress in the fatigue pair contributions than that produced by the Sp peak time. If both times result in significant fatigue pairs, this is a conservative accounting of the transient stress cycle, as illustrated below. The user is therefore provided options to reduce this conservatism if necessary. In addition to the RAI response described above, the applicant revised Section 4.1.5 of the TR to state that justification for elimination of conservative peak times is limited to the above three root causes. As a result of its review, the NRC staff concludes that the applicant has adequately identified the "root cause" for redundant peaks, which, as stated above, were generated in an initial attempt to conservatively account for all possible peaks in the fatigue calculation. Therefore, the RAI WSTM-001 is resolved and closed.

The staff's acceptance review letter dated November 13, 2012 (Reference 8), noted that the TR does not clearly address the technical basis regarding how the WESTEMS™ computer program requires user controlled modification in some cases, and that further understanding would be necessary to determine that WESTEMS™ produces justifiable and conservative results. Therefore, in RAI WSTM-002, the NRC staff requested that the applicant compare peaks and valleys from hand calculations with the results from WESTEMS™ analysis and ensure that no real peaks and valleys are missed by WESTEMS™ calculation. Alternatively, the applicant was asked to demonstrate that the hand calculated peaks and valleys are at least a subset of WESTEMS™ output peaks and valleys.

In its response dated March 4, 2013 (Reference 15), the applicant provided an example to demonstrate WESTEMS™ analysis would generate conservative results such that the hand calculated peaks and valleys would be at least a subset of WESTEMS™ output peaks and valleys. The following calculations are provided in the two part example:

(1) An NB 3600 fatigue analysis is performed using traditional manual (hand calculation) methods to select peak and valley stress states.

(2) The same NB 3600 model and loading is analyzed in WESTEMS™ to demonstrate that the same set of manually selected peaks is also identified by the software.

The example considers a representative NB 3600 fatigue analysis of a standard component (a 3 inch valve) with a thermal transient loads and enveloping moment stress ranges applied. The component also includes a structural discontinuity. The thermal stress history inputs are used to select the peak and valley stress states (peak) using a traditional manual approach. Manual calculations are also used to evaluate the fatigue pairs, including alternating stress, cycle consumption, and usage factors. The same fatigue analysis is then run in WESTEMS™ and reviewed to demonstrate that all peaks identified manually are also identified by the WESTEMS™ peak selection process.

The response described the details of the hand calculation, including the temperature and pressure transients, the associated thermal stress responses, the resulting combinations of fatigue load pairs, and the calculation of total CUF. The response also described the parallel calculation using the WESTEMS™ computer code and the peaks identified in this calculation. The staff reviewed these calculation results. With respect to the manual method stated above, the NRC staff concludes that the peak times set identified while performing the fatigue analysis by manual methods is a subset of these peak times identified by the WESTEMS™ computer code. Therefore, RAI WSTM-002 is resolved and closed.

The NRC staff's acceptance review letter also noted that the TR does not address the technical criteria in performing the user controlled modification in which the redundant peaks are eliminated for the reanalysis. Instead, the TR focuses on procedures for the user to perform each of the operations and to provide justification in the analysis documentation to support the decisions made. To ensure that no real peaks are removed when performing the second phase analysis, the NRC staff requested in RAI WSTM-003 that the applicant provide an example problem in which the initial run output peaks are modified by users to reduce the resulting CUF value and confirm that the final results are correct by comparing the final results with the hand calculation.

In its response dated March 4, 2013 (Reference 15), the applicant presented information using the example problems described in response to RAI WSTM-002. In this example problem, the WESTEMS™ analysis also included a number of additional peaks beyond those selected by manual methods. There were 11 WESTEMS™ run output peaks that translate to 55 possible fatigue load pairs to be considered. The total CUF from WESTEMS™ analysis is 0.782, comparison to 0.776 from the hand calculation.

Following the process from the Westinghouse procedure flowchart in Figure 4-5 of the TR, the example analysis included justification confirming which peaks are redundant based on one of the three causes of NB 3600 redundant peaks listed in Section 4.1.5 of WCAP-17577. Redundant peaks are eliminated from the fatigue analysis following Reference 7 of the TR (PSDR QP 4.7), "WESTEMS™ NB 3600 Fatigue Analysis and Verification Procedure."
Re analysis of the modified peak set is performed, and the results were compared with the hand calculation results presented in the response to RAI WSTM-002. The final CUF from WESTEMS™ analysis is reduced to 0.7757, which is consistent with 0.776 of the hand calculation. The staff reviewed this example and determined that the methodology and procedure will reduce CUF by eliminating redundant peaks for the reasons listed in

Section 4.1.5 of the TR, and the resulting reduced CUF is consistent with the hand calculation. Therefore, the NRC staff concludes that RAI WSTM-003 is resolved and closed.

It is noted that for this example, the CUF calculated by WESTEMS™ is less than 1, and further refinement (peak editing) would not typically be necessary based on the acceptance criteria in Section 5.3.1 of the procedure (PSDR QP 4.7). Even though the elimination of redundant peaks would not normally be done for a calculation with this CUF result, the same example was used for both RAI responses for simplicity. The full process was followed to demonstrate the methodology as outlined in Section 4.1.5 of the TR to reduce the usage factor, and to show that the adjusted WESTEMS™ results are verified by the manual fatigue calculations when these conservatisms are removed.

On April 23 and 24, 2013 (Reference 10), the NRC staff conducted an audit to review the detailed calculations that supported the Westinghouse responses to RAIs WSTM-002 and 003. The audit was conducted by a team of NRC staff members who are knowledgeable in various aspects of the piping and component stress evaluation, fatigue analysis, and computer program review. During this audit, Westinghouse presented the responses to RAI WSTM-002 and 003 and walked through the analysis performed and how it was performed in accordance with the procedure. Westinghouse explained how this sample problem provides a sufficient demonstration of the process for reducing conservatism by removing redundant peaks in accordance with the program documentation, when needed for an analysis.

As a result of the audit, Westinghouse is committed (1) to document the analyses performed for these responses to RAI WSTM-002 and 003 and (2) to provide an explanation for how a change to the procedure would impact the TR.

Regarding the first item, Westinghouse later completed a formal calculation note CN-PAFM-13-29, "Sample NB-3600 Fatigue Analysis in Response to RAIs Received on WESTEMS™ Topical Report WCAP-17577," and discussed this calculation with the NRC staff in a closed meeting on June 3, 2013. The staff found that the results of the spreadsheet calculation and the WESTEMS™ computer run match the response. Therefore, the audit followup item is satisfied and closed.

Regarding the second item, the NRC in WSTM-003, Supplement 1, requested that Westinghouse review the references to the topical report that refer to the NB 3600 procedure and ensure that all the key methodologies and criteria are included in the TR. In its response dated May 10, 2013, the applicant indicated that the revision numbers from the program documentation references in the TR will be removed in the next revision of the TR since the key methodology and criteria of the NB 3600 and NB 3200 analyses using WESTEMS™ are included in the TR and considered as the licensing basis for the use of the program for AP1000. The staff reviewed Revision 2 of the TR and found that the revision number of the analysis procedure PSDR QP 4.7 (Reference 7 of the TR) was removed. Base on this review, the NRC staff concludes that the second audit followup item and associated RAI WSTM-003, Supplement 1, are also closed.

4.0 Conclusion

On the basis of the NRC staff's evaluation documented in this report, the NRC staff determined that the analysis of ASME Section III piping and components using the WESTEMS™ code is consistent with the requirements and guidance listed in Section 2 above and, therefore, acceptable.

5.0 REFERENCES

(1) NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” Chapter 3, Section 3.9.1, Revision 3, Special Topics for Mechanical Components, March 2007.

(2) “Summary of the AP1000 Design Certification–Regulatory on Site and Off-Site Reviews of Open Items for the WESTEMS Computer Code,” dated April 1, 2011, (Agencywide Documents Access and Management System (ADAMS) Accession No. ML110250634).

(3) Regulatory Issue Summary 2011-14, “Metal Fatigue Analysis Performed by Computer Software,” December 29, 2011, (ADAMS Accession No. ML11143A035).

(4) WCAP-17577, Revision 0, February 29, 2012, “Topical Report on ASME Section III Piping Fatigue Analysis Utilizing the WESTEMS™ Computer Code.” (ADAMS Accession No. ML120610676).

(5) “Withdrawal Request for WCAP-17577-P and –NP,” May 9, 2012, (ADAMS Accession No. ML12132A367).

(6) “Withdrawal Acknowledgement Letter for Topical Report on ASME Section III Piping Fatigue Analysis Utilizing the WESTEMS™ Computer Code.” Revision 0, June 1, 2012, (ADAMS Accession No. ML12151A221).

(7) WCAP-17577, Revision 1, September 28, 2012, “Topical Report on ASME Section III Piping Fatigue Analysis Utilizing the WESTEMS™ Computer Code.” (ADAMS Accession No. ML12275A115).

(8) Acceptance for Review Letter, November 13, 2012, WCAP-17577, Revision 1, “Topical Report on ASME Section III Piping Fatigue Analysis Utilizing the WESTEMS™ Computer Code” (ADAMS Accession No. ML12310A052).

(9) Audit Summary for Review of WCAP-17577, Revision 1, December 2012, (ADAMS Accession No. ML13017A125).

(10) Audit Summary for Review of WCAP-17577, Revision 1, April 2013, (ADAMS Accession No. ML13134A290).

(11) Summary of Public and Closed Meeting with Westinghouse Electric Company on Request for Additional Information Responses from the Review of WESTEMS Topical Report WCAP-17577, April 25, 2013, (ADAMS Accession No. ML13122A282).

(12) Summary of Public and Closed Meeting with Westinghouse Electric Company on Request for Additional Information Responses from the Review of WESTEMS Topical Report WCAP-17577, June 3, 2013, (ADAMS Accession No. ML13156A078).

(13) Westinghouse Response to Requests for Additional Information on WCAP-17577, Revision 1, February 18, 2013, (ADAMS Accession No. ML13051A655).

(14) Westinghouse Response to Requests for Additional Information on WCAP-17577, Revision 1, February 26, 2013, (ADAMS Accession No. ML13063A163).

(15) Westinghouse Response to Requests for Additional Information on WCAP-17577, Revision 1, March 4, 2013, (ADAMS Accession No. ML13066A113).

(16) Westinghouse Response to Requests for Additional Information on WCAP-17577, Revision 1, May 10, 2013, (ADAMS Accession No. ML13134A475).

(17) WCAP-17577, Revision 2, June 17, 2013, “Topical Report on ASME Section III Piping and Component Fatigue Analysis Utilizing the WESTEMS™ Computer Code.” (ADAMS Accession No. ML13170A025).

(18) Supplemental Request for Additional Information Letter No. 2, April 25, 2013, (ADAMS Accession No. ML13115A909).

(19) NUREG-1793, “Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design,” Supplement 2, Volume 1, September 2011, (ADAMS Accession No. ML11293A087).

(20) Letter Regarding Westinghouse Electric Company Quality Management System, Revision 6, February 24, 2011, (ADAMS Accession No. ML110310088).