February 23, 2007

Mr. James A. Gresham, Manager
Regulatory Compliance and Plant Licensing
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: FINAL SAFETY EVALUATION FOR WESTINGHOUSE ELECTRIC COMPANY (WESTINGHOUSE) TOPICAL REPORT (TR) WCAP-16045-P-A, ADDENDUM 1, "QUALIFICATION OF THE NEXUS NUCLEAR DATA METHODOLOGY" (TAC NO. MC9606)

Dear Mr. Gresham:

By letter dated November 29, 2005, Westinghouse Electric Company (Westinghouse) submitted TR WCAP-16045-P-A, Addendum 1, "Qualification of the NEXUS Nuclear Data Methodology," to the U.S. Nuclear Regulatory Commission (NRC) staff for review. By letter dated January 4, 2007, an NRC draft safety evaluation (SE) regarding our approval of TR WCAP-16045-P-A, Addendum 1, was provided for your review and comments. By letter dated January 17, 2007, Westinghouse commented on the draft SE. The NRC staff's disposition of Westinghouse's comments on the draft SE are discussed in the attachment to the final SE enclosed with this letter.

The NRC staff has found that TR WCAP-16045-P-A, Addendum 1, is acceptable for referencing in licensing applications for uranium-fueled pressurized water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed final SE. The final SE defines the basis for our acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that Westinghouse publish accepted proprietary and non-proprietary versions of this TR within three months of receipt of this letter. The accepted versions shall incorporate this letter and the enclosed final SE after the title page. Also, they must contain historical review information, including NRC requests for additional information and your responses. The accepted versions shall include an "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, Westinghouse and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

/RA/

Ho K. Nieh, Deputy Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure: Final SE

cc w/encl:
Mr. Gordon Bischoff, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

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Enclosure: Final SE

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FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT WCAP-16045-P-A, ADDENDUM 1

"QUALIFICATION OF THE NEXUS NUCLEAR DATA METHODOLOGY"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION AND BACKGROUND

By letter dated November 29, 2005, the Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16045-P-A, Addendum 1, "Qualification of the NEXUS Nuclear Data Methodology" (Reference 1), to the U.S. Nuclear Regulatory Commission (NRC) for review and approval. The objective of the TR was to provide the necessary information to license the NEXUS methodology within the PARAGON/ANC code system.

PARAGON is a stand alone neutron transport code based on collision probability techniques and approved for use as a stand alone lattice physics code and as a cross section generation tool for core simulators, such as ANC, for uranium-fueled pressurized water reactors (PWRs). ANC is a core simulator code system which performs calculations based on nuclear data supplied by a code such as PARAGON or PHOENIX-P.

Westinghouse proposes to alter the coupling between PARAGON and ANC using a different methodology than previously approved by the NRC. The NEXUS methodology is a reparameterization of the PARAGON nuclear data output and a new reconstruction approach within the ANC core simulator code to simplify the use of this code system for design use. The NEXUS methodology provides a linkage between PARAGON and ANC, establishing a new code system, while still using PARAGON. Westinghouse refers to this new methodology as NEXUS/ANC.

2.0 REGULATORY EVALUATION

Section 50.34 of Title 10 of the *Code of Federal Regulations* (10 CFR) requires that licensees (or vendors) provide safety analysis reports to the NRC detailing the performance of structures, systems, and components provided for the prevention or mitigation of potential accidents. As NEXUS/ANC is a replacement to the PARAGON/ANC, Westinghouse is seeking generic approval of the NEXUS/ANC code system to be used as a stand alone analysis tool, or a direct replacement of the PARAGON/ANC code system for previously licensed applications.

ENCLOSURE

3.0 TECHNICAL EVALUATION

3.1 Scope of the Review

The PARAGON/ANC code system was previously approved by the NRC by Safety Evaluation dated March 18, 2004 (Reference 2). The scope of the current review is limited to the cross section parameterization and reconstruction according to the NEXUS methodology described in Reference 1. As the code system itself has already been the subject of previous review and approval by the NRC, this review is limited to only the coupling between PARAGON and ANC.

This review is limited to the review of uranium-fueled cores as the PARAGON/ANC methodology has not been approved for alternative fuel loadings, such as Mixed Oxide (MOX) fuel.

Westinghouse has provided information regarding the relative performance of PARAGON/ANC and NEXUS/ANC code systems in regards to MOX fuel assemblies. No comparison between NEXUS/ANC against plant data with MOX fuel has been presented. Therefore, this review does not include any conclusions related to neutronic analyses with MOX fuel and NEXUS/ANC is not approved for those purposes.

The NEXUS/ANC code system was only reviewed as applicable to PWR applications, based on the scope of the assessment information provided by Westinghouse.

3.2 Technical Review of NEXUS/ANC

The primary difference between the PARAGON/ANC code system and the NEXUS/ANC code system is the method of communicating the nuclear data generated by PARAGON to the ANC code simulator. In previous applications, the PARAGON/ANC code system required specific boron letdown curves specified by the user to account for variations in the neutron spectrum as a result of changing boron concentration during the cycle (Reference 3). While this is a valid approach to accounting for this phenomena, Westinghouse has proposed a more direct approach to accounting for the spectral changes by parameterizing the cross section output of PARAGON, such that cycle specific boron letdown curves do not need to be provided in the analysis.

The NEXUS approach uses a calculational matrix of lattice code calculations performed with PARAGON to form a set of data in order to parameterize the cross sections according to a spectral index (SI), the moderator temperature (T_m), and fuel temperature (T_f). These parameters, in conjunction with nuclide tracking during irradiation, allow for feedback-free cross sections, and correction functions to be generated. The lattice calculations are performed using a base-line reference depletion case with several branches to account for the effects of different local conditions, thus providing a data set that covers a wide range of potential local conditions ranging from those typical of a cold shutdown reactor condition to full power conditions.

The SI is based on the ratio of the epithermal to thermal neutron flux and is a measure of the local neutron spectrum. The T_m and T_f dependences account for changes in moderation and resonance adsorption respectively. These parameters are used to develop a series of correction factors to account for these physical effects using a multivariable least-squares technique. The correction factors are dependent on the differences between the nodal values for these parameters and the values used in the reference lattice depletion calculations.

The effects of xenon, actinides, other fission products, and burnable absorbers are directly accounted for by first tracking the number density of each isotope directly, thereby accounting explicitly for fuel depletion. The macroscopic cross sections themselves are reconstructed based on these number densities and the microscopic cross section for each particular isotope given the nodal conditions. The microscopic cross sections in these cases are adjusted by correction functions based on local nodal parameters.

As the exposure history of the fuel is explicitly treated based on exact nuclide tracking, the parameters are selected such that they account for changes to a baseline reference cross section based on the neutron spectrum in a given node at its current exposure point. The T_f, which is an important parameter given the Doppler effect, the T_m, which is an important factor concerning slowing down power and neutron thermalization, and the spectral index, which characterizes the neutron spectrum, are all used to determine the cross sections and diffusion coefficients for each node in ANC for a reference case.

Boron concentration is accounted for in the methodology by developing boron concentration branch cases. A branch case is created by varying the boron concentration at each depletion point and performing an instantaneous calculation within PARAGON. Branch cases are also performed for fuel and moderator temperatures, as well as for spacer grid arrangements and control rod configurations. The branch points are then used as part of a calculational matrix for the purpose of determining the parameterization coefficients. These data are also used to construct an additional history correction factor which characterizes the cross sections for a given exposure based on the history of the spectral index to properly account for the neutronic impact of differences in fuel composition arising from the depletion at varying conditions during irradiation.

The ANC core simulator code is adapted such that three nodal parameters are used to reconstruct the cross section based on the local conditions in any given node. The parameterization and reconstruction, therefore, allow for NEXUS/ANC to run in essentially the same way that PARAGON/ANC would run. The primary difference is merely in the translation of lattice physics data from PARAGON to the ANC core simulator. The parameterization, as described by Westinghouse, adequately accounts for the relevant neutronic effects of temperature feedback, fuel depletion, burnable poisons, boron concentration, and fission products.

In order to qualify the NEXUS/ANC system Westinghouse has performed several assessment calculations. The NEXUS/ANC system was compared directly to calculations performed with the already approved PARAGON/ANC system for various cases. Additionally, the NEXUS/ANC code system was used to perform calculations for specific operating plant conditions and the results of those calculations were compared to actual plant data. Each of these assessments was reviewed by the NRC staff.

3.2.1 Qualification Against PARAGON/ANC Calculations

NEXUS/ANC and PARAGON/ANC comparisons were carried out by Westinghouse comparing predicted infinite lattice eigenvalue calculations based on single assembly models at identical conditions. Westinghouse performed these analyses using various assemblies. The qualification cases covered a range of assembly configurations, enrichments, and burnable poison loadings (e.g. Integral Fuel Burnable Absorber (IFBA), Wet Annular Burnable Absorber (WABA), or Gadolinia) to illustrate the NEXUS/ANC performance. The following cases were considered:

- Westinghouse 17 x 17 fuel assembly, 5.0 w/o enrichment, 156 1.5x IFBA, 24 WABA
- Westinghouse 14 x 14 fuel assembly, 4.0 w/o enrichment, 64 IFBA
- Westinghouse 15 x 15 fuel assembly, 4.5 w/o enrichment, 116 IFBA
- Combustion Engineering 16 x 16 fuel assembly, 4.2 w/o enrichment, 16 Gadolina
- Westinghouse 17 x 17 fuel assembly, 4.95 w/o enrichment, 48 IFBA
- Westinghouse 17 x 17 fuel assembly, 2.6 w/o enrichment, no burnable poison

The NEXUS/ANC calculations were performed with temperature branches ranging from cold zero power to hot full power, depletion steps up to 82 MWD/kgHM, and boron concentrations ranging from 0 ppm to 2600 ppm. The results indicate maximum differences between the PARAGON predictions and NEXUS predictions of no greater than 100 per cent mille (pcm), which meets the maximum difference of 100 pcm criterion. In only three cases the differences exceeded 100 pcm, in each of these cases at the highest burnup points. The maximum differences were only slightly greater than 100 pcm (~120 pcm), and at these high exposures differences of this order are acceptable based on the low worth and power of assemblies at these conditions.

Cold restart calculations and off-power cases were run using the same set of assemblies. These calculations show that the methodology is not sensitive to the reactor power for the depletion, thus illustrating that the formalism of the methodology appropriately accounts for the relative pace of isotope production and destruction in regards to fission as well as radioactive decay. The second series of calculations also illustrates adequate agreement between NEXUS/ANC and PARAGON/ANC. In the most limiting cases the maximum difference in the predicted infinite lattice eigenvalues ranged between 120 to 180 pcm. These larger differences are acceptable as they are limited to the highest (160 percent power) and lowest power (40 percent power) cases considered for two assemblies. For all other power cases, for all assemblies, the differences were less than or approximately equal to 60 pcm for the remainder of the comparison points.

Full core calculations were performed using PARAGON/ANC and NEXUS/ANC code systems for a standard Westinghouse 17 x 17 fuel assembly, 4 loop plant, in the equilibrium cycle. The code systems were used to predict the core power distribution, control rod worths, and cold critical boron concentration.

The NEXUS/ANC code system predicts power peaking factors that agree with PARAGON/ANC calculated factors for each assembly at each of three exposure points during the simulated equilibrium cycle. The maximum difference was 0.032 for a peripheral fuel assembly at one exposure point. The difference in the predicted maximum power peaking factor was less than 1 percent for all exposure points. Aside from the differences in the peripheral assembly peaking factors, for nearly all assemblies the agreement between the two codes was within 1 to 2 percent. As stated earlier, the maximum difference for any peripheral assembly power peaking factor was small (0.032).

Control rod worth calculations were also performed using both code systems with differences in worth of 2 percent, indicating adequate agreement. Critical boron concentration was also computed using both code systems for cold conditions (68 ^{o}F to 350 ^{o}F). The calculations show a maximum difference of 58 ppm in boron concentration. Small differences of less than 60 ppm illustrate adequate agreement between the two code systems, because critical boron concentrations are high for cold conditions.

3.2.2 Qualification Against Operating Plant Data

Full PWR core calculations were performed with the NEXUS/ANC code system. Several cycles were considered for each core modeled. The following cores were modeled using PARAGON/ANC as well as NEXUS/ANC:

A. Combustion Engineering, 217 16 x16 Assemblies, Gadolinia, Cycles 11 - 14
B. Westinghouse, 193 17 x 17 Assemblies, IFBA, Cycles 10 - 12
C. Westinghouse, 157 17 x 17 Assemblies, IFBA, Cycles 13 - 16
D. Combustion Engineering, 177 16 x 16 Assemblies, Gadolinia, Cycles 1 - 3

The calculations determined the cycle burnup and critical boron concentration for the duration of each cycle considered. In all cases the PARAGON/ANC, NEXUS/ANC, and operating plant data were plotted on the same figure. For plants A, B, and D the two code systems, as well as plant data are in very good agreement. For plant C the two code systems slightly under predict the critical boron concentration, however, they both predict the cycle burnup with very good agreement.

Since neither code accounts for the depletion of ^{10}B in the boric acid solution in the coolant, some differences are expected between the actual and calculated boron concentrations, with the code systems slightly under predicting the measured values. This is the observed trend for the calculations. Differences observed for these four plants, though small, are related to the residency of boric acid in the core. However, in each case for each cycle, the NEXUS/ANC code system accurately predicts the cycle burnup and adequately predicts the critical boron concentration.

The NRC staff has reviewed the comparisons between NEXUS/ANC, PARAGON/ANC, and plant data and determined that NEXUS/ANC adequately calculates at-power critical boron concentration and cycle burnup.

4.0 LIMITATIONS AND CONDITIONS

Westinghouse has provided a series of assessments for the NEXUS/ANC code system in order to qualify the system as an NRC-approved code. While the re-parameterization within the NEXUS approach captures the dominant physical phenomena, the NEXUS/ANC code system is only approved to perform calculations on uranium-fueled, PWRs.

The NEXUS/ANC code system is limited to uranium-fueled, PWR applications as the only plant data assessments presented were for uranium-fueled, PWRs. While Westinghouse has provided comparisons of the relative performance of PARAGON/ANC and NEXUS/ANC for calculations with MOX fueled, PWR fuel assemblies, the PARAGON/ANC code system was not approved for this purpose. In the absence of actual plant data, NEXUS/ANC has not been approved for MOX applications.

5.0 CONCLUSION

The NRC staff has reviewed the TR submitted by Westinghouse and determined that the NEXUS/ANC code system is adequate to replace the PARAGON/ANC code system wherever the latter is used in NRC-approved methodologies. The NRC staff, furthermore, has determined that NEXUS/ANC is qualified as a stand alone code system so long as its use is limited by the provisions listed in Section 4.0 of this safety evaluation.

If the NRC's criteria, or regulations, change so that its conclusions about the acceptability of the TR are invalidated, Westinghouse or the licensee referencing the report, or both, will be expected to revise and resubmit its respective documentation, or submit justification for the continued effective applicability of the report without revision of the respective documentation.

6.0 REFERENCES

1. WCAP-16045-P-A, Addendum 1, "Qualification of the NEXUS Nuclear Data Methodology, Westinghouse Electric Company," November 29, 2005 (ADAMS Accession Number ML053460154).

2. Safety Evaluation by the Office of Nuclear Reactor Regulation for WCAP-16045-P, Revision 0, "Qualification of the Two-Dimensional Transport Code PARAGON," March 18, 2004 (ADAMS Accession Number ML040780402).

3. WCAP-16045-P-A, "Qualification of the Two-Dimensional Transport Code PARAGON," August 2004 (ADAMS Accession Number ML042250345).

Attachment: Resolution of Comments

Principle Contributors: A. Attard
P. Yarsky

Date: February 23, 2007

RESOLUTION OF COMMENTS ON DRAFT SAFETY EVALUATION FOR

TOPICAL REPORT (TR) WCAP-16045-P-A, ADDENDUM 1,

"QUALIFICATION OF THE NEXUS NUCLEAR DATA METHODOLOGY"

By letter dated January 17, 2007 (Agencywide Document Access and Management System Accession No. ML070230721), Westinghouse Electric Company (Westinghouse) provided comments on the draft safety evaluation (SE) for TR WCAP-16045-P-A, Addendum 1, "Qualification of the NEXUS Nuclear Date Methodology." The following is the U.S. Nuclear Regulatory Commission (NRC) staff's resolution of those comments.

Westinghouse Comment:

Page 1, Line 19: replace the phrase "is an intermediate step" with the phrase "provides a linkage."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 2, Line 38: replace "(S)" with "(SI)."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 2, Line 46 thru Page 3, Line 2: revise this paragraph to read: "The spectral index is based on the ratio of the epithermal to thermal neutron flux and is a measure of the local neutron spectrum. The T_m and T_f dependences account for changes in moderation and resonance adsorption respectively."

NRC Resolution:

The NRC staff has substantially revised this paragraph to incorporate most of the suggested changes.

ATTACHMENT

Westinghouse Comment:

Page 3, Lines 15-16: replace the phrase "which is the ratio of the epithermal to thermal flux" with the phrase "which characterizes the neutron spectrum."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 3, Lines 19-30: replace the two paragraphs contained in these lines with one paragraph as follows:

"Boron concentration is accounted for in the methodology by developing boron concentration branch cases. A branch case is created by varying the boron concentration at each depletion point and performing an instantaneous calculation within PARAGON. Branch cases are also performed for fuel and moderator temperatures, as well as for spacer grid arrangements and control rod configurations. The branch points are then used as part of a calculational matrix for the purpose of determining the parameterization coefficients. These data are also used to construct an additional history correction factor which characterizes the cross sections for a given exposure based on the history of the spectral index to properly account for the neutronic impact of differences in fuel composition arising from the depletion at varying conditions during irradiation."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 4, Line 4: insert the word "lattice" between the words "infinite" and "eigenvalue."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 4, Line 6: replace the phrase "ranged several" with the phrase "covered a range of."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 4, Line 21: replace the phrase "power cooling mismatch" with the phrase "per cent mille."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 4, Line 34: insert the word "lattice" between the words "infinite" and "eigenvalues."

NRC Resolution:

The NRC staff agreed to this change.

Westinghouse Comment:

Page 5, Line 10: delete the phrase "(approximately 1000 ppm)."

NRC Resolution:

The NRC staff agreed to this change.