March 18, 2004

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

SUBJECT: FINAL SAFETY EVALUATION FOR WESTINGHOUSE TOPICAL REPORT WCAP-16045-P, REVISION 0, "QUALIFICATION OF THE TWO-DIMENSIONAL TRANSPORT CODE PARAGON" (TAC NO. MB8040)

Dear Mr. Gresham:

By letter dated March 7, 2003, and supplement dated September 9, 2003, the Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16045-P, Revision 0, "Qualification of the Two-Dimensional Transport Code PARAGON" to the staff for review. On February 6, 2004, an NRC draft safety evaluation (SE) regarding our approval of the TR was provided for your review and comments. By fax dated February 19, 2004, Westinghouse commented on the draft SE. The staff's disposition of Westinghouse's comments on the draft SE is discussed in the attachment to the final SE enclosed with this letter.

The staff has found that the TR is acceptable for referencing as an approved methodology in plant licensing applications. The enclosed SE documents the staff's evaluation of Westinghouse's justification for the improved methodology.

Our acceptance applies only to the 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's TR website, we request that Westinghouse publish an accepted version of this TR within three months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed SE between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in appendices historical review information, such as questions and accepted responses, draft SE comments, and original report pages that were replaced. The accepted version shall include a "-A" (designating "accepted") following the report identification symbol.

If the NRC's criteria or regulations change so that its conclusions in this letter, that the TR is acceptable, is invalidated, Westinghouse and/or the licensees referencing the TR will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the TR without revision of the respective documentation.

Sincerely,

/RA/
Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 700

Enclosure: Safety Evaluation

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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Herbert N. Berkow, Director
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Project No. 700

Enclosure: Safety Evaluation

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WESTINGHOUSE TOPICAL REPORT WCAP-16045-P, REV.0, "QUALIFICATION OF THE TWO-DIMENSIONAL TRANSPORT CODE PARAGON"

WESTINGHOUSE ELECTRIC COMPANY

PROJECT NO. 700

1.0 INTRODUCTION

By letter dated March 7, 2003, as supplemented by letter dated September 9, 2003, the Westinghouse Electric Company (Westinghouse) submitted Topical Report (TR) WCAP-16045-P, "Qualification of the Two-Dimensional Transport Code PARAGON," to the NRC for review and approval. The objective of this TR was to provide the information and data necessary to license PARAGON both as a stand-alone transport code and as a nuclear data source for a core simulator in a complete nuclear design code system for core design, safety and operational calculations. PARAGON is a new transport code developed by Westinghouse. PARAGON is based on collision probability methods and is written entirely in FORTRAN 90/95. PARAGON can provide nuclear data, both cross sections and pin power information, to a core simulator code such as ANC.

2.0 REGULATORY EVALUATION

Section 50.34, "Contents of Applications; Technical Information," of Title 10 of the *Code of Federal Regulations* requires that safety analysis reports be submitted that analyze the design and performance of structures, systems, and components provided for the prevention of accidents and the mitigation of the consequences of accidents. As part of the core reload design process, licensees (or vendors) perform reload safety evaluations to ensure that their safety analyses remain bounding for the design cycle. To confirm that the analyses remain bounding, licensees confirm that key inputs to the safety analyses (such as the critical power ratio) are conservative with respect to the current design cycle. If key safety analysis parameters are not bounded, a reanalysis or reevaluation of the affected transients or accidents is performed to ensure that the applicable acceptance criteria are satisfied.

There are no specific regulatory requirements or guidance available for the review of TR revisions. As such, the staff review will be based on the evaluation of technical merit and compliance with any applicable regulations associated with reviews of TRs.

3.0 TECHNICAL EVALUATION

The qualification presented in this TR followed a systematic qualification process which has been used previously by Westinghouse to qualify nuclear design codes. This process starts with the qualification of the basic methodology used in the code and proceeds in logical steps to qualification of the code as applied to a complete nuclear design code system. The qualification process consists of benchmarking the code against raw data and industry accepted Monte-Carlo codes such as MCNP.

3.1 Benchmarking and Monte-Carlo Code Calculations

Consistent with the qualification process described above, Westinghouse presented the results of PARAGON runs for a series of critical experiments. These experiments included the Strawbridge-Barry 101 criticals, the KRITZ high temperature criticals, and a large number of spatial criticals from the Babcock and Wilcox (B&W) physics verification program. The B&W critical calculations provided both reactivity and power distribution measurements data to benchmark PARAGON output predictability.

The Strawbridge-Barry 101 critical calculations (criticals) cover a wide range of lattice parameters, providing an important test for the PARAGON lattice code. Since these experiments are uniform lattices, the criticals were run as single pin cells in PARAGON. There are 40 UO2 experiments among the 101 criticals. The results produced by PARAGON showed no particular bias or trends as a function of uranium enrichment, experimental buckling, pellet diameter or soluble boron.

The KRITZ high-temperature calculations provide critical benchmark data for uranium-fueled, water-moderated lattices at high temperatures. The calculations were performed at temperatures as high as 245°C. PARAGON modeled 12 KRITZ experiments. No significant trends across the large temperature range of these critical calculations were observed. The small standard deviation obtained is indicative of PARAGON predictive capabilities across the large temperature range.

The B&W spatial criticals provided data on both reactivity and power distribution for a variety of uranium-oxide fueled lattices. A total of 29 configurations were analyzed by the vendor, at different enrichments and burnable poisons. K-infinity comparisons were carried out between PARAGON and the Monte Carlo code MCNP for all 29 experiments. In addition, the measured axial bucklings were used with the PARAGON results to calculate K_{eff}. The reactivity results for all configurations resulted in a very comparable K_{eff} for the 29 experiments, with a standard deviation of less than 0.05 percent. Westinghouse also submitted rod power distribution comparisons of PARAGON results against measurements for six experiments, two with no burnable absorbers, two with gadolinia burnable absorbers, and two with Pyrex burnable absorbers. The average difference between the measured and PARAGON power distribution for the six experiments was slightly greater than 1.0 percent with an average standard deviation of 1.5 percent.

Westinghouse also benchmarked PARAGON against well known Monte-Carlo codes. Specifically, Westinghouse performed 13 different assembly configuration calculations using both PARAGON and the Monte Carlo code MCNP. These assembly configurations were chosen to cover a variety of lattice types and burnable absorbers over a large enrichment range. These calculations included 11 Westinghouse and 2 Combustion Engineering (CE) assemblies. The PARAGON and MCNP calculations were compared for both reactivity and power distribution. The mean difference in reactivity between the MCNP and PARAGON calculations over the 13 assemblies was about 100 percent mill (pcm), with a standard deviation of less than 100 pcm. The results of comparison between the MCNP and PARAGON power distributions showed very good agreement. The average difference in rod powers for each assembly ranged from less than 0.4 percent to less than 0.8 percent.

Westinghouse also performed calculations using PARAGON to compare with spectrograph-measured isotopics data from the Saxton reactor Cores 2 and 3 containing mixed oxide fuel. Additional comparisons were performed using PARAGON to other plants such as Yankee Cores 1, 2, and 4 with stainless steel clad fuel, and Yankee Core 5 with zircaloy clad fuel. In these calculations isotopic concentrations from PARAGON were used to simulate the power history corresponding to these cores. The results of these isotopic comparisons show no significant trend for any isotope with burnup, again demonstrating the capability of PARAGON for predicting the depletion characteristics of UO2 light-water reactor fuel over a wide range of burnup conditions. Although Westinghouse included mixed oxide fuel (MOX) data in the TR, the data base is insufficient to enable the staff to reach a conclusion regarding PARAGON's ability to predict depletion characteristics for a MOX fueled core at this time.

3.2 Plant Cycles Operation Comparisons

Westinghouse stated in the submittal that the primary use of PARAGON will be to generate nuclear data for use in Westinghouse core simulator codes. Thus, the most important qualification for PARAGON is the comparison of results of core calculations using PARAGON supplied nuclear data against plant measured data. In the submittal, Westinghouse presented ANC results for pressurized water reactor (PWR) core calculations with nuclear data supplied by PARAGON (PARAGON/ANC) which were compared to corresponding plant measurements, where available, and to PHOENIX-P/ANC results for the same calculations. The results of the calculations demonstrated the accuracy of the PARAGON nuclear data when applied to a complete nuclear design system.

Cycles from 11 plants including both Westinghouse and CE type plants, were used for measured-to-PARAGON/ANC-predicted comparisons of startup data and at-power critical boron versus cycle burnup data. In addition, measured radial power data was compared to PARAGON/ANC predicted values from 28 radial power maps from 5 different plants. Beginning-of-cycle (BOC) and end-of-cycle (EOC) radial power and EOC burnup predictions from PHOENIX-P/ANC were compared to those calculated by PARAGON/ANC for nine cycles in five plants.

PARAGON/ANC axial power predictions were compared to PHOENIX-P/ANC at BOC, middle-of-cycle (MOC), and EOC for four plants. Finally, PARAGON/ANC results were compared to PHOENIX-P/ANC results for events for which measurements are generally not made or cannot be made. These are ARI-WSR (worst stuck rod) rodworth (four plants), dropped rod events (four plants) and rod ejection events (BOC and EOC for four plants).

The PARAGON code qualification included 24 cycles from 11 different plants. These plants included both Westinghouse (15 cycles) and Combustion Engineering (9 cycles) type cores. The vendor chose the plants to cover a wide variety of lattices, burnable absorbers, blanket types, core sizes, as well as the availability of plant measured data.

Some of the tests considered were startup physics tests. Comparisons were made for PARAGON/ANC predictions against measurements for BOC hot zero power (HZP) all rods out (ARO) critical boron, BOC HZP ARO isothermal temperature coefficient (ITC), and BOC HZP rodworths. Results from 22 cycles from 11 different plants were compared for the BOC HZP critical boron concentration.

The mean difference between measured and predicted boron was found to be about 15 ppm for both PARAGON/ANC and PHOENIX-P/ANC, with standard deviations for both code systems of about 15 ppm.

For the same 22 cycles, results from BOC HZP ARO ITC were also compared. The statistics from the isothermal temperature coefficient (ITC) comparison were quite similar between the two code systems. The mean predicted to measured difference in ITC was less than 0.2 pcm/°F for PARAGON/ANC and less than 0.3 pcm/°F for PHOENIX-P/ANC. The standard deviations were the same for both code systems at less than 1.0 pcm/°F.

Predicted versus measured rodworths were compared for nine cycles in seven plants. The cycles used three different methods for rodworth measurement: dynamic rod worth measurement, rod swap, and boron dilution. All rodworth predictions met the measurement review criteria.

Westinghouse also performed at-power critical boron calculations. At-power critical boron measurements were compared to results from PARAGON/ANC and PHOENIX-P/ANC core depletion calculations for 22 plant cycles. The results showed very good performance by PARAGON/ANC for EOC predictions. All plant cycles showed the effects of B10 depletion since the uncorrected measured and predicted critical boron values difference grew through the MOC. Accounting for B10 depletion reduces the difference between measured and predicted values through the middle of the cycle as was demonstrated in the report for one of the cycles.

Measured to PARAGON-predicted radial assembly power comparisons were made for 5 plants (28 total flux maps). These plants included both even (16x16 and 14x14) and odd (15x15 and 17x17) lattices. The average value of the measured to predicted differences over the 28 maps was less than 1.0 percent with an average standard deviation of 1.0 percent. These results show that the radial assembly powers are indeed well predicted by PARAGON/ANC.

3.3 PARAGON/ANC to PHOENIX-P/ANC Comparison Results

PARAGON/ANC and PHOENIX-P/ANC calculational results were compared for radial assembly power distribution, axial power distribution, all rods in minus worst rod stuck (ARI-WSR) rodworth, rod drop, and rod ejection calculations. Radial assembly power (BOC and EOC) distributions were compared for nine cycles in five plants. EOC assembly burnup distributions were compared for the same cycles. Axial power distributions are shown at BOC, MOC, and EOC for eight cycles in four plants. The plant cycles for both radial and axial comparisons include Westinghouse and CE type cores. The results of both radial and axial power comparisons show very little difference between PARAGON/ANC and PHOENIX-P/ANC. The small difference between the PARAGON/ANC results and those from PHOENIX-P/ANC confirms that PARAGON/ANC also predicts these power distributions very well.

ARI-WSR shutdown rodworths were calculated in PARAGON/ANC at BOC for four plants. The results were compared to PHOENIX-P/ANC for the same calculations. The largest difference for the worst stuck rodworth was less than 7 pcm. The largest peaking factor difference was about three percent in local peaking factor (F_q). Both differences are well within the uncertainties used with the ARI-WSR calculations.

Dropped rod calculations were also performed with PARAGON/ANC at BOC for four plants and the results were compared to corresponding PHOENIX-P/ANC results. The largest difference in the dropped rod worth was less than 5 pcm. The largest difference in peaking factor was less than 1.7 percent in F_q. The last set of comparisons between PARAGON/ANC and PHOENIX-P/ANC was for BOC and EOC rod ejection calculations for four plants. The rod ejection calculations were performed for both HZP and hot full power conditions. Rod ejection calculations are similar to stuck rod calculations except the feedback is frozen from pre-ejection conditions leading to much larger peaking factors and rodworths. The largest difference in rodworth was less than 15 pcm. The peaking factor differences were very small and well within the uncertainties used with this event.

4.0 CONDITIONS AND LIMITATIONS

1. The PARAGON code can be used as a replacement for the PHOENIX-P lattice code, wherever the PHOENIX-P code is used in NRC-approved methodologies.

2. The data base is insufficient to enable the staff to reach a conclusion regarding PARAGON's ability to predict depletion characteristics for a MOX fueled core at this time.

5.0 CONCLUSION

The staff has reviewed the analyses and results presented in the TR and determined that the analyses and results are in accordance with the guidance and limitations, and the applicable sections of NUREG-0800, "Standard Review Plan." The staff concludes that PARAGON is acceptable for use as a stand-alone lattice code and as a nuclear data source for core simulators for PWR analyses for uranium-fuel cores. In addition, the staff considers the new PARAGON code to be well qualified as a stand-alone code replacement for the PHOENIX-P lattice code, wherever the PHOENIX-P code is used in NRC-approved methodologies. The staff concludes that it is acceptable for licensing applications.

Attachment: Resolution of Comments

Principle Contributor: A. Attard

Date: March 18, 2004

RESOLUTION OF COMMENTS

ON DRAFT SAFETY EVALUATION FOR WCAP-16045-P, REVISION 0, "QUALIFICATION OF THE TWO-DIMENSIONAL TRANSPORT CODE PARAGON"

By fax dated February 19, 2004, Westinghouse provided comments on the draft safety evaluation (SE) for WCAP-16045-P, Revision 0, "Qualification of the Two-Dimensional Transport Code PARAGON". The following is the staff's resolution of those comments.

1. Westinghouse Comment: Section 3.1, third paragraph, fifth sentence stated, "The reactivity results for all configurations resulted in a very comparable K_{eff} for the 29 experiments, with a standard deviation of less than 0.4 percent."

   Westinghouse Proposed Resolution: The reactivity results for all configurations resulted in a very comparable K_{eff} for the 29 experiments, with a standard deviation of less than 0.05 percent.

   NRC Action: The comment was fully adopted into the final SE.

2. Westinghouse Comment: Section 3.1, fifth paragraph, fourth sentence contained numbers that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: The mean difference in reactivity between the MCNP and PARAGON calculations over the 13 assemblies was about 100 percent mill (pcm), with a standard deviation of less than 100 pcm.

   NRC Action: The comment was fully adopted into the final SE.

3. Westinghouse Comment: Section 3.2, sixth paragraph contained numbers that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: The mean difference between measured and predicted boron was found to be about 15 ppm for both PARAGON/ANC and PHOENIX-P/ANC, with standard deviations for both code systems of about 15 ppm.

   NRC Action: The comment was fully adopted into the final SE.

4. Westinghouse Comment: Section 3.2, seventh paragraph, last sentence contained a number that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: The standard deviations were the same for both code systems at less than 1.0 pcm/°F.

   NRC Action: The comment was fully adopted into the final SE.

5. Westinghouse Comment: Section 3.2, last paragraph, third sentence contained numbers that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: The average value of the measured to predicted differences over the 28 maps was less than 1.0 percent with an average standard deviation of 1.0 percent.

   NRC Action: The comment was fully adopted into the final SE.

6. Westinghouse Comment: Section 3.3, first paragraph, next to last sentence contained a number that Westinghouse considered proprietary.

   Westinghouse Proposed Resolution: The largest peaking factor difference was about three percent in local peaking factor (F_q).

   NRC Action: The comment was fully adopted into the final SE.

7. Westinghouse Comment: Section 5.0, second paragraph could be more clearly stated as a new second sentence in the conclusion.

   Westinghouse Proposed Resolution: Add, "The staff concludes that PARAGON is acceptable for use as a stand-alone lattice code and as a nuclear data source for core simulators for PWR analyses for uranium-fuel cores." and eliminate, "Therefore, on the basis of the above review and justification, the staff concludes that the proposed change to the Westinghouse control rod ejection methodology is acceptable for use as a replacement code for the PHOENIX-P lattice code."

   NRC Action: The comment was fully adopted into the final SE.