November 30, 2004

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

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT WCAP-15872-NP, REV. 00, "USE OF ALTERNATE DECAY HEAT REMOVAL IN MODE 6 REFUELING" (TAC NO. MB9020)

Dear Mr. Bischoff:

On May 12, 2003, as supplemented on November 18, 2003, the Westinghouse Owners Group (WOG) submitted Topical Report (TR) WCAP-15872-NP, Rev. 00, "Use of Alternative Decay Heat Removal in Mode 6 Refueling" to the staff for review. On July 22, 2004, the NRC provided the WOG a copy of the staff's draft safety evaluation (SE). Subsequently, on August 13, 2004, a corrected SE regarding our approval of WCAP-15872-NP was provided for your review and comments. By e-mail dated September 8, 2004, Mr. Virgil Paggen of the WOG commented on the draft SE. The WOG comments on the draft SE were discussed in a conference call on September 14, 2004, and it was agreed upon between Mr. Virgil Paggen (WOG) and Mr. Yuri Orechwa (NRC) that no changes were required to the final SE enclosed with this letter.

The staff has found that WCAP-15872-NP is acceptable for referencing in licensing applications for Westinghouse-designed pressurized water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for 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 the WOG 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 historical review information, such as questions and accepted responses, draft SE comments, and original TR pages that were replaced. The accepted version shall include a "-A" (designating accepted) following the TR identification symbol.

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

Sincerely,

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

Project No. 694

Enclosure: Safety Evaluation

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

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WCAP-15872-NP, REV. 00, "USE OF ALTERNATE DECAY HEAT REMOVAL

IN MODE 6 REFUELING"

WESTINGHOUSE OWNERS GROUP

PROJECT NO. 694

1.0 INTRODUCTION

By letter dated May 12, 2003, and its supplement dated November 18, 2003, the Westinghouse Owners Group (WOG) submitted Topical Report (TR) WCAP-15872-NP, Rev. 00, "Use of Alternative Decay Heat Removal in Mode 6 Refueling," for staff review and approval of an alternate method for shutdown cooling during Mode 6 plant operations as specified in the current technical specifications (TSs) for the plant. The alternate decay heat removal method may be used to supplement or to substitute for the shutdown decay heat removal system during refueling operations. The TR describes a computational methodology for assessing the necessary conditions for entry into and operation under the alternate heat removal alignment. These conditions are governed by a combination of factors such as decay heat generation rate, heat removal capabilities, temperature of the refueling pool, and the heat sink temperatures. The computational model of the alternate heat removal alignment is formulated as a series of one-dimensional control volumes within which the fluid mass, momentum, and energy are conserved. The model describes the transfer, by natural convection, of the decay heat from the reactor cavity to the refueling pool, and then by forced convection into the cooling system aligned via the alternate cooling method.

The validity of the one-dimensional formulation is dependent on the estimation of the values of two parameters:

- mixing coefficient for the fluid from the reactor cavity, and
- bypass coefficient for the fluid in the refueling pool.

These values are plant and alternate decay heat removal alignment dependent. The values for these coefficients are computed via multi-dimensional computational fluid dynamics calculations.

The methodology has been validated through a comparison of predicted-to-recorded data at the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 2 during the March 2001 refueling outage. The applicability of the methodology in general is predicated on a plant-specific validation similar to the one given in WCAP-15872-NP, Rev. 00 for the CCNPP, Unit 2.

2.0 REGULATORY EVALUATION

The methodology presented in WCAP-15872-NP, Rev. 00, "Use of Alternate Decay Heat Removal in Mode 6 Refueling," addresses the computational issues associated with demonstrating compliance with the requirements for a residual decay heat removal system set forth in General Design Criterion (GDC) 34. In particular, the numerical values computed with this methodology may be used to support the demonstration that the transfer of fission product decay heat and other residual heat from the reactor core is at a rate such that specified acceptable fuel design limits are not exceeded. The approval of the computational methodology in WCAP-15872-NP, Rev. 00 is consistent with the requirements set forth in Appendix B to Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50) "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." WCAP-15872-NP describes actions necessary to provide adequate confidence that the alternate heat removal system will perform satisfactorily in service.

3.0 SUMMARY OF WCAP-15872-NP, REV. 00

The TR discusses the operational and technical issues associated with the introduction of an alternate decay heat removal system which takes suction from and discharges to the refueling pool while in Mode 6, with the refueling pool fully flooded. Standard decay heat removal in Mode 6 is provided by the shutdown cooling system. In this system, suction is taken from the hot leg, and the flow is fed to the shutdown cooling pump, and passed through a shutdown cooling heat exchanger. Cooled water is then returned to the reactor coolant system through a nozzle located in the cold leg. The alternate heat removal alignment is a specific alignment of existing plant systems as a substitute for conventional decay heat removal by the shutdown cooling system. In the alternate heat removal alignment, the core decay heat circulates from the open reactor vessel by natural circulation into the flooded refueling pool. The refueling pool is then cooled by an alternate cooling system. In the alternate cooling alignment, a pump takes suction from the refueling pool, then after passing through a heat exchanger, the flow is directed back into the refueling pool. The specific locations of the suction pipe from the refueling pool and the refill pipe to the refueling pool can be optimized depending on the specific plant design. In the case of CCNPP Unit 2, the alternate heat removal alignment consists of the spent fuel pool pump that takes suction from the refueling pool, then after passing through the spent fuel pool heat exchanger, the flow is directed back into the refueling pool. This flow is directed into the refueling pool through piping near the bottom of the pool. The suction from the refueling pool to the spent fuel pool cooling line is through a drain in the bottom of the refueling pool, at the side of the pool opposite the inlet point. This arrangement results in cooled water inventory drawn across the pool region directly above the open vessel.

Activation of the alternate heat removal alignment is dependent on the ability of the decay heat to circulate from the open reactor vessel (upper guide structure removed) by natural circulation and constrained by the water level in the refueling pool, the pool temperature, and the residual decay heat of the reactor core. Factors influencing the performance of the alternate heat removal alignment include the heat transfer ability of the spent fuel pool cooling system when aligned to the refueling pool, the pumped flow rates, and the ultimate heat sink temperature.

3.1 Computational Method

The computational methodology described in WCAP-15872-NP, Rev. 00 addresses the requirements for a residual decay heat removal system set forth in GDC 34. The computation in particular evaluates the capability of an alternate decay heat removal system to transfer decay heat and other residual heat from the reactor such that fuel design limits are not exceeded. The computational methodology consists of two interrelated models. A one-dimensional, time-dependent, lumped-parameter model of the core coupled to the refueling pool, and a three-dimensional, steady-state, computational fluid dynamics (CFD) model of the refueling pool.

3.1.1 One-Dimensional Model

The one-dimensional model divides the refueling pool and the reactor vessel internals into a series of control volumes that describe the upper guide structure, core and refueling pool. Ten state points that represent natural boundaries between the control volumes are defined in the model. These are consistent with the set of assumptions used to reduce the refueling pool and core coupled circulation problem to a mathematically tractable form. Conservation of mass, momentum, and energy are solved for these control volumes to predict the mass flow rate between the reactor vessel and the refueling pool. Temperatures of the refueling pool, the suction and discharge are calculated. The flow rate through the alternate decay heat removal system is also calculated. The model also considers the heat lost at the pool surface due to natural convection and evaporation from the free surface.

3.1.2 Computational Fluid Dynamics Model

The one-dimensional model cannot account for the geometric effects of the pool regions where the cooler fluid near the bottom of the pool does not fully mix with the hot plume rising from the core. Thus, two empirical coefficients, a mixing and a bypass coefficient, are introduced. The mixing coefficient accounts for the portion of the reactor cavity fluid that does not mix with the core flow. The bypass coefficient accounts for the alternate decay heat removal train flow that does not mix with the core exit flow. The values of these coefficients are specific to the geometry of the refueling pool and the alternate heat removal alignment. A three-dimensional CFD model of the refueling pool and boundary conditions consistent with the one-dimensional nodal model of the refueling pool and reactor cavity, are used to compute these coefficients.

4.0 TECHNICAL EVALUATION

Key elements of the methodology described in the TR, such as the mixing and bypass coefficients, are plant and alternate heat removal alignment specific. The model validation presented in the TR is based on a comparison of model predictions with data recorded at CCNPP Unit 2 during the March 2001 refueling outage. Under limited conditions, CCNPP units were permitted to use an alternate refueling pool cooling system during Mode 6 with the refueling pool flooded and with the shutdown cooling secured. Test data were recorded for two days during which the alternate pool cooling alignment was in use. Fluid temperatures in the refueling pool were recorded by thermocouples located at the reactor vessel flange level, at mid-level in the pool and close to the pool surface. The temperatures and shutdown cooling flow rates were recorded as a function of time. Switching from the conventional shutdown cooling decay heat removal, both before and after the head is removed, followed by switching to the alternate decay heat removal are taken into account via the following sequence of operations:

1. reduce shutdown cooling flow for vessel head removal
2. restore full shutdown cooling flow
3. initiate alternate heat removal cooling flow, continue shutdown cooling flow
4. secure shutdown cooling flow, continue alternate heat removal cooling flow
5. secure alternate heat removal flow, restore shutdown cooling flow

4.1 Validation of the Computational Method

During the alternate heat removal alignment the refueling pool temperature data, at different elevations above the reactor vessel flange, indicate that the pool temperature decreases with elevation. This suggests that the hot plume from the core thermally mixes with the colder refueling pool water and cools as it rises to the top of the pool. The CFD predictions of the refueling pool water temperatures at locations corresponding to the measurement points compare favorably with the measured temperatures.

The variation with time of the computed and measured temperatures (shutdown cooling outlet, spent fuel pool outlet, and refueling pool average) and flow rates, over the sequence of operations that define entrance into steady-state operation and exit from the alternate decay heat removal alignment during the CCNPP Unit 2 March 2001 refueling outage, agree well. Some of the differences can be explained as due to the uncertainties in decay heat values and initial refueling pool temperatures at the time the head is removed. Thus, the mixing and bypass coefficients based on the CFD calculations account well for the non-uniform dynamic effects in the refueling pool in the one-dimensional analysis.

4.2 Alternate Heat Removal System Entry Conditions

The key factors that govern entry into the alternate heat removal alignment are decay heat generation rate, heat removal capability, the temperature of the refueling pool, and the heat sink temperature. The limiting time for entry into alternate heat removal is when the decay heat is first low enough to satisfy the refueling pool temperature limit given by the TS for a given heat sink temperature. At CCNPP the calculational methodology, described above and in WCAP-15872-NP, Rev. 00 has been employed with plant-specific data to determine the minimum time after shutdown for entry into the alternate heat removal alignment corresponding to the limiting refueling pool temperature versus ultimate heat sink temperature and other variables. The good agreement between predictions and measurements of the average refueling pool temperatures during the March 2001 refueling outage at CCNPP Unit 2 demonstrate the efficacy of the methodology for computing the conditions for entry into the alternate heat removal alignment at CCNPP.

4.3 Effect of Pool Fluid Velocity on Fuel Movement

Due to thermal convection between the core and refueling pool and the subsequent mixing with the pool circulation flow, a fuel assembly can become tilted and difficult to insert into the core. Limiting values of tilt angle as a function of time after shutdown are computed based on the predicted one-dimensional model flow rates due to natural convection between the core and the refueling pool. The allowable window for the initiation of the alternate heat removal alignment is computed consistent with temperature limits. The allowable window may require further refinement based on the computed tilt angles so as to preclude problems with the insertion of fuel assemblies. The specific limiting values of tilt angle depend on plant-specific experience with fuel assembly insertion.

5.0 CONCLUSIONS

The staff has reviewed WCAP-15872-NP, Rev. 00 and the supporting documentation submitted in response to its request for additional information. On the basis of this review, the staff only approves the computational methodology, together with its validation, as described in WCAP-15872-NP, Rev. 00 for referencing in licensing actions with regard to implementing an alternate method for shutdown cooling during routine Mode 6 operations at CCNPP. Application of the methodology for referencing in licensing actions to other plants is conditional on the validation of the methodology by the licensee on a plant-specific basis and a review by the staff of the licensee's validation in the license amendment request using the methodology.

This validation by the licensee for each plant-specific alternate decay heat removal system and refueling pool flow configuration entails:

- A quantitative validation of the CFD model of the refueling pool with respect to measurements comparable to those described in Appendix C of WCAP-15872-NP, Rev. 00.

- A quantitative comparison of the results of the computational model (as described in Appendix A of WCAP-15872-NP, Rev. 00) to measurements comparable to those described in Appendix B of WCAP-15872-NP, Rev. 00.

- An estimate of the sensitivity of the bypass and mixing coefficients of the computational model to model assumptions and the effects of this sensitivity on the computed results.

Principal Contributor: Yuri Orechwa

Date: November 30, 2004