ATTACHMENT

SAFETY EVALUATION REPORT
BY THE OFFICE OF NUCLEAR REACTOR REGULATION
RELATING TO TOPICAL REPORTS WCAP-13524 AND WCAP-13524, REVISION 1
APOLLO--A ONE DIMENSIONAL NEUTRON DIFFUSION THEORY PROGRAM
WESTINGHOUSE ELECTRIC CORPORATION

1 BACKGROUND

By letters dated October 22, 1992, and August 24, 1995, the Westinghouse Electric Corporation submitted the topical reports WCAP-13524 and WCAP-13524 Revision 1, "APOLLO-A One dimensional Neutron Diffusion Theory Program" (References 1 & 2), for the staff's review. The reports give a description of the APOLLO computer code and its application for reactor analyses of Westinghouse pressurized water reactors (PWRs). The reports describe the analyses and present the assumptions, conservatisms, limitations, and results of the APOLLO computer program.

APOLLO is a one-dimensional, two-group diffusion code that was evolved from the NRC-approved computer code "PANDA." Both codes solve the two-group diffusion equations using typical finite difference techniques. The primary difference between the two codes is the method by which the two codes solve for the flux. PANDA solves for the flux at the interface between the mesh intervals, while APOLLO solves for the interval mean flux. Data submitted by the vendor shows that the two methods are fundamentally alike and yield virtually identical results. Westinghouse indicated that APOLLO has been used for all standard 1-dimensional design analyses since 1974, and that the evolution of PANDA to APOLLO was described to the NRC staff in 1984. APOLLO is used for nuclear design analyses that do not require three-dimensional methods. The calculational accuracy of the APOLLO code for predicting the reactivity and axial power shapes is comparable to the three-dimensional "advanced nodal code" (ANC).

In APOLLO's current design application, nuclear data for input into APOLLO are provided by a model based on the three-dimensional ANC model. The revision to the one-dimensional APOLLO computer code incorporates into APOLLO the ability to use diffusion constants generated by the three-dimensional ANC program. This revision will enhance the accuracy of the final results achieved by APOLLO.

2.0 Technical Evaluation -- Methods and Models

2.1 Steady-State Neutron Diffusion Model

2.1.1 Diffusion Difference Equation

The APOLLO computer code solves the diffusion equation on an interval basis rather than on a point-by-point basis. In its numerical approach, it makes use of the average (mean) flux on a given mesh interval and solves the two group diffusion equation accordingly.

APOLLO makes use of group diffusion constants specific to each mesh interval to perform interval-wise fuel depletion. Incorporated in APOLLO are feedbacks that are very similar to those used in ANC; consequently, APOLLO can model an extensive range of different core conditions.

APOLLO solves the two group diffusion equations by assuming the total reactor geometry is divided into small units of volume. In these small units of volume, APOLLO is forced to assume the flux had a mean value. So the flux in the small unit volume (mesh interval) is a constant. The macroscopic cross sections are also assumed to be a constant on these same mesh intervals. At all times, the current (J) terms must be continuous across the dividing mesh boundaries in accordance with Fick's Law.

2.2 Boundary Conditions and Recursion Equation

The procedure for calculating the boundary conditions and the recursion equations have not been changed in going from the PANDA code to the APOLLO code or by the revision made to APOLLO. APOLLO utilizes three boundary conditions: (1) "zero flux", or non-reflective boundary; (2) "zero current", or reflective boundary; and (3) "albedo", or semi-reflective boundary, (Reference 3). The recursion equations are used together with the flux boundary conditions to calculate required matrixes to describe the flux behavior in going from the left-hand interval boundary to the right-hand (or bottom-to-top) mesh interval boundary.

Fuel depletion and xenon and samarium buildup calculations remain the same in APOLLO and its revision. The actual fuel depletion takes place before the iterative flux calculation is performed. The flux distribution used is that from the previous case or time step. The group constants and the mean burnup increment are from the input deck for the present case or are carried over from a previous case or time step.

Fission product poisons, such as Xe(135), Sm(149), I(135), and Pm(149) are defined by typical decay chains. The nuclide chains are solved analytically by assuming that the core power level, power distribution, and cross sections are constant over the period of integration (i.e., the time-step interval).

Currently, three options are available in APOLLO to deplete the core: (1) deplete the xenon and/or samarium from the previous time step or case, using the flux distribution from the previous time step, for a user-specified time interval delta T(hours); (2) determine the equilibrium xenon and/or samarium distribution compatible with the current neutron fluxes; and (3) leave the xenon and/or samarium distribution untouched, such that the same distributions from the previous calculation or time step will be applied to the current calculation.

2.3 Cross Section Representation

APOLLO computes the effective two-group cross sections for each mesh interval using the macroscopic cross-section tables (tabulated versus burnup) and microscopic corrections for xenon, samarium, boron, water density, and fuel temperature. These corrections are the same as those applied to the ANC

(Reference 4). In the case of steady state, the cross sections are evaluated each iteration. For transient cases, the cross sections are evaluated at the beginning of each time step. Typically, the user supplies tables of various burnup values. Knowing the burnup value for each mesh interval, the code will use the table look-up procedure and interpolate to find matching values of diffusion constants, macro-cross sections, fission cross sections, and so on.

2.4 The Buckling Model

Since APOLLO is a one-dimensional model (thus lacking the remaining two dimensions), corrections must be applied to the model to account for its shortcomings, namely, representation of those components that are transverse to the geometrical representation. In a typical axial (slab) model (geometric representation in the z-direction, neutron leakage out of the top and bottom), the missing component is the equivalent leakage out of the core in the radial direction. This fact can be represented very conveniently by a transverse buckling. The transverse buckling is established by determining the fast and thermal flux values that will create a match between the APOLLO and the ANC fast and thermal axial flux distributions.

2.5 Automated Sequences

APOLLO has a number of automated sequences to facilitate design calculations. These sequences include automated depletion using optional burnup dependent data, a transverse buckling sequence, control rod optional sequences to establish rod insertion allowances and limit lines, and differential and integral rod worth sequences. APOLLO calculates integral rod worths with an accuracy comparable to the three-dimensional ANC. This is so because APOLLO has the capability to determine control rod constants from ANC data such that APOLLO and the dimensional ANC rod worths agree, thus enabling APOLLO to be used for integral as well as differential rod worth calculations.

The staff has reviewed the subject reports, including the mathematical models and analytical procedures and methods. The staff finds the approach as described above to be technically sound and reasonable.

2.6 Analysis of Results

As part of the submittal, the Vendor provided the staff with data representative of comparisons between APOLLO and the 3D ANC for parameters which are of interest in the types of calculations for which APOLLO is used, i.e. the core reactivity and axial power distribution. As indicated by the data, APOLLO-calculated reactivity and axial power distributions compare very favorably with those calculated by the 3D ANC. These comparisons are also indicative of APOLLO's suitability to perform calculations for which accuracy in these parameters is important. These Condition II calculations are associated with both the Constant Axial Offset Control (CAOC) and the Relaxed Axial Offset Control (RAOC) operations, differential and integral rod worth calculations and trip reactivity calculations.

3 CONCLUSION

The staff has reviewed the analyses in Topical Reports WCAP-13524, and WCAP-13524, Revision 1, " APOLLO--A One-Dimensional Neutron Diffusion Theory Program," and concluded that WCAP-13524 and the revision 1 to it, are acceptable. WCAP-13524 is acceptable because it compares very favorably with those calculated by the 3D ANC. The first revision to this same WCAP, is acceptable because the use of the three-dimensional diffusion constants over the one-dimensional constant, is an enhancement to the one-dimensional APOLLO code, and as demonstrated by the Vendor's analyses, APOLLO's results compare very favorably with those calculated by the three-dimensional ANC. APOLLO is thus well suited for calculations in which accuracy in determining such parameters as reactivity and axial power and differential and integral rod worth is very important.

References:

1. Letter from Nicholas J. Liparulo, Westinghouse, submitting Topical Report WCAP-13524 (Proprietary), "APOLLO--a One-Dimensional Neutron Diffusion Theory Program," to the U.S. Nuclear Regulatory Commission, October 22, 1992.

2. Letter from Nicholas J. Liparulo, Westinghouse, submitting Topical Report WCAP-13524 (Proprietary), "APOLLO--a One-Dimensional Neutron Diffusion Theory Program, Revision 1," to the U.S. Nuclear Regulatory Commission, August 24, 1995.

3. Letter, Nicholas J. Liparulo, Westinghouse, ET-NRC-92-3736, "Presentation Material from the October 10, 1984 NRC/Westinghouse Meeting on the Improved Version of Nuetronics Codes Being Utilized" (Non-Proprietary), August 27, 1992.

4. Report by Y.S. Liu, et al., "ANC: A Westinghouse Advanced Nodal Computer code", WCAP-10965-P-A (proprietary), December 1985.