ENCLOSURE

Review of WCAP-9485, "PALADON - Westinghouse

Nodal Computer Code"

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Report No. WCAP-9485 (Proprietary)
Report Title: PALADON - Westinghouse Nodal Computer Code
Report Date: December, 1978
Originating Organization: Westinghouse Electric Corporation
Reviewed By: Core Performance Branch/W. L. Brooks

Westinghouse Nuclear Energy Systems has submitted licensing topical report WCAP-9485 entitled, "PALADON - Westinghouse Nodal Computer Code". The report describes the calculational models employed in the code, including both the neutronics and thermal-hydraulic models, and documents the qualification of the results against both experiment and higher order calculations. Our evalution of this report follows:

1. Summary of Report

The methodology used in the PALADON code is discussed. PALADON is an improved version of earlier nodal codes. The improvements are discussed and the calculational algorithm is derived. Both neutronic and thermal-hydraulic consideration are discussed. Fuel and burnable poison depletion calculations are described. The xenon steady state and transient equations are presented as well as the steady state and buildup equations for samarium.

In addition to the description of the PALADON code, data are presented to qualify the code for the calculation of power distributions, control rod worths and reactivity coefficients. Comparisons are made to measured data from startup tests or to calculations performed with the Westinghouse-design diffusion theory code TURTLE. The data base used in the comparison includes data from 15 different plants and 36 different core designs including a wide spectrum of possible core configurations. The following areas are addressed:

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1. isothermal temperature coefficient comparison to measurement,
2. control rod worth comparison to measurement,
3. power distribution comparisons to fine mesh diffusion theory (TURTLE) and measurement,
4. critical boron concentration comparison to fine mesh TURTLE,
5. dropped bank accident power distribution comparison to fine mesh TURTLE,
6. dropped rod accident power distribution comparison to measure ment, and
7. N-1 rod worth comparison to measurement.

For each area addressed the data base is presented, including individual comparisons between calculations and standard (measurement or higher order calculation), the mean and standard deviation of the discrepancy between calculation and standard are presented, and conclusions are drawn regarding the suitability of PALADON to perform the calculations.

2. Summary of Review

We have reviewed the description of the PALADON model including the neutronics calculations, the geometric model, and the thermal-hydrualics calculation. The nodal calculation technique has a history of successful application for reactor calculations and the description of the PALADON code is sufficient to permit the conclusion that it is state-of-the-art and is therefore acceptable.

Comparisons are presented between measured and calculated isothermal temperature coefficients for 3- and 4-loop plants for core conditions ranging from unrodded to all regulating banks (A+B+C+D) in and for three cycles of operation. A total of 55 data points for first cores and 27 data points for reload cores are presented. Based on these data it may be concluded that PALADON predicts measured values, when appropriate biases have been applied, to within 3 pcm/°F. (3×10^{-5} $\Delta k/k$ per °F)

PALADON control rod bank worth predictions were compared to measured data collected in Westinghouse's control rod worth program. Comparisons were made for 3- and 4-loop plants and for single bank and multiple bank configurations. The data presented support the conclusion that PALADON predicts rod bank worths to the same accuracy as that of the currently approved design methods.

Comparisons of power distribution have been made between those calculated by PALADON and those calculated by fine mesh diffusion theory. Comparisons were made for both 3- and 4-loop plants and for up to three cycles of operation. Two types of comparisons were made - average assembly power and peak rod power in an assembly. PALADON does not calculate the peak rod powers directly - rather, they are derived from the assembly average powers and an algorithm for local peaking factor which is derived from fine mesh diffusion theory calculations.

The results of these comparisons are presented and support the conclusion that PALADON calculates average assembly power to the same accuracy as does fine mesh diffusion theory. While this is not the case with the calculation of peak rod powers a fine mesh correction factor is applied to the PALADON calculation of peaking factors which makes these quantities conservative. This is an acceptable procedure.

Comparisons between fine mesh diffusion theory and PALADON calculations of critical boron concentration at zero power and full power have been made for up to four cycles of operation for several 3- and 4-loop plants. The data presented show that a small bias exists between PALADON and fine mesh diffusion theory and that the bias is the same for zero power and full power and at beginning and end of cycle. This fact is further evidence that moderator and Doppler thermal feedbacks and fission product worths in PALADON are comparable to fine mesh diffusion theory.

Three upset conditions have been investigated with the PALADON code. These include the power distributions resulting from a dropped control rod bank and a single dropped control rod and the N-1 rod worth. The dropped bank

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comparisons are made with the results of fine mesh diffusion theory calculations and the latter two comparisons are made with measured values. The comparisons for dropped control rod bank configurations were done for average assembly power, peak assembly power and peak $F_{\Delta H}$. In all cases the PALADON results were equivalent to or conservative with respect to fine mesh diffusion theory when the fine mesh correction factor is applied to the peak results.

For the single dropped control rod comparisons were made to measurements performed during plant startup tests. These comparisons provide evidence that these upset power distributions may be calculated by PALADON and also provide sufficient data to derive a value for the uncertainty to be applied to the calculated peaking factors. We conclude that PALADON acceptably calculates dropped rod peaking factors when the appropriate uncertainty has been added.

The data presented regarding the calculation of the N-1 rod worth are from startup physics test for thirteen reactors. These data demonstrate that PALADON calculations of the N-1 rod worth are of similar accuracy to those of standard design methods and the uncertainty is low compared to that assumed for this quantity (10 percent) in safety analysis.

3. Evaluation Procedure

We have reviewed the topical report WCAP-9485 within the guidelines provided by the Standard Review Plan, Section 4.3. We conclude that sufficient information has been provided to permit a knowledgeable person to conclude that the PALADON code is a state-of-the-art nodal analysis code.

We have reviewed the data presented in support of the verification of the PALADON code. Sufficient data are presented and analyses performed to permit the following conclusions:

1. Isothermal temperature coefficients are predicted to within 3 pcm/°F when appropriate biases are applied.

2. Control rod bank worths are predicted to within the same accuracy as presently approved design methods.

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3. Assembly average powers are predicted to within the same accuracy as the present design methods.

4. Assembly peak powers are predicted conservatively when corrected by the fine mesh correction factor.

5. Critical boron concentrations are predicted with acceptable accuracy.

6. Dropped control rod bank peaking factors are predicted to the same accuracy as design methods when the fine mesh correction is applied.

7. Dropped single rod peaking factors are predicted with acceptable accuracy.

8. The N-1 rod worth is predicted to an accuracy consistent with approved design methods - much less than the ten percent uncertainty assumed in safety analyses.

4. Regulatory Position

On the basis of our review we conclude that topical report WCAP-9485 may be referenced in licensing actions for calculations of those quantities described above for which it has been qualified. Further qualification will be required before the PALADON code may be used to calculate axial or three-dimensional power distribution or perform xenon transient calculations (such as those for constant axial offset control analysis).