

EVALUATION OF CENPD - 266-P

THE ROCS AND DIT COMPUTER CODES FOR NUCLEAR DESIGN (TACS NO. 47469)

Report Title: The ROCS and DIT Computer Codes for Nuclear Design
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1. SUMMARY OF REPORT

This report describes two computer codes used by Combustion Engineering, Inc. (CE) for the design and analysis of pressurized water reactor cores.

The two codes are:

- ROCS, for two- and three-dimensional neutronics analysis;
- DIT, for the generation of few-group neutron cross sections.

The methods, capabilities, verification and level of accuracy for the codes are documented. Neutronic parameters calculated include two- and three-dimensional neutron flux and power distributions, control rod and absorber reactivity worths, and reactivity coefficients, as well as the coefficient libraries for the incore instrumentation previously generated by the PDQ-7 code. The accuracy of the codes for each of these applications is quantified statistically.

The original ROCS code used a modified one-group diffusion theory model with the Higher Order Difference (HOD) method. More recently, the modified one-group model was extended to two energy groups. An alternative neutronics formulation, the Nodal Expansion Method (NEM) is also presented in addition to the standard HOD method. Assembly power distributions obtained with both neutronics formulations are compared as well as local flux and power peaking calculations between PDQ-7 and ROCS.

A coarse mesh depletion model is available for each node in two or three dimensions. The depletion nuclides include the principal uranium and plutonium isotopes, a fuel exposure chain, xenon and samarium fission product chains, and boron and gadolinium burnable absorber chains.

A thermal-hydraulic calculational model which represents the core as an array of closed, parallel flow channels is included. Each radial node corresponds to an individual flow channel. The channels are axially segmented for each plane so that the thermal-hydraulic calculation is performed for each node.

Independent feedback calculations for moderator density, moderator temperature, fuel temperature, and equilibrium xenon are available as options. The macroscopic cross sections used in the neutron flux calculations are updated for each feedback variable specified.

A module (MIC) is available which uses an imbedded fine mesh diffusion theory method for obtaining fuel pin power distributions from coarse mesh two- or three-dimensional calculations. Pin peaking can, therefore, be obtained for each node.

The report describes the logic structure, transport theory methods, basic cross section library and depletion calculation used in the DIT code. The DIT predictive capability is also verified by comparisons of reactivity and reaction rates with critical experiment measurements.

Benchmark comparisons of ROCS, using DIT cross sections, with experiments are presented and grouped into the two categories of normal conditions and upset conditions. Power distributions, control rod bank worths and reactivity coefficients are included under normal conditions whereas upset conditions cover single control rod worths and assembly power distributions for anomalous control rod configurations.

2. SUMMARY OF EVALUATION

We have reviewed the information presented with regard to calculational methods and comparisons of calculations and experiment.

a. ROCS Code

The neutronics models in ROCS employ a nodal method for solving the standard two-group diffusion equations. The original HOD method used in ROCS was based on a modified one-group diffusion theory model.— This has now been extended to two energy groups. The NEM has also been developed as an alternate method for future insertion in ROCS and provides higher computational efficiency than the HOD method.

The NEM and HOD methods have been compared to each other and to fine mesh PDQ-7 calculations using two-dimensional models of the Arkansas Nuclear One Unit 2 (ANO-2) plant during Cycle 1 operation. For these calculations, NEM was used in a special version of the HERMITE (Ref. 1) kinetics code rather than in ROCS whereas the HOD calculations were performed with ROCS as the host code. Cross sections for all calculations were obtained with DIT.

Two-dimensional midplane fuel assembly relative power densities calculated by the NEM and HOD coarse-mesh methods have been compared to fine-mesh PDQ-7 results for beginning-of-cycle (BOC), middle-of-cycle (MOC), and end-of-cycle (EOC). The standard deviations and maximum differences between the coarse-mesh and the PDQ-7 assembly powers are comparable to those obtained by other presently approved design methods. Three-dimensional comparisons of NEM with HOD were made for BOC unrodded full power ANO-2 conditions. Radially averaged axial power distributions agreed quite well. Midplane assembly relative power densities also showed close agreement between the two methods as did the comparisons at other axial positions. Based on the good agreement for two- and three-dimensional power distributions between the NEM and HOD methods and between NEM and HOD and fine-mesh PDQ-7 calculations, we find either method (NEM or HOD) acceptable for coarse-mesh power distribution calculations.

Further verification of ROCS with experiment was performed for other important physics parameters but only with the HOD formulation. These included boron worths, isothermal temperature coefficients, control rod worths, power coefficients, asymmetric power distributions, and local fuel pin power peaking. However, in response to the staff's request, additional information was submitted by CE showing results of comparisons of physics parameters between HOD in ROCS and NEM in HERMITE (Refs. 2 & 3).

Most of the HOD comparisons were made for four different operating reactors over several cycles of operation and at various power levels and control rod configurations. The NEM comparisons were for the BOC ANO-2 model. Comparisons between calculated and measured soluble boron reactivity worths show that the average bias and the 95/95 probability/confidence tolerance limit for predicting boron worth are consistent with those obtained from currently approved design methods and are, therefore, acceptable.

For the isothermal temperature coefficient comparisons, the resulting ppm-dependent bias curve and the associated tolerance band about the curve are consistent with those obtained from currently approved design methods. Although low temperature EOC measurements are not available, the staff believes that the good agreement obtained with other core states establishes confidence in the use of ROCS for predicting temperature coefficients for all core conditions.

Three-dimensional ROCS calculations were used to simulate sequential insertions of control rod banks from startup physics tests. First cycle rod bank worths were predicted somewhat better than reload cycles. However, the calculational biases and uncertainties for all cycles were still comparable to those obtained from currently approved methods and are acceptable.

Three-dimensional calculations were also used to compare with measured power coefficients for various power levels and operating cycles. The average calculational bias and the uncertainty in the ROCS power coefficients as characterized by 95/95 probability/confidence tolerance limits are acceptable since they are consistent with those obtained from currently approved methods.

Dropped, ejected, and net (N-1) rod worth predictions were compared to measured values from startup tests. The (N-1) rod worth calculations simulate the insertion of all control rods except the most reactive one which remains stuck out of the core. These calculations of asymmetric rod configurations showed good agreement with measured values and the standard deviations compared well with those for normal control rod operation.

These dropped and ejected rod configurations provide a method for verifying the ROCS code for asymmetric (i.e., radially skewed) power distributions. Both two-dimensional and three-dimensional calculations were made. Comparisons of calculated and measured ratios of after (drop or ejection) - to - before (drop or ejection) powers were comparable to those obtained from currently approved methods.

Assembly power results were combined with local power peaking results to obtain one-sided tolerance limits for the random error in pin peaking calculated by ROCS and MC for the three-dimensional core power peak (F_q), the integrated radial peaking factor (F_r) and the planar radial peaking factor (F_{xy}). Numerical values of these tolerance limits were smaller in all cases than the values presently used by CE as input to the safety analyses, signifying conservatism in the safety analyses input.

Since the HOD comparisons were performed with ROCS as the host code while the NEM comparisons used HERMITE as the host code, additional comparisons were submitted between ROCS-HOD and HERMITE-NEM k-infinity values at BOC, MOC and EOC (Ref. 3). The close agreement indicates that the future replacement of the HOD method in ROCS with the NEM formulation should not have a major impact on calculational results. Also, although the standard deviations of the differences between the HOD method and measurement were within an acceptable level of agreement, they were several times larger than those for the HOD vs. NEM formulations used to calculate relative power densities. This indicates that the DIT cross section models are more important than the neutronics (HOD or NEM) models in determining the overall calculational uncertainty. The staff, however, recommends further verification when the NEM is inserted into the ROCS code in order to be assured that equivalent biases and uncertainties are obtained with ROCS-NEM as compared to ROCS-HOD.

b. DIT Code

The DIT lattice code prepares few-group averaged neutron cross sections for coarse mesh (ROCS) or fine mesh (PDQ-7 and MC module of ROCS) diffusion theory codes. The use of two-dimensional integral transport theory in DIT allows explicit representation of the geometry of a PWR fuel assembly. This eliminates the need for intermediate calculations for homogenizing the fuel pin and absorber cells prior to performing the transport calculation in assembly geometry.

The 85 group microscopic cross section library is based on data from ENDF/B-IV with several minor adjustments which improve the agreement with data from integral experiments and from operating power reactors. Isotopic depletion calculations can be performed for every cell in the assembly.

The DIT predictive capability has been verified by analyzing clean critical experiments. Both uniform critical experiments, which contain uniform arrays of fuel rods, and non-uniform criticals, which contain heterogeneous arrangements more closely resembling PWR assembly designs, were used. The agreement between calculated and measured criticality and reaction rates is comparable to that obtained from currently approved neutron spectral codes. Also, the cores selected for these comparisons provide an adequate combination of parameters such as moderator-to-fuel ratio, UO_2 enrichment, and dissolved boron concentration to test the calculative methods and data over typical PWR operating ranges of interest. Therefore, we find the DIT code and its associated data library to be acceptable for the generation of few-group cross sections to predict the physical processes important for PWR design.

3. EVALUATION PROCEDURE

We have reviewed the report within the guidelines provided by Section 4.3 of the Standard Review Plan. Included in our review was the description of the analytical methods used in ROCS and DIT, the experimental data base, the calculations performed, and the comparisons made to support the conclusion that the computer models are adequate to calculate steady-state physics parameters for CE licensing actions.

The Core Performance Branch has been assisted by our consultants at Brookhaven National Laboratory under Technical Assistance contract FIN No. A 3398 in the review of ROCS and DIT (Ref. 4).

4. REGULATORY POSITION

We have reviewed the ROCS and DIT computer codes as described in CENPD-266-P and CENPD-266-NP and find them to be acceptable for nuclear core design and safety-related neutronics calculations made by CE in licensing actions for power distributions, control rod worths, depletion, reactivity coefficients and reactivity differentials. We also conclude that the ROCS code, including the fine-mesh module MC, is of sufficient accuracy for the generation of coefficient libraries for the in-core instrumentation.

The staff, however, recommends that CE perform further verification when the NEM is incorporated into the ROCS code in order to be assured that equivalent calculational biases and uncertainties are obtained with ROCS-NEM as compared to ROCS-HOD.

5. REFERENCES

1. P. E. Rohan, S. G. Wagner, S. E. Ritterbusch, "HERMITE: A Multi-dimensional Space-Time Kinetics Code for PWR Transients," Combustion Engineering, Inc., CENPD-188-A, March 1976.
2. Memorandum from C. H. Berlinger (CPB) to C. Thomas (SSPB), dated September 10, 1982, transmitting request for additional information on CENPD-266 ROCS and DIT Computer Codes.
3. Letter from A. E. Scherer (CE) to C. Thomas (NRC), dated February 1983, transmitting Amendment 1 to CENPD-266.
4. Letter from D. Cokinos (BNL) to L. Kopp (NRC), dated September 16, 1982, transmitting general comments and questions on ROCS and DIT.