TECHNICAL EVALUATION REPORT

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1.0 INTRODUCTION

ABB Combustion Engineering (ABB-CE) and the Omaha Public Power District (OPPD) have submitted in References-1 and 2 the three volumes of the CENTS Technical Manual Topical Report CE-NPD 282-P for NRC review and approval. CENTS is a new ABB-CE computer code for the simulation of PWR transient behavior under normal and abnormal conditions. CENTS provides an interactive capability for simulating the standard NSSS components, and may be used to determine the transient thermal-hydraulic conditions in the primary and secondary systems and the transient core power. CENTS is intended for prediction of plant behavior for conditions ranging from normal plant operation to operational and licensing transients.

CENTS is a best-estimate code designed to provide a realistic simulation of the neutronics, thermal-hydraulics and plant systems response during transient conditions. The CENTS models are based on PWR design codes. The primary system models are based on the ABB-CE design version of CEFLASH-4AS (Reference-3) and the secondary system models are based on the Long Term Cooling (LTC) computer code (Reference-4). The point reactor kinetics and decay heat models are taken from FLASH (Reference-5).

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The CENTS modeling of the reactor core, primary and secondary systems, and control systems is presented in Volume-1. A detailed description of the CENTS input is given in Volume-2. Comparisons of CENTS to startup measurements, operational transient measurements and to the CESEC (Reference-6) and CEFLASH-4AS codes are presented in Volumes 2 and 3.

The purpose of this review was to evaluate the acceptability of CENTS for performing PWR licensing analyses. This involved the evaluation of both the CENTS methodology and the completeness and accuracy of the CENTS benchmarking. The CENTS methodology and benchmarking are summarized in Section-2, and the evaluation of the important technical issues raised during this review is presented in Section-3. The technical position is given in Section-4.

2.0 SUMMARY OF THE TOPICAL REPORT

2.1 CENTS Methodology

2.1.1 Reactor Core

In the CENTS methodology, the transient core power is determined by either a point kinetics or three-dimensional neutronics model. In the point kinetics model a user-specified axial power distribution is employed. The kinetics and decay heat calculation used in the point kinetics model is based on the treatment of FLASH (Reference-5) using six delayed groups. The fission decay power calculation uses eleven fission product groups together with fission product decay constants and yields, assuming steady-state operation at the initial power level. The decay heat is calculated using the ANS/ANSI-5.1 decay heat curve, including the fission product capture contribution and without uncertainties.

The core heat transfer to the coolant is determined using a finite difference form of the heat transfer equation in cylindrical geometry for a finite axial height including the fuel pellet, gap, clad and coolant. Temperature dependent conduction and heat capacities are used. Heat transfer coefficients are provided for both forced convection and pool boiling, and from subcooled through critical heat flux conditions. The coolant axial temperature distribution is determined using a closed channel heat balance.

2.1.2 Primary System

The CENTS model employs a flow path network together with a control volume representation of the primary system components to solve the fluid conservation equations. The primary system representation includes models for the inner-vessel, upper head, hot-leg, pressurizer, steam generator (3 nodes), coolant pumps, cold-leg, and the annulus and lower plenum. Each Reactor Coolant System (RCS) loop is modeled explicitly. The thermal-hydraulic model solves a one-dimensional conservation equation for each of the following: liquid mass, mixture mass, mixture energy, steam enthalpy and mixture momentum. The numerical solution is carried out using a linearized discretized form of these equations together with an iterative calculation of the nodal pressure and enthalpy.

The heat rate includes contributions from the fuel, pumps, steam generator, pressurizer heater and control element assembly (CEA). Correlations are provided for condensation and critical flow. The primary system wall temperatures are calculated by integrating the nodal heat conduction equations.

2.1.3 Secondary System

The CENTS secondary system includes control volumes for the steam generator downcomer, evaporator/riser and steamdome, and an additional volume for the main steamline header. Safety valves, atmospheric dump valves, MSIVs, and steamline/feedline check values are included. The Steam Generator (SG) model maintains the conservation equations using a node-flowpath representation. The flows between internal SG control volumes are determined using empirical correlations. The SG model also includes calculations of the nuclide concentrations, heat losses, and indicated level. CENTS provides a simplified SG model in which the feedwater flow specified in the control system is input directly to the SG, as well as a detailed model in which the feedwater flow network is represented.

2.1.4 Control Systems

The CENTS control system model simulates the operation of the reactor protection, control rod regulation, pressurizer level and pressure, feedwater, turbine and safety injection control systems. CENTS employs a set of generic modules to perform the standard arithmetic, integro-differential and logic transforms used in these control systems. The model provides an extensive set of Reactor Protection System (RPS) trips, including the power rate-of-change and the overpower and overtemperature ΔT trips. The pressurizer level control system model determines an error signal based on the programmed level and adjusts the charging/letdown flow rates and/or the pressurizer heaters. The turbine control model typically generates a turbine trip with a core trip, feedwater trip, loss of load, or high SG level. The control rod regulating model may be used to maintain criticality, satisfy power demand, and trip the reactor. A typical control rod regulator determines an error signal from the core average and reference temperatures, and the core power and turbine demand mismatch. The control rod speed and reactivity worth are input.

2.2 CENTS Benchmarking

In order to qualify the CENTS coding and models for PWR transient analysis, ABB-CE has compared the CENTS predictions to startup measurements, operating transients, and to calculations made with the ABB-CE CESEC and CEFLASH-4AS design codes. As an initial test of the coding, initialization procedure, numerical stability and conservation laws, a "steady-state" transient calculation (with the controllers disabled) was performed. After fifteen minutes, the CENTS calculation indicated the changes in the important system variables were very small. Comparison of CENTS with CESEC and plant flow measurements for a four pump coastdown startup test indicated good agreement with the CESEC and measured RCS flow. CENTS calculations of a plant overcooling transient and the St. Lucie-1 natural circulation plant cooldown transient (Reference-7) were also carried out. Calculation-to-measurement comparisons of the pressure, and hot and cold leg temperatures for those transients indicated generally good agreement.

In Volume-3 of CE-NPD 282-P, additional benchmarking is presented for two ABB-CE PWRs. Startup measurement comparisons as well as comparisons for a set of representative

CESEC licensing calculations are presented. Detailed CENTS/CESEC comparisons of the sequence-of-events, and primary and secondary system parameters indicate that the agreement is generally good, and consistent with the differences in the modeling and accuracy of these codes.

3.0 SUMMARY OF THE TECHNICAL EVALUATION

The CENTS Technical Manual Topical Report CE-NPD 282-P provides a detailed description of the CENTS methodology and the benchmarking qualification via comparisons to plant measurements and to the NRC approved CESEC and CEFLASH-4AS codes. The review of CENTS focused on the approximations and assumptions implicit in the CENTS methodology, and the completeness and accuracy of the benchmarking of this methodology. Several important technical issues were raised during the initial review which required additional information and clarification from ABB-CE. This information was requested in Reference-8 and was provided in the ABB-CE response included in Reference-9. This evaluation is based on the material presented in the topical report and in Reference-9, and on discussions with ABB-CE and the NRC staff at a meeting in Rockville, Maryland on January 28, 1993. The evaluation of the major issues raised during this review are summarized in the following.

3.1 CENTS Modeling

3.1.1 Comparison of CENTS, CESEC and CEFLASH-4AS Models

The CENTS models are improved versions of the models included in the NRC approved

CESEC and CEFLASH-4AS codes. The CEFLASH-4AS models have been adapted to the specific intended non-LOCA licensing analyses and the CESEC-III models have been updated and improved by including more detail for certain components.

The CENTS neutronics model includes a three-dimensional capability however, since no benchmarking of this capability has been provided in the topical report, the present review includes only the point kinetics neutronics model. The neutronics input to the CENTS kinetics model is determined in the same manner as for CESEC. As indicated in Response 25 (Reference-9), the determination of the effective delayed neutron fraction for the point kinetics model accounts for the reduced worth of the delayed neutrons.

The CENTS primary system calculation uses a non-equilibrium, non-homogeneous model with five conservation equations (mixture and liquid mass, mixture energy, steam enthalpy, and mixture momentum), while CEFLASH-4AS uses a non-homogeneous, equilibrium model with three mixture conservation equations. CESEC-III uses an equilibrium, homogeneous model with nodal mass and energy equations and a momentum equation for each coolant pump loop. The CENTS primary system nodalization is similar to that of CEFLASH-4AS. CENTS solves the conservation and core heat transfer equations implicitly providing improved stability for large time steps.

Explicit models for determining (1) the nodal solute concentrations (e.g., boron, xenon, iodine and hydrogen) and (2) heat loss to the containment have been added to CENTS. CENTS includes an improved model of the upper head which allows a leakage path from the annulus. CENTS provides a multinode steam generator model while CESEC-III employs a single node steam generator model. The CENTS steam generator model has been benchmarked against plant secondary side measurements for a range of transients including a turbine trip, loss of load, pump coastdown and overcooling transient.

The flow mixing model is important for the steamline break analysis. The CENTS mixing model employs an enthalpy tilt factor to the hot legs. The inlet, outlet and flow imbalance factors used in determining the enthalpy tilt are described in Response-27 (Reference-9). CESEC uses experimentally based constants to calculate the mixing in the lower plenum, upper plena and in the upper head. In Figures 19.1-19.3 the CENTS and CESEC calculated temperatures for the affected and unaffected loops are compared for a steamline break event and indicate good agreement.

3.1.2 Neutronics Modeling

When point kinetics is used to calculate the core neutronics, the time-dependent radial and axial power distributions are calculated outside of CENTS. These calculations are performed as part of the local DNBR and fuel limits analysis and are performed with NRC approved design codes such as ROCS/MC. The DNBR and fuel limits analyses use the system response data calculated by CENTS (average heat flux and RCS pressure, temperature and flow) together with conservative radial and axial power distributions. The DNBR and local limits analyses are performed with NRC approved methods outside of CENTS. This approach is the same as used with CESEC. CENTS provides a separate DNBR calculation for determining overall trends in thermal margin. However, this DNBR calculation is not approved and should not be used for safety related or licensing analyses.

The CENTS procedure for determining the boron reactivity employs a precalculated table of reactivity as a function of boron concentration. This reactivity table assumes a constant moderator density. This approximation introduces no error in transients where the boron concentration does not change. In Response-7 (Reference-9), ABB-CE indicates that the steamline break is the only Standard Review Plan event which might be affected by this approximation. In this case, the CENTS reactivity table underestimates the negative boron reactivity insertion which makes the steamline break analysis conservative.

3.1.3 Numerical Methods

The CENTS primary system nodalization is similar in concept to the approach used in CESEC and uses approximately the same number of nodes. The CENTS secondary side nodalization is more detailed than CESEC. CENTS uses up to ten radial nodes to describe the fuel rod. ABB-CE has performed sensitivity analyses which indicate that increasing the number of radial nodes in the fuel rod from six to ten has very little effect on the NSSS response (Response-14, Reference-9). ABB-CE will use multiple nodes in the pellet to insure an accurate transient response. (Response-31, Reference-9).

ABB-CE has also performed detailed time step sensitivity calculations to demonstrate the numerical convergence of the CENTS solution. Results of these calculations indicate that the necessary time step depends on the specific transient and acceptable values are given for the steamline break and CEA withdrawal transients in Appendix A of Reference 9.

CENTS determines the primary and secondary side pressures using an iterative procedure. For equilibrium conditions the primary system pressure is converged to within 0.5 psia or better.

For non-equilibrium conditions, the primary system pressure is converged to within 0.2 psia and the enthalpy is converged to within 0.2 Btu/lbm. CENTS converges the secondary side pressure to within 5.0 x 10^{-4} psia. For non-LOCA transients voiding does not occur and a void iteration is not required.

3.2 CENTS Benchmarking

3.2.1 Selection of Benchmarking Transients

As part of the CENTS qualification for the analysis of non-LOCA design basis transients and for performing safety related analyses, ABB-CE has analyzed a series of design basis events. The events analyzed have been selected to provide the most severe design basis events. In Response-3 (Reference-9), ABB-CE indicates that the selected steamline break (SLB) event provides the most rapid and severe NSSS response for a secondary side heat removal transient. The feedline break event provides the most rapid and severe overpressurization of the secondary side heatup transients, and allows the evaluation of affected loop versus unaffected loop asymmetries. The seized rotor event selected provides characteristic DNB limits evaluations for loss of flow transients. The CEA withdrawal and the CEA drop events are the only reactivity and power distribution anomaly events that will be analyzed with CENTS. The CEA withdrawal event provides the most severe power and heat flux transient for this event classification. The comparisons for the CEA withdrawal from subcritical and from hot-zero-power provided in Appendices B and C, respectively, indicate good agreement in the predicted power and heat flux transients relative to the predictions with the approved CESEC methodology.

The benchmark comparisons provided in the topical report generally indicate good agreement relative to the CESEC calculations and plant measurements. CENTS-to-Benchmark differences which were larger than expected are described in the following.

3.2.2 Steamline Break Analysis

The Plant-A steamline break analysis presented indicates a relatively large difference between the CENTS and CESEC predictions of the cold leg temperature. In Response-19 (Reference-9), it is indicated that this difference is due to an inconsistency in the mixing model input between the CENTS and CESEC calculations. In Figures 19.1-19.3 of Reference-9, ABB-CE has provided a comparison of CESEC and an updated CENTS calculation in which the mixing models are consistent. These comparisons indicate good agreement for both the affected and unaffected loop temperatures.

In the Plant-B steamline break analysis, the CENTS safety injection occurs earlier than in the CESEC prediction. This difference in the safety injection timing is due to a more detailed upperhead model in CENTS. In Response-21 (Reference-9), ABB-CE provides detailed calculations that show that the reduced time to the safety injection setpoint is due to a faster depressurization which results primarily from the more detailed CENTS upperhead modeling.

3.2.3 Steam Generator Tube Rupture

In the Plant-A steam generator tube rupture analysis, after the initial coolant system depressurization, the CENTS break flow decreases while the CESEC break flow increases. This decreased break flow in CENTS (relative to CESEC) is due to a reduced RCS temperature and pressure. In Response-29 (Reference-9), ABB-CE indicates that the lower RCS pressure is due to a more detailed modeling of the vessel upper head region.

CENTS predicts a lower RCS pressure, pressurizer pressure and break flow in the Plant-B steam generator tube rupture (with loss of AC power) event. After the reactor trip, the RCS pressure is determined by the temperature of the coolant in the upper head. In a manner similar to Plant-A, the more detailed and accurate CENTS upper head modeling results in a lower RCS temperature, pressure and break flow (Response-22, Reference-9).

3.3 CENTS Applications

The CENTS models and solution methodology provides a realistic best estimate calculation rather than a conservative or bounding approach. It is intended that the conservatism required in licensing analyses will generally be provided by the selection of transient-specific initial conditions and plant performance data. The initial conditions are typically taken as the worst-case conditions allowed by the Technical Specifications resulting in the most severe transient results. The CENTS neutronics input is calculated to provide a conservative transient prediction. Redundant plant equipment is assumed to be out of service if allowed by the Technical Specifications. The plant performance parameters such as the RPS response times, safety/relief valve flow capacities, coolant pump flywheel inertia and HPSI/LPSI flows are taken to be conservative relative to actual best estimate values (Response-1, Reference-9).

The CENTS models, options and overall capabilities allow a detailed representation of both the CE and Westinghouse plants. However, the benchmarking provided in Volumes 1-3 of CENPD 282-P only includes comparisons for CE type reactors. In Response-2 of Reference-

9, ABB-CE indicates that the benchmarking comparisons required for the qualification of CENTS for application to Westinghouse type plants will be provided in Volume-4 of CENPD 282-P. Consequently, until Volume-4 of CENPD 282-P is approved, the application of CENTS is limited to CE plants.

CENTS is intended for the analysis of the design basis licensing events. The benchmarking provided in Volumes 1-3 of CENPD 282-P includes no severe accident comparisons and only one small break LOCA comparison. In Response-3 (Reference-9), ABB-CE indicates that CENTS will not be used for performing LOCA or severe accident licensing analyses.

CENTS includes a three-dimensional coupled neutronic/thermal-hydraulic calculational capability. No benchmarking of this capability was provided in Volumes 1-3 of CENPD 282-P. Consequently, the licensing applications of CENTS are limited to the point kinetics model.

The benchmarking comparisons provided in Volumes 1-3 of CENPD 282-P do not include large rapid power transients with strong local reactivity effects typical of the control element assembly (CEA) ejection transient. In Response-3 (Reference-9), ABB-CE indicates that the CEA ejection licensing analyses will be performed with the NRC approved methods of Reference-10.

4.0 TECHNICAL POSITION

The Topical Report CE-NPD 282-P and supporting documentation provided in Reference-9 have been reviewed in detail. Based on this review, it is concluded that the CENTS code is acceptable for performing reload licensing analyses for ABB-CE PWRs subject to the conditions stated in Section-3 of this evaluation and summarized in the following.

1) CENTS DNBR Analysis

The CENTS DNBR calculation for determining overall trends in thermal margin should not be used for licensing analyses. The DNBR licensing analyses should be performed with the presently approved ABB-CE DNBR methods (Section-3.1.2).

2) Limitation to CE Type Plants

The application of CENTS is limited to CE plants until Volume-4 of CENPD 282-P receives NRC approval (Section-3.3).

3) LOCA and Severe Accident Analyses

Adequate benchmarking of the CENTS LOCA and severe accident capabilities has not been provided. Consequently, CENTS should not be used for performing LOCA or severe accident licensing analyses (Section-3.3).

4) Three-Dimensional Core Neutronics

Benchmarking for the CENTS three-dimensional core neutronics capability has not been provided and, consequently, licensing applications of CENTS must use the point kinetics model (Section-3.3).

5) CEA Ejection Analysis

Benchmarking for the CEA ejection transient has not been provided and, consequently, CENTS is not approved for performing CEA ejection licensing analyses. The CEA ejection analyses should be performed with the NRC approved ABB-CE methods of Reference-10 (Section-3.3).

REFERENCES

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4. "Response of Combustion Engineering Nuclear Steam Supply System to Transients and Accidents," CEN-128, Vol. 1 (Non-proprietary), April 1980.

5. Margolis, S.G. and Redfield, J.A., "FLASH - A Program for Digital Simulation of the Loss of Coolant Accident," WAPD-TM-534, May 1966.

6. "CESEC Digital Simulation of a Combustion Engineering Nuclear Steam Supply System," Enclosure 1-P to LD-82-001, Letter, A.E. Scherer to D.G. Eisenhut, December 1981.

7. "Analysis and Evaluation of St. Lucie Unit 1 Natural Circulation Cooldown," INPO-2, NSAC-16, December 1980.

8. "Request for Additional Information on the CENTS Code Topical Report," Letter, R. C. Jones (NRC) to S. A. Toelle (ABB-CE), dated December 7, 1992.

9. "Response to NRC Request for Additional Information on the CENTS Code Topical Report," CENPD 282-P, Supplement 1-P, June 1993.

10. "C-E Method for Control Element Assembly Ejection Analysis," CENPD-190-A, January, 1976.