ATTACHMENT

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TECHNICAL EVALUATION REPORT

Topical Report Title:	Qualification of Transient Analysis Methods for BWR Design and Analysis
Topical Report Number:	PL-NF-89-005
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1.0 INTRODUCTION

By letter (Reference-1), the Pennsylvania Power and Light Company (PP&L) has submitted the Topical Report PL-NF-89-005, "Qualification of Transient Analysis Methods for BWR Design and Analysis." The methodology described in the report is intended as a technical basis for the PP&L qualification to perform transient analyses for the two Susquehanna Steam Electric Station (SES) GE BWR-4 Reactors.

The methodology is based on the EPRI computer codes SIMTRAN-E (Reference -2), ESCORE (Reference-3), and RETRAN-02 MOD-004 (Reference-4). The steady-state core physics input to these codes is provided by SIMULATE-E (Reference-5). The thermal margin evaluation is performed with the Advanced Nuclear Fuels (ANF) XN-3 critical power correlation (Reference-6). The topical report includes a description of the Susquehanna models, and the qualification benchmarking against the Susquehanna SES Units 1 and 2 startup tests and the Peach Bottom-2 turbine trip tests. The calculations and models are intended as best-estimates in order to determine the code and model uncertainty and their adequacy for performing transient

analyses. The conservative licensing analyses and models are described in the PP&L reactor analysis methods applications Topical Report PL-NF-90-001 (Reference-7).

The review of the PL-NF-89-005 topical report is summarized in the following sections. The topical report is outlined in Section-2 and the evaluation of the PP&L transient analysis methods is summarized in Section-3. The technical position is given in Section-4.

2.0 SUMMARY OF THE TOPICAL REPORT

The topical report provides (1) a detailed description of the Susquehanna SES RETRAN-02 system model, (2) the benchmarking comparisons of this model versus reactor test data and (3) the determination of the code and model uncertainty based on these comparisons.

2.1 Susquehanna RETRAN-02 Model

The RETRAN-02 model includes a detailed nodalization and geometry description of the Susquehanna Reactor System. The reactor core and bypass regions are modeled with 27 axial nodes, 25 of which are in the active core. The power in the active zones is determined by the one-dimensional kinetics model using the same 27-zone axial representation. In this model the void and doppler feedback are determined using the local moderator density and average fuel pellet temperature. The moderator density calculation accounts for subcooled voids in the neutronics feedback. The fuel pellet temperature is calculated with a three region (pellet, gap and clad) thirteen mesh model. Both conduction and direct moderator heating of the bypass region are included.

The two recirculation loops are modeled explicitly including volumes for the suction piping, recirculation pump and discharge piping. The recirculation model is based on a detailed model which has been compared to vendor data.

The steam line is modeled with nine volumes. The model was validated by a series of sensitivity calculations in which the number of volumes was systematically increased. The steam line is connected to the vessel steam dome and the steam line valves (HPCI and RCIC supply valves, and safety/relief valves) are included as negative fill junctions. A signal for the pressure regulator control system and for MSIV closure are taken from steam line volumes. The main steam bypass system includes a junction representing the bypass valves and a volume for the bypass header and steam chest. Heat conduction through the bypass piping has been included in order to provide improved agreement with the test data. The pressure reducers, spargers and condenser in the bypass line are all modeled with individual volumes. The loss coefficient in the bypass line were determined by comparison to measured bypass flow.

The upper plenum is modeled as a single volume connected to a standpipe region which empties into the separators. The separator carryunder and dryer carryover are based on vendor data. An upper downcomer, middle downcomer and lower downcomer region are included. The separator and upper downcomer models provide good agreement between measurements and calculations of upper plenum pressure and dome pressure. The lower plenum is modeled as a single volume and the lower plenum to core bypass loss coefficient has been adjusted to preserve the core pressure drop as determined by SIMULATE-E.

The jet pump model used in the RETRAN-02 analysis is a collapsed simplified version of a detailed (53-volume) model which PP&L has shown to give good agreement with vendor

supplied jet pump performance data. The recirculation pumps are modeled using vendor pump characteristic curves.

The Susquehanna RETRAN-02 model includes five safety/relief valves (SRVs). Each valve represents a composite of up to four valves having a common pressure setpoint. The specific SRV modeling is based on the FSAR data of Reference-8. The four inboard main steam isolation valves (MSIVs) are represented by a single valve. The form loss coefficient of this valve is increased as the valve closes to provide an accurate calculation of the pressure increase during an MSIV event.

The Susquehanna RETRAN-02 model includes an extensive set of trips based on calculated variables including core power, pressure, water level and flow. The trips include insertion of control rods, activation of the SRVs, recirculation pump trip and runback, turbine trip, feedwater trip and HPCI and RCIC trip. In addition, a set of special trips on elapsed time have been included to analyze special events such as loss of feedwater heating and generator load rejection.

The RETRAN-02 core neutronics analysis is performed using a one-dimensional axial model. The kinetics parameters including two-group cross-sections, diffusion coefficients and delayed neutron parameters are calculated with SIMULATE-E in three dimensions via a set of perturbation calculations in which the moderator density and fuel temperature independent variables are varied. The kinetics parameters are collapsed radially using adjoint or volume weighting at the required transient initial statepoint conditions and as a function of rod insertion if scram occurs during the transient.

In order to establish the adequacy of the steam line nodalization, an additional calculation

was performed in which the number of steam line volumes was increased from eight to fifteen. The Peach Bottom-2 turbine trip test was then calculated with both nodalizations and the core peak power and peak reactivity was found to agree to within $\sim 1\%$.

2.2 Susquehanna Model Benchmarking

In order to validate the Susquehanna RETRAN-02 model, PP&L has made detailed comparisons of the RETRAN-02 predictions with the Susquehanna Units 1 and 2 Cycle-1 startup test data, the Peach Bottom-2 turbine trip measurements and the licensing basis transient (LBT) calculations of General Electric (GE) and Brookhaven National Laboratory (BNL), References 9 and 10, respectively.

The Cycle-1 startup tests at Susquehanna Unit-2 are at close to operating conditions and include the feedwater system water level and pressure regulator setpoint tests, a loss of feedwater heating test and the recirculation pump trip tests. The setpoint tests provide validation for the controller models and the calculation of the overall system response. The feedwater heater transient resulted in a gradual increase in power (over ~ 300 seconds) which RETRAN-02 predicted to within $\sim 10\%$ and provides validation of the neutronics temperature feedback models at close to rated conditions. The recirculation pump trip tests result in a substantial reduction in core power which RETRAN-02 predicted to within $\sim 5\%$. These tests provide validation of the RETRAN-02 calculation of the pump coastdown and system response.

PP&L has also provided a RETRAN-02 benchmark comparison for a Susquehanna-1 generator load rejection event at the end of Cycle-1. This was a rapid pressurization event similar to (although much milder than) the licensing basis overpressurization transient. The

RETRAN-02 calculated power increase of 29% compares reasonably well with the measured power increase of 34%.

The Peach Bottom-2 turbine trip tests were performed to provide benchmark data for BWR transient analyses. In fact, these transients are similar to the BWR licensing basis overpressurization transient. The three tests (TT1, TT2, and TT3) were performed at close to rated flow (81 to 91%) and over a range of core powers (47 to 69% of rated). The PP&L simulation of these transients is based on the same codes and best estimate methods used in the analysis of the Susquehanna units. The comparison of the RETRAN-02 calculated core power indicates a conservative overprediction of TT1 and good agreement for the TT2 and TT3 tests. The core pressure increase calculated by RETRAN-02 for all tests agreed with the measured values to within <10%.

The licensing basis transient consists of a turbine trip without bypass from 104.5% power and rated flow. The initial conditions are for the Peach Bottom-2 end-of-Cycle-2 statepoint. The PP&L evaluation of this transient was based on the standard methods and included a Cycle-1 and Cycle-2 depletion and neutronics feedback calculation with SIMULATE-E. The initial axial power shape compares well with the GE and BNL results. The transient peak power was conservatively overpredicted by RETRAN-02 by ~30%.

2.3 Susquehanna Model Code Uncertainty

In order to estimate the RETRAN-02 calculational uncertainty in predicting the fractional change in critical power ratio, RCPR, PP&L has made calculation-to-measurement comparisons for the three Peach Bottom-2 turbine trip tests. The comparisons assume the fuel is similar to

ANF 9x9 fuel, and are not valid for fuel bundles that are significantly different. Based on these comparisons a 95/95 upper bound of 26.2% for internal rods and 32.2% for peripheral rods is determined for RETRAN-02 calculations of RCPR.

3.0 TECHNICAL EVALUATION

The PP&L BWR transient analysis methods qualification topical report describes the Susquehanna RETRAN-02 model and the benchmarking comparisons used to validate the model for reload licensing applications. The initial review of the topical report resulted in a request for additional information (RAI) which was transmitted to PP&L in Reference-11. This evaluation included both the model and benchmarking description included in the report, as well as the PP&L response to the RAI provided in References 12 and 13. The major issues raised during this review are summarized in the following.

3.1 Susquehanna RETRAN-02 Model

The core neutronics statepoint and transient feedback data are determined by a three-dimensional SIMULATE-E core calculation. The licensing transients are generally sensitive to both the initial statepoint conditions and precalculated reactivity feedback coefficients. In Response-1 (Reference-12) PP&L has indicated that a SIMULATE-E calculation is performed for each initial statepoint exposure distribution, power level, rod pattern and core flow, and that the one-dimensional RETRAN-02 cross-sections and feedback will include this detailed statepoint dependence.

The SIMULATE-E/SIMTRAN-E one-dimensional cross-sections include an adjustment to account for differences between the SIMULATE-E three-dimensional thermal hydraulics and the RETRAN-02 one-dimensional average channel thermal hydraulics. The adjustment is only required for the overpressurization transients: generator load rejection and feedwater controller failure events. For these applications the adjustment has been validated by the RETRAN-02 comparisons to the Peach Bottom-2 turbine trip tests and to the LBT calculations. The calculation of peak pressures in licensing analyses is performed without the adjustment which results in a conservative overprediction of the limiting pressure (Response-3, Reference-12).

The fuel rod gap conductance used to determine core response in the RETRAN-02 model is calculated with ESCORE using a core-average power history and axial power shape. In order to provide a bounding hot-bundle calculation, a separate conservative gap conductance is used for each potentially limiting hot-bundle fuel type (Response-26, Reference-12). The ESCORE calculation requires a resonance escape probability (REP) to determine the fuel rod parameters. PP&L uses a high value for REP to insure a conservatively high gap conductance. (Response 30, Reference-12).

The PP&L application of the RETRAN-02 model is consistent with the limitations of the RETRAN-02 SER (Response-31). For the relevant portions of the benchmarking calculations and the licensing basis transients, only pre-CHF heat transfer is required, the jet pump flow remains in the forward direction and a dominant flow direction exists in the volumes where the temperature delay model is used. As required, the upper downcomer volume will neither be completely full or empty due to a water level scram. PP&L executes a 10-second null transient to insure proper model initialization, and time step sensitivity calculations have been performed to demonstrate that the time step selection is adequate. If future licensing analyses require the application of the Susquehanna model outside the limitations of the RETRAN-02 SER additional justification will be provided.

The PP&L hot-bundle calculation for pressurization transients includes several modeling assumptions which result in an overprediction of the transient RCPR. The time-dependence of the radial bundle power used in the CPR calculation is assumed to be the same as the core thermal power (Response-22, Reference-12). However, since the limiting bundles at EOC are typically more bottom-peaked than the core-average axial power distribution, the scram in the limiting locations occurs earlier in the transient and the relative bundle power increase is less than that inferred from the core thermal power. This approximation results in an overprediction of the transient RCPR.

In the hot-bundle RCPR calculation the time-dependence of the axial power distribution is neglected. The hot-bundle axial power shape is taken to be the same as the initial core-average axial power distribution and independent of time. The void collapse and rod insertion during the generator load rejection without bypass (GLRWOB) and feedwater controller failure (FWCF) transients result in a shift of the axial power distribution toward the top of the core. To account for the neglect of the time-dependence of the axial power shape the PP&L methodology employs a hot-bundle gap conductance determined assuming a conservative fuel rod power history. In Reference-13, PP&L has evaluated the adequacy of this approach by reanalyzing both the GLRWOB and FWCF transients using a more realistic hot-bundle gap conductance together with a time-dependent axial power shape. The more realistic gap conductance was determined for Susquehanna-1 Cycle-7, using a SIMULATE-E cycle step-out analysis in which the hot-bundle power history was determined. Using the realistic fuel rod power history determined with SIMULATE-E (rather than the conservative power history) reduced the gap conductance from 1462 to 924 BTU/hr-ft^2-°F. PP&L has indicated that this reduced conductance is conservative relative to the value calculated using NRC approved methods.

The Reference-13 analysis indicates that for Susquehanna-1 Cycle-7, the PP&L methodology predicts GLRWOB and FWCF transient RCPRs that are equal to, or larger than, those predicted by the more realistic analyses using a time-dependent axial power shape. We therefore conclude that the PP&L hot-bundle model is acceptable for Susquehanna-1 Cycle-7 GLRWOB and FWCF transient RCPR calculations. In applications of the methodology to future reload cores, the conservatism in the hot-bundle gap conductance must be shown to be sufficient to compensate for the neglect of the time-dependence in the hot-bundle axial power shape.

3.2 Susquehanna Model Benchmarking

The Susquehanna model benchmarking comparisons to the startup and turbine trip test data and to the LBT calculations provide the validation of the RETRAN-02 model and procedures. PP&L has indicated that the model described in PL-NF-89-OO5 is based on best estimate input and procedures, rather than the conservative methods that will be used in the licensing analyses described in the applications Topical Report PL-NF-90-001. These benchmark comparisons will therefore allow the determination of the code/model calculational uncertainty. PP&L has indicated that the methods and procedures used in these benchmark comparisons are the same as will be used in the Susquehanna licensing analyses, except for

conservatism that will be added in PL-NF-90-001. In particular, the moderator density adjustment to the SIMULATE-E/SIMTRAN-E cross-sections was only made for the Peach Bottom-2 turbine trip tests and the LBT calculation, where the moderator density effects are significant. This is consistent with the licensing application, since the adjustment will only be made to the generator load rejection and the feedwater controller failure overpressurization events (Responses 3 and 20, Reference-12).

The PP&L calculations of the Peach Bottom-2 turbine trip tests indicate generally good agreement between the RETRAN-02 predictions and measurements. However, the comparisons for the TT1 test indicate a 24% overprediction of the peak core power and an overprediction of the transient ΔCPR by 14% in the TT3 test. PP&L attributes the overprediction of the TT1 power to conservatism in the prediction of the increase in core pressure and to uncertainties in the time of the turbine trip (Response-18, Reference-12). Since these overpredictions are in the conservative direction and result in larger transient ΔCPRs, they are acceptable.

Based on the evaluation of the Susquehanna model and procedures and the benchmarking comparisons, it is concluded that the Susquehanna RETRAN-02 model is acceptable.

3.3 Susquehanna Model Code Uncertainty

The Susquehanna model code uncertainty was determined by comparing the predicted transient ΔCPR with values inferred from the Peach Bottom-2 measurements. There are significant differences between the Peach Bottom-2 and Susquehanna steam lines and in order to insure a consistent comparison, a special RETRAN-02 calculation, in which the measured dome pressure was imposed as an external boundary condition, was used for predicting the transient ΔCPR. As a result, the calculation-to-measurement ΔCPR differences do not include the effect of the uncertainty in the steamline modeling. In Response-13 (Reference-12) PP&L

has indicated that these uncertainties have been evaluated and will be applied in licensing calculations as described in the applications Topical Report PL-NF-90-001.

The hot-bundle calculation used in the uncertainty analysis assumes ANF 9x9 fuel, and the CPR calculation is carried out with the XN-3 correlation. If a significantly different fuel type is used in a future Susquehanna reload a new code uncertainty will be required.

The Peach Bottom-2 ΔCPR comparisons to measurement indicate a substantial ~9% conservative overprediction of the transient RCPR. This average bias is based on three calculation-to-measurement differences ranging from ~3% to 14%. The topical report does not provide any discussion of the uncertainty in the prediction of the peak transient pressure. In Response-11 (Reference-12) PP&L has indicated that the measured and calculated peak dome pressures for the three Peach Bottom-2 tests agreed to within ~5 psi. In addition, a ~57 psi conservatism is included in the licensing overpressure analysis described in PL-NF-90-001.

With the limitations discussed above it is concluded that the Susquehanna model uncertainty analysis is acceptable.

4.0 TECHNICAL POSITION

The PP&L transient methods Topical Report PL-NF-89-005 and supporting documentation provided in the PP&L responses of Reference-12 and Reference-13 have been reviewed in detail. The topical report provides the description of the core and system model to be used in the transient analyses of the Susquehanna Units 1 and 2, the code/model validation, and an uncertainty analysis for the prediction of transient ΔCPR. Based on this review it is concluded that the PP&L transient methods and uncertainty estimates are acceptable for Susquehanna reload licensing analyses under the conditions stated in Section-3 of the evaluation and summarized in the following.

(1) RETRAN-02 Model Limitations

If future licensing analyses result in conditions that are outside the RETRAN-02 model limitations, as specified in the RETRAN-02 SER, additional model justification will be required (Section-3.1).

(2) Application to New Fuel Designs

The uncertainty estimates, $E_{95/95}$ upper tolerance factors, and hot-bundle ΔCPR calculation are based on the assumption that the core is loaded with ANF 9x9 fuel. Consequently, the methodology and results are acceptable for cores loaded with ANF 9x9 or similar fuel. If a significantly different fuel type is introduced in a future Susquehanna reload, the methods will require further justification and a new ΔCPR uncertainty estimate will be required (Sections 3.1 and 3.3).

(3) Hot-Bundle Fuel Rod Gap Conductance

In applications of the transient methodology to reload cores other than Susquehanna-1 Cycle-7, the conservatism in the fuel rod gap conductance must be shown to be sufficient to compensate for the neglect of the time-dependence in the hot-bundle axial power shape (Section-3.1).

REFERENCES

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3. "ESCORE - The EPRI Steady-State Core Reload Evaluator Code: General Description", EPRI-NP-5100, February 1987.

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7. "Application of Reactor Analysis Methods for BWR Design and Analysis", PL-NF-90-001, Pennsylvania Power and Light Company, August 1990.

8. "Susquehanna Steam Electric Station Units 1 & 2, Final Safety Analysis Report", Revision 41, May 1989.

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10. "Analysis of Licensing Basis Transients for a BWR/4", BNL-NUREG-26684, September 1979.

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12. "Susquehanna Steam Electric Station, Response to RAI on PL-NF-89-005", Letter, H.W. Keiser (PP&L) to Director of NRR, dated March 13, 1991.

13. "Susquehanna Steam Electric Station, Response to RAI on Transient Analysis Methods", Letter, H. W. Keiser (PP&L) to Director of NRR, dated February 12, 1992.