ENCLOSURE 1

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION
RELAP5YA'S HEAT TRANSFER MODEL SUBJECT TO 10CFR50 APPENDIX K REQUIREMENTS
VERMONT YANKEE NUCLEAR POWER CORPORATION
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1.0 INTRODUCTION

RELAP5YA (Ref. 1) is a computer code for Light-Water Reactor (LWR) system thermal-hydraulic analysis which provides integral analysis capability of system and core steady-state and transient simulation for normal and off-normal events. RELAP5YA is based on RELAP5/MOD1 (Ref. 2) Cycle 18 with modifications made by Yankee Atomic Electric Company (YAEC) for use in Loss-of-Coolant Accident (LOCA) analyses. RELAP5YA was submitted to the Nuclear Regulatory Commission (NRC) by Yankee Atomic Electric Company (YAEC) for review and approval for licensing applications as a method to analyze the entire Boiling Water Reactor (BWP) break spectrum in a manner that conforms to Appendix K of 10CFR50. In particular, YAEC seeks approval of its licensing model for the Vermont Yankee Nuclear Power Station (VYNPS) LOCA analysis.

RELAP5YA, with YAEC modifications, was previously approved as a best-estimate code for performing BWR small and large break LOCA and fuel cycle independent analyses with some conditions (Refs. 3, 4). However, it was concluded that the limiting LOCA scenario for VYNPS had not been analyzed. Furthermore, review of the evaluation model for licensing analyses of LOCA scenarios revealed that requirement II.5 of Appendix K was not satisfied. A summary of YAEC's effort to assess and qualify heat transfer models in RELAP5YA as part of LOCA analysis methodology was presented in Reference 6.

Subsequently YAEC performed a break spectrum study using the best-estimate model to identify the limiting break size and scenario. The case thus determined was submitted to the NRC for approval as the VYNPS Evaluation Model (EM) Sample Problem (Ref. 7). During the review of the analysis of that sample problem, NRC agreed that it was not necessary for YAEC to use heat transfer models conforming with Appendix K, and that alternate heat transfer models would be acceptable provided that they were justified by comparison to appropriate experimental data. Therefore, instead of using the conservative models listed in I.D.5 and 6 as acceptable, YAEC uses the best-estimate post-critical heat flux (CHF) heat transfer algorithm of RELAP5/MOD1 with YAEC modifications for its EM model and has provided qualification analysis and comparison to Two-Loop-Test-Apparatus (TLTA), Full Length Emergency Cooling Heat Transfer (FLECHT) and the Thermal Hydraulic Test Facility (THTF) tests to support their acceptability.

This technical evaluation report contains results of the review of the RELAP5YA heat transfer algorithm with respect to conditions I.D.5 and 6 of Appendix K for BWR applications in computation of heat transfer coefficients during the low flow steam heat transfer phase. The review was also conducted in the context of 10CFR50, Appendix K, Item I.C.5 requirements.

2.0 EVALUATION

2.1 Appendix K Conditions

The heat transfer coefficient calculational methodology contained in the RELAP5YA code was reviewed and evaluated with respect to the code's ability to satisfy the following two Appendix K conditions:

> Condition I.D.5
>
> Convective Heat Transfer Coefficients for Boiling Water Reactor Fuel Rods Under Spray Cooling: Following the blowdown period, convective heat transfer shall be calculated using coefficients based on appropriate experimental data.
>
> Condition I.D.5 further defines what convective coefficients are acceptable during (1) the period following lower plenum flashing but prior to the core spray reaching rated flow, (2) the period after core spray reaches rated flow but prior to reflooding, and (3) after the two-phase reflooding fluid reaches the level under consideration.
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> Condition I.D.6
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> The Boiling Water Reactor Channel Box Under Spray Cooling: Following the blow-down period, heat transfer from, and wetting of, the channel box shall be based on appropriate experimental data.
>
> Condition I.D.6 further defines what heat transfer coefficients and wetting time correlation are acceptable during (1) the period after lower plenum flashing but prior to the core spray reaching rated flow, (2) the period after core spray reaches rated flow but prior to wetting of the channel, and (3) wetting of the channel box assumed to occur 60 seconds after the time determined using the correlation based on the Yamanouchi analysis.

In both cases, however, instead of using the conservative models listed and identified as acceptable I.D.5. and 6, YAEC chose to use the best-estimate post-CHF heat transfer algorithm of RELAP5/MOD1. This is a direct result of a discussion at a meeting between YAEC and NRC on September 7, 1989, during which NRC staff stated that it was not necessary to use heat transfer models listed in Appendix K as acceptable, and that alternate heat transfer models would be acceptable provided that they were justified by comparison to appropriate data, subject to Condition I.C.5 requirements.

As to Condition I.D.5, RELAP5YA models the channel box as a normal heat structure in the RELAP5YA model of BWRs with convective boundary conditions on either side. Thus the heat transfer coefficients for the channel box under spray cooling conditions are determined by the normal RELAP5YA heat transfer algorithms for the hydrodynamic conditions calculated to exist at the channel box surfaces.

Therefore, determination of compliance of the heat transfer portions of the RELAP5YA VYNPS LOCA analysis to Conditions I.D.5 and I.D.6 focuses on review of RELAP5YA's ability to compute conservative heat transfer coefficients during all phases of a typical BWR LOCA scenario.

2.2 RELAP5YA Heat Transfer Algorithm

The Critical Heat Flux (CHF) option implemented in RELAP5YA uses two CHF correlations to cover the range of conditions expected during a LOCA in a BWR core. The Biasi Correlation modified for bundle geometry is used at high mass flux values. At low mass flux values the Griffith-Zuber Correlation is used. Interpolation between the two correlations provided values in the intermediate mass flux range.

Appendix K Condition I.C.4 requires that a code must prohibit or lockout return to nucleate boiling heat transfer once CHF has been predicted at an axial fuel rod location during blowdown. To satisfy this Appendix K requirement, the RELAP5 heat transfer algorithm was modified to include a lockout option in the return to nucleate boiling computation.

During the quench/rewet period, the nucleate boiling lockout can be overridden via the quench model determining that the node has quenched or by manually deleting the option on a problem restart. RELAP5YA incorporated a multiplier (XMNB) with a value between 0.0 and 1.0 which multiplies the calculated nucleate boiling heat transfer coefficient to degrade the heat transfer coefficient used. Use of 0.05 or less for XMNB was previously approved and is required by a prior SER (Refs. 3, 4).

Appendix K further requires that a code must lockout return to transition boiling during the blowdown phase of a LOCA even if the clad superheat returns below 300 F; nevertheless, during the reflood portion of the LOCA a return to transition boiling is acceptable when justified by the calculated local fluid and surface condition. Once the lockout has been calculated to have occurred, only film boiling heat transfer coefficients are applied at that heat structure surface. If, during the RELAP5YA computation, local conditions indicate that either the transition or nucleate boiling modes should be used, then the RELAP5YA logic will extrapolate the film boiling correlations into these regions to yield a degraded heat transfer coefficient.

Detailed review of both of these lockout options as well as other aspects of RELAP5YA heat transfer algorithm was performed during previous reviews (Refs. 3, 4) of the code and was not repeated during this review.

2.3 Assessment through Benchmark against Experimental Data

Conformity to the Appendix K requirements of the RELAP5YA predicted heat transfer coefficients during a BWR LOCA was assessed by the licensee by comparison to two sets of integral test data obtained at the TLTA at General Electric Company (GE). Although there is only limited data generally available, the range of test parameters (pressure, mass flux, wall temperatures and fluid conditions) encountered during these tests encompass the range of parameters expected during the VYNPS EM calculation except for the wall temperatures.

The logic for selecting heat transfer correlations and the adequacy of the correlations in superheated steam conditions was assessed by the licensee by comparison to data from the FLECHT Facility at Westinghouse and the THTF at Oak Ridge National Laboratory.

2.3.1 TLTA Test Benchmark

Performed at General Electric, TLTA tests approximated 8x8 fuel assembly designs in a BWR/6 to simulate several accident scenarios for both large and small breaks with the Emergency Core Cooling Systems (ECCS).

Two tests, 6426/1 and 6425/2, were selected as appropriate for assessment of the RELAP5YA heat transfer algorithm and post-CHF correlation during low flow post-CHF conditions.

Test 6426/1 simulated a large break design base accident for a BWR/6 with average bundle power assuming no emergency core cooling (ECC). Test 6425/2, was similar to 6426/1 but included ECC availability simulating both top and bottom rewet.

Benchmark analyses were performed by the licensee using a nucleate boiling multiplier of 0.1, instead of 0.05 which had been suggested by INEL as necessary to produce conservative results (Ref. 3).

2.3.1.a TLTA 6426/1 Test - Large Break LOCA with No ECC

The test conditions for TLTA 6426/1 best resemble those conditions expected in BWR LOCA analysis (Ref. 8) and permit assessment of the post-CHF heat transfer algorithm. This test was significant since the peak cladding temperature (PCT) for VYNPS LOCAs was computed by YAEC to occur during the heatup phase of the transient with no ECC, therefore simulation of heat transfer coefficients and clad heat-up rate are of great importance.

The YAEC RELAP5YA calculation was begun at a lower mass inventory level. An error was uncovered in the earlier licensee responses and materials which had caused predicted clad temperatures to have a non-conservative diverging trend during the heatup phase. Corrected plots comparing the predicted cladding temperatures with the measured data were presented by YAEC for selected elevations (Ref. 9). For this benchmark, the core nodalization was selected in such a way that each of the middle three computational nodes would contain the location of test thermal-couple. The predicted cladding temperatures agreed well with the measured data, although at the node above the one containing the peak cladding temperature, the predicted rate of temperature rise was less than the data. This underprediction was said by YAEC to be due to the fact that the thermal-couple was not at the center of the computional node.

YAEC stated further that for each licensing analyses, conservative assumptions made for selection of input, such as power level, decay heat multiplier and discharge coefficient, as well as code options such as heat transfer lock out, would result in conservative prediction.

2.3.1.b TLTA 6425/2 Test - Large Break LOCA with ECC (top and bottom quench test)

YAEC performed an assessment study for this test using both the best estimate (BE) and evaluation model (EM) methodologies. Detailed discussion of evaluation of the study was provided in Reference 3. Good agreement between the test data and BE calculations was obtained for this test. Use of the EM model resulted in conservative PCT predictions. In both cases key phenomena were predicted by RELAP5YA.

2.3.2 THTF Test Benchmark

The THTF test program at ORNL was conducted to investigate important phenomena under large and small break PWR LOCA conditions and provide data on heat transfer to steam at low steam flow rates in heated rod bundles. The experiments produced steady-state data on wall and vapor temperatures at constant pressures, flowrates and wall heat fluxes. Thus they provide a means for direct assessment of heat transfer coefficient correlations at these conditions. Similarly, FLECHT tests data were used for the same purpose in a different range of parameters.

To assess RELAP5YA against test data, the RELAP5YA heat transfer algorithm for post-CHF heat transfer was programmed separately. This program was set up to provide heat transfer coefficients for a given pressure, hydraulic diameter, mass flux, wall temperature and vapor temperature. For each set of test conditions, the calculated heat transfer coefficients from the program were compared to those obtained in the test.

The ratios of the RELAP5YA heat transfer coefficients to the experimental data were plotted versus the dimensionless parameter of Grashoff number (Gr) divided by the square of the Reynolds number (Re). The ratio is used as an indicator of natural convection; natural convection is dominant when the ratio exceeds 3.0, whereas at lower values forced convection is more dominant. YAEC used FLECHT and THTF data to benchmark its heat transfer correlations. The FLECHT data are more applicable to the forced convection region and the THTF data to the natural convection region. The PCT in a LOCA occurs while the core is uncovered and pin cooling is by very low flows of steam, and is therefore in natural convection. There are two regions of data/code prediction disagreement in Gr/Re^2: less than 0.01 and greater than 1.0. Conditions corresponding to <0.01 are not expected to be encountered during the relevant portions of a typical BWR LOCA scenarios (since those correspond to forced flow conditions), but the ratio is instead strongly expected to be in the 10^2 - 10^4 range which is natural convection.

A good overall comparison (in a best-estimate sense) was demonstrated for the RELAP5YA heat transfer correlations against data for the natural convection region. In the steam heat transfer regime, the RELAP5YA computed heat transfer was conservative for ten of the eleven data points presented (Ref. 10). The following analysis is applied to assessment of the impact of the one slightly non-conservative data point. Three of the eleven data points presented (including the one for which a non-conservative result was obtained) were in very nearly the same transfer regime (as indicated by Gr/Re^2). These three data points are approximately assessed by examining their mean. Two of these predicted data points are significantly less than the measured value. Therefore, a mean value taken for those three computations would be less than the measured data. For the balance of the applicable range of the THTF experiment, the RELAP5YA heat transfer correlation predicts less heat transfer than that measured. Furthermore, its predictions of wall temperatures for the same experiment are generally more conservative with increasing temperatures. Therefore, Condition I.C.5(a) to Appendix K to 10CFR50, with respect to qualification of the Post-CHF Heat Transfer Correlations, is satisfied for the range of the presented THTF data. 10CFR50 Appendix K Section I.C.5(a) also requires the user to "quantify the relation of the correlations to the statistical uncertainty of the applicable data". YAEC provided the uncertainty range of test data to which the computed wall temperatures are compared.

3.0 SUMMARY

This report covers the review and evaluation of the heat transfer modeling capabilities of the Yankee Atomic Electric Company (YAEC) computer code, RELAP5YA (Ref. 1), to simulate the full spectrum of LOCAs for licensing analysis applicable to the Vermont Yankee Nuclear Power Station.

RELAP5YA is based on RELAP5/MOD1 (Ref. 2) Cycle 18 which was originally developed and released by the Idaho National Engineering Laboratory (INEL) in 1983. YAEC has incorporated into its version significant modifications to incorporate features which permit compliance with requirements in 10CFR50.46 and Appendix K. The code and the LOCA licensing analysis model were previously submitted by YAEC for NRC review and approval. In connection with that previous submittal, RELAP5YA was reviewed and approved for use in both best-estimate and licensing BWR LOCA analysis (Refs. 3, 4). However, the NRC concluded that requirement II.5 of Appendix K was not satisfied by the evaluation model submitted by YAEC and that YAEC's evaluation model (EM) was found to be acceptable only in the SECY 83-472 (Ref. 5) sense.

The review presented in this report addresses only those aspects of heat transfer relevant to BWR related LOCA licensing analysis and their compliance to Conditions I.C.5 and I.D.6 of Appendix K (Refs. 6 - 11) of 10CFR50. It is focused solely upon the ability of RELAP5YA to predict heat transfer during simulation of the worst case BWR LOCA for licensing analysis.

The ability of the RELAP5YA heat transfer algorithms to compute heat transfer coefficients was reviewed to assure that the requirements of Item I.C.5 of Appendix K were satisfied. RELAP5YA predictions of wall temperatures and heat transfer coefficients were compared against selected TLTA and THTF test data. Generally, differences between the calculated and experimental wall temperatures grew larger at higher temperatures even after the data uncertainty was considered, with calculated wall temperatures being generally higher than the experimental data. Similarly, the heat transfer coefficients were computed to be generally less than those measured during the tests.

Based upon this review, it was found that the RELAP5YA provides sufficient assurances of conservatism, thus, is approved for use in RELAP5YA applications as a licensing code for performing BWR large break LOCA analyses.

4.0 CONCLUSIONS AND LIMITATIONS

The review completes the evaluation of the Vermont Yankee LOCA analysis methodology and the partial evaluation of the RELAP5YA code documented in Reference 4. RELAP5YA as documented in References: 1, 6-11, 13 and the restriction of Reference 12 is now acceptable for referencing in Vermont Yankee licensing applications covering the entire spectrum of LOCAs and satisfying the Appendix K requirements. The staff recommends that the licensee incorporates all of the information in the above submittals in a revised version of Ref. 13. The following is a summary of the limitations including the previous (Ref. 4) SER and the present review.

1. The licensee is required to demonstrate that convergence of core nodalization and time step size has been achieved for each plant specific licensing analysis.

2. Coding restrictions in items 1, 2 and 4 in section 2.3 of Reference 4, are applicable. (Item 3 has been removed in the HUXY SER, see Reference 14).

3. The treatment of the Vermont Yankee RELAP5YA separator component is limited to the multi-component separator model used in the Vermont Yankee sample problem presented in Reference 4 and YAEC-1547.

4. The staff requires that the version of RELAP5YA as described in references 1, 6-11 and 13 be protected with appropriate quality assurance procedures, subject to auditing by the staff.

5. The use of RELAP5YA and the associated NSSS and HC model is contingent on staff approval at the FROSTEY-2 code or an equivalent staff approved fuel performance code.

5.0 REFERENCES

1. "RELAP5YA - A Computer Program for Light-Water System Thermal-Hydraulic Analysis," Yankee Atomic Electric Company Report YAEC-1300P, October 1982.

2. RELAP5/MOD1 Code Manual, EG&G Idaho Inc., NUREG/CR-1826, EGG-2070, November 1980.

3. Letter from P. Wheatley (INEL) to M. Carrington (NRC), "Transmittal of the Final TER for RELAP5YA Code Review," June 30, 1987. ("Technical Evaluation Report: Report and Evaluation of the RELAP5YA Computer Code and the Vermont Yankee LOCA Analysis Model for Use in Small and Large Break BWR LOCAs," EGG-RTH-7506, JUNE 1987)

4. Letter from V. L. Rooney (NRC) to R. W. Capstick (VYNPS), "Approval of Use of Thermal-Hydraulic Code RELAP5YA (TAC NO. 60193)," August 25, 1987

5. Letter from W. J. Dircks (NRC) to the Commissioners (USNRC), "Emergency Core Cooling System Analysis Methods," SECY 83-472, November 17, 1983.

6. Letter from L. A. Tremblay (YAEC) to USNRC, "Supplementary Information Regarding NRC LOCA Analyses Review Effort," March 9, 1990.

7. Letter from L. A. Tremblay (YAEC) to USNRC "Responses to June 7, 1990 NRC requests for Additional Information on RELAP5YA", July 1990.

8. Letter from L. A. Tremblay, Jr. (YAEC) to USNRC, "Responses to Second Request for Additional Information on the Use of RELAP5YA," January 9, 1991.

9. Letter from L. A. Tremblay, Jr. (YAEC) to USNRC, "Responses to Third Request for Additional Information on the Use of RELAP5YA," April 19, 1991.

10. Letter from L. A. Tremblay, Jr. (YAEC) to USNRC, "Responses to Fourth Request for Additional Information on the Use of RELAP5YA," July 9, 1991.

11. Letter from L. A. Tremblay, Jr. (YAEC) to USNRC, "Supplementary Information Regarding the Use of RELAP5YA," February 7, 1992.

12. Letter from L. A. Tremblay, Jr. (YAEC) to USNRC, "RELAP5/MOD3 Computer Code Error Associated with the Conservation of Energy Equation," March 6, 1992.

13. "Vermont Yankee BWR Loss-of-Coolant Accident Licensing Analysis Method" YAEC-1547, by R.T. Fernandez and H.C. deSilva Jr., June 1986.

14. Letter from M. Fairtile (USNRC) to L. A. Tremblay, Jr. YAEC "HUXY Safety Evaluation", February 27, 1991.

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