CEOG COMBUSTION ENGINEERING OWNERS GROUP

CENPD-279
SUPPLEMENT 9

ANNUAL REPORT ON ABB CE ECCS PERFORMANCE EVALUATION MODELS

FINAL REPORT

CEOG TASK 1024

prepared for the
C-E OWNERS GROUP

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ABB Combustion Engineering Nuclear Operations

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ABSTRACT

This report describes changes and errors in the ABB Combustion Engineering evaluation models for ECCS performance analysis in 1997 per the requirements of 10CFR50.46. For this reporting period, there were four sets of reportable changes or errors in the evaluation models or application of the models:

1. All of the ECCS performance analysis codes were converted to HP workstations operating under the HP/UX operating system. This had no effect on the peak cladding temperature (PCT).
2. A change in the implementation of the methodology for small break LOCA (SBLOCA) ECCS performance analysis was made to improve the analysis process which would introduce a 3°F cumulative change in PCT for SBLOCA when the new process is used for the analysis of record.
3. An error in the implementation of the boric acid concentration calculation with flushing flow for both large and small break LOCA was found and corrected. This affected the post-LOCA boric acid concentration but is unlikely to affect the time to initiate combined hot-side/cold-side injection for LBLOCA. It had no effect on the boric acid precipitation conclusions for SBLOCA. Hence, there is no effect on core coolability or PCT.
4. An error in the decay heat energy redistribution factor used for large break LOCA ECCS performance analysis was found and corrected. This required compensatory action such as a reduction in the maximum linear heat generation rate, a reduction in the pin-to-box factor margin, or other action to maintain the applicability of the analyses of record and meet the ECCS acceptance criteria.

The following summary describes the generic status of the ABB CE ECCS performance analysis methodology. The sum of the absolute magnitude of the PCT changes for large break LOCA from all reports to date, except for the effect of the decay heat energy redistribution factor (ERF) error, continues to be less than 1°F. The effect of the ERF error is plant specific so the total LBLOCA PCT impact for each plant is the sum of 1°F and the plant specific contribution given in Appendices A through E. The sum of the absolute magnitude of the maximum cladding temperature changes for small break LOCA from all reports to date is less than 3°F. No change occurred in the PCT for post-LOCA long term cooling. Per the criteria of 10CFR50.46, no action beyond this annual report is required for the generic results.

The impact of the error in the ERF for large break LOCA is plant specific. The nature of the error, how it was resolved, and an approximation of the impact of the error on PCT is provided herein. Plant specific evaluation is needed to fully quantify the impact of this error for a complete response to the requirements of 10CFR50.46.

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1.0 INTRODUCTION

This report addresses the NRC requirement to report changes or errors in ECCS performance evaluation models. The ECCS Acceptance Criteria, Reference 1, spells out reporting requirements and actions required when errors are corrected or changes are made in an evaluation model or in the application of a model for an operating licensee or construction permittee of a nuclear power plant.

The action requirements in 10CFR50.46(a)(3) are:

1. Each applicant for or holder of an operating license or construction permit shall estimate the effect of any change to or error in an acceptable evaluation model or in the application of such a model to determine if the change or error is significant. For this purpose, a significant change or error is one which results in a calculated peak fuel cladding temperature (PCT) different by more than 50°F from the temperature calculated for the limiting transient using the last acceptable model, or is a cumulation of changes and errors such that the sum of the absolute magnitudes of the respective temperature changes is greater than 50°F.

2. For each change to or error discovered in an acceptable evaluation model or in the application of such a model that affects the temperature calculation, the applicant or licensee shall report the nature of the change or error and its estimated effect on the limiting ECCS analysis to the Commission at least annually as specified in 10CFR50.4.

3. If the change or error is significant, the applicant or licensee shall provide this report within 30 days and include with the report a proposed schedule for providing a reanalysis or taking other action as may be needed to show compliance with 10CFR50.46 requirements. This schedule may be developed using an integrated scheduling system previously approved for the facility by the NRC. For those facilities not using an NRC approved integrated scheduling system, a schedule will be established by the NRC staff within 60 days of receipt of the proposed schedule.

4. Any change or error correction that results in a calculated ECCS performance that does not conform to the criteria set forth in paragraph (b) of 10CFR50.46 is a reportable event as described in 10CFR50.55(e), 50.72 and 50.73. The affected applicant or licensee shall propose immediate steps to demonstrate compliance or bring plant design or operation into compliance with 10CFR50.46 requirements.

This report documents all the errors corrected in and/or changes to the presently licensed ABB CE ECCS performance evaluation models, made in the year covered by this report, which have not been reviewed by the NRC staff. This document is provided to satisfy the reporting requirements of the second item above. ABB CE reports for earlier years are given in References 2-10.

2.0 ABB CE CODES USED FOR ECCS EVALUATION

ABB CE uses several digital computer codes for ECCS performance analysis that are described in topical reports, are licensed by the NRC, and are covered by the provisions of 10CFR50.46. Those for large break LOCA calculations are CEFLASH-4A, COMPERC-II, HCROSS, PARCH, STRIKIN-II, and COMZIRC. CEFLASH-4AS is used in conjunction with COMPERC-II, STRIKIN-II, and PARCH for small break LOCA calculations. The codes for post-LOCA long term cooling analysis are BORON, CEPAC, NATFLOW, and CELDA.

3.0 EVALUATION MODEL CHANGES AND ERROR CORRECTIONS

This section discusses all error corrections and model changes to the ABB CE ECCS performance evaluation models which may affect the calculated PCT.

3.1 Code Conversion

All of the NRC licensed codes and related utility programs used for ECCS performance analysis were converted from operation on Hewlett Packard (HP) Apollo workstations (WS) operating under the Domain operating system (OS) to HP WS operating under the HP/UX operating system. The coding changes to maintain numeric precision and comply with FORTRAN programming conventions described in the 1992 code conversion, Reference 6, were preserved. A few changes to the FORTRAN coding were necessary to accommodate differences in FORTRAN compiler implementations and replace non-standard coding with standard coding. Some new edits were added to facilitate use of the codes. The code version numbers and implementation dates were adjusted to maintain unique identification of the new code versions. Except for one new procedure for small break LOCA described in Section 3.2, no changes were made to the models or their implementation.

The same procedures used to validate the converted codes in the 1992 conversion, Reference 6, were used in this conversion. Direct comparison of all results from runs on the HP Apollo computers with those from the new HP computers were made with an acceptance criterion of 0.01% when feasible. For some codes, such as those that compute their own time step lengths, a direct comparison of all output is not possible due to differences in the times at which results are reported. In such cases, comparison of key parameters passed on to subsequent steps in the analysis, objective parameters such as PCT and peak cladding oxidation, or graphical comparison of the time history of important parameters are used to validate the converted codes.

3.1.1 Large Break LOCA

The only changes made to the ECCS performance analysis codes used for large break LOCA (LBLOCA) analysis are those required to make them function on the new computers, add new edits, and provide unique version identification. No changes to the models used for large break LOCA analysis or their implementation were made. The overall impact of the conversion was no change in PCT to the precision of the printed results, <0.01°F.

3.1.2 Small Break LOCA

One change was made to the ECCS performance analysis codes used for small break LOCA (SBLOCA) analysis beyond those required to make them function on the new computers, add new edits, and provide unique version identification. That change and its impact on peak cladding temperature, including the impact of code conversion is discussed in Section 3.2.

3.1.3 Post-LOCA Long Term Cooling

The only changes made to the ECCS performance analysis codes used for post-LOCA long term cooling analysis are those required to make them function on the new computers, add new edits, and provide unique version identification. No changes to the models or their implementation were made. The overall impact of the conversion was no significant change to any result. Hence, there was no effect on peak cladding temperature due to conversion of the post-LOCA long term cooling codes.

3.2 Automation of Data Transfer for Small Break LOCA Analysis

As part of the code conversion process, one change was made to the ECCS performance analysis codes used for SBLOCA analysis beyond those required to make them function on the new computers, add new edits, and provide unique version identification. An option was added to transfer the core boundary conditions computed by the CEFLASH-4AS blowdown hydraulics computer code to the hot rod heatup code PARCH via a file created by CEFLASH-4AS and read by PARCH. Previously, the procedure had been to manually transfer up to 50 values of each boundary condition from CEFLASH-4AS to PARCH. These two codes were revised to transfer 2000 evenly spaced values in time during the transient for core pressure, coolant mixture level, coolant mass, and power from CEFLASH-4AS to PARCH in a disk file. The revised process for data transfer provides a more accurate and efficient method of transferring the data. In a sample calculation, this change produced a 2.4°F reduction in maximum cladding temperature during the transient.

3.3 Post-LOCA Boric Acid Concentration

An error in the calculation of the boric acid concentration for post-LOCA long term cooling was found in the BORON code for LBLOCA and in the CELDA code for SBLOCA. The error affects the boric acid concentration in the reactor core and the sump when the hot side injection flow rate exceeds the boil-off rate in the core. It does not affect the results before recirculation between the sump and reactor vessel as described below.

Once recirculation between the sump and reactor vessel begins, after the boric acid storage or makeup tanks (BASTs) and refueling water tank (RWT) empty, the BORON code calculates the boric acid concentration in the reactor vessel and sump from the following differential equations, p. C-10 in Reference 11:

$$dB_{COR}/dt = (W_{OUT} \times B_{SUMP} - W_{IN} \times B_{COR}) / V_R$$

$$dB_{SUMP}/dt = (W_{IN} \times B_{COR} - W_{OUT} \times B_{SUMP}) / V_{SGAL}$$

where

B_{COR}	boric acid concentration in core (wt%)
B_{SUMP}	boric acid concentration in sump (wt%)
V_R	volume of liquid water in reactor vessel (gallons)
V_{SGAL}	volume of water in sump (gallons)
W_{IN}	flow rate into sump (gpm)
W_{OUT}	flow rate from sump (gpm)

The CELDA code finds the boric acid concentrations using the same methodology.

In the original implementation of the BORON and CELDA codes, the flow rate into the sump and out of the sump were found, respectively, as

$$W_{IN} = W_{FLUSH}$$
$$W_{OUT} = W_{BOIL}$$

where

W_{BOIL}	boil-off rate (gpm)
W_{FLUSH}	flushing flow rate (gpm)

The flow rate out of the sump into the core should include the flushing flow rate as well as the boil-off rate or

$$W_{OUT} = W_{BOIL} + W_{FLUSH}$$

This change was implemented in the BORON and CELDA codes. The effect of correcting the codes is discussed below.

3.3.1 Effect of Error for LBLOCA Boric Acid Concentration

The BORON code finds the boric acid concentration in the core after a LBLOCA. The effect of the error in W_{OUT} depends on the timing of hot side injection and the magnitude of the flow. Two examples are used to illustrate this point.

The first example initiates hot side injection with a flow rate sufficient to exceed the boil-off rate at the time hot side injection begins. The boric acid concentration in the core for this case is shown in Figure 1 for the erroneous and corrected calculation. The correction has no effect on the maximum boric acid concentration although it shows a slower rate of decrease than the erroneous implementation of the boric acid concentration model.

The second example initiates hot side injection with a flow rate less than the boil-off rate at the time injection begins. Figure 2 shows that the core boric acid concentration continues to rise until nearly four hours with injection starting at three hours. The corrected maximum boric acid concentration is about 0.22 wt% higher and occurs about one-tenth of an hour later. Consistent with the results of the first example, the rate of decrease is slower with the corrected model.

Results similar to those reported in Figures 1 and 2 are expected for all post-LOCA boric acid precipitation analyses performed by ABB CE although the magnitude of the results would differ from plant to plant. The effect of the error shown in Figure 2 is small compared to the difference between the maximum calculated boric acid concentration for ABB CE plants and the associated solubility limit.

3.3.2 Effect of Error for SBLOCA Boric Acid Concentration

CELDA includes a copy of the BORON coding as a subroutine with revisions to link it to the overall CELDA hydraulics calculation. The BORON subroutine is run at the end of the CELDA calculation to evaluate boric acid concentration using flushing flows calculated by CELDA. The corrected code gives a maximum boric acid concentration about 0.1 wt% higher than the erroneous implementation of the boric acid concentration model. This increase is insignificant in comparison to the margin to the boric acid solubility limit for the SBLOCA boric acid concentration analysis.

3.4 Decay Heat Energy Redistribution Factor Error

An error in the decay heat energy redistribution factor (ERF) for voided conditions used in the large break LOCA analysis was discovered and corrected in 1997, References 12 and 13. The ERF is defined as the ratio of the fission energy deposited in the hot fuel rod divided by the

energy generated in the hot rod. Typical values range from 0.92 to 0.98 depending on the hot rod pin-to-box ratio.

As described in the ABB CE large break LOCA evaluation model topical report (Reference 14) the ERF used in the large break LOCA evaluation model includes the effect of moderator voiding. Because of fuel design changes made in the 1970s which produced flatter power distributions with the hot rod no longer adjacent to a guide tube, ABB CE calculated new values for the ERF for both fission and decay heat power. Erroneously, the calculations did not include the effect of moderator voiding on the recalculated values for the decay heat ERFs.

The magnitude of the error in ERF is dependent on the pin-to-box ratio and pin lattice as shown in the table below. A generic approximation of the effect on PCT can be made based on an observed sensitivity of about 40°F in PCT per 1% change in ERF for a typical plant where the limiting PCT occurred during the reflood phase of the event.

Pin/Box	14x14 Fuel Assembly ERF Change (%)	16x16 Fuel Assembly ERF Change (%)
1.03	1.3	1.0
1.10	1.0	0.7

ABB CE Infobulletin 97-04, Reference 12, and its status updates provide additional information regarding the ERF error. A plant specific discussion of the ERF error is given in Appendices A through E.

Figure 1

Initial Hot-Side Injection Rate Exceeds Boil-off Rate

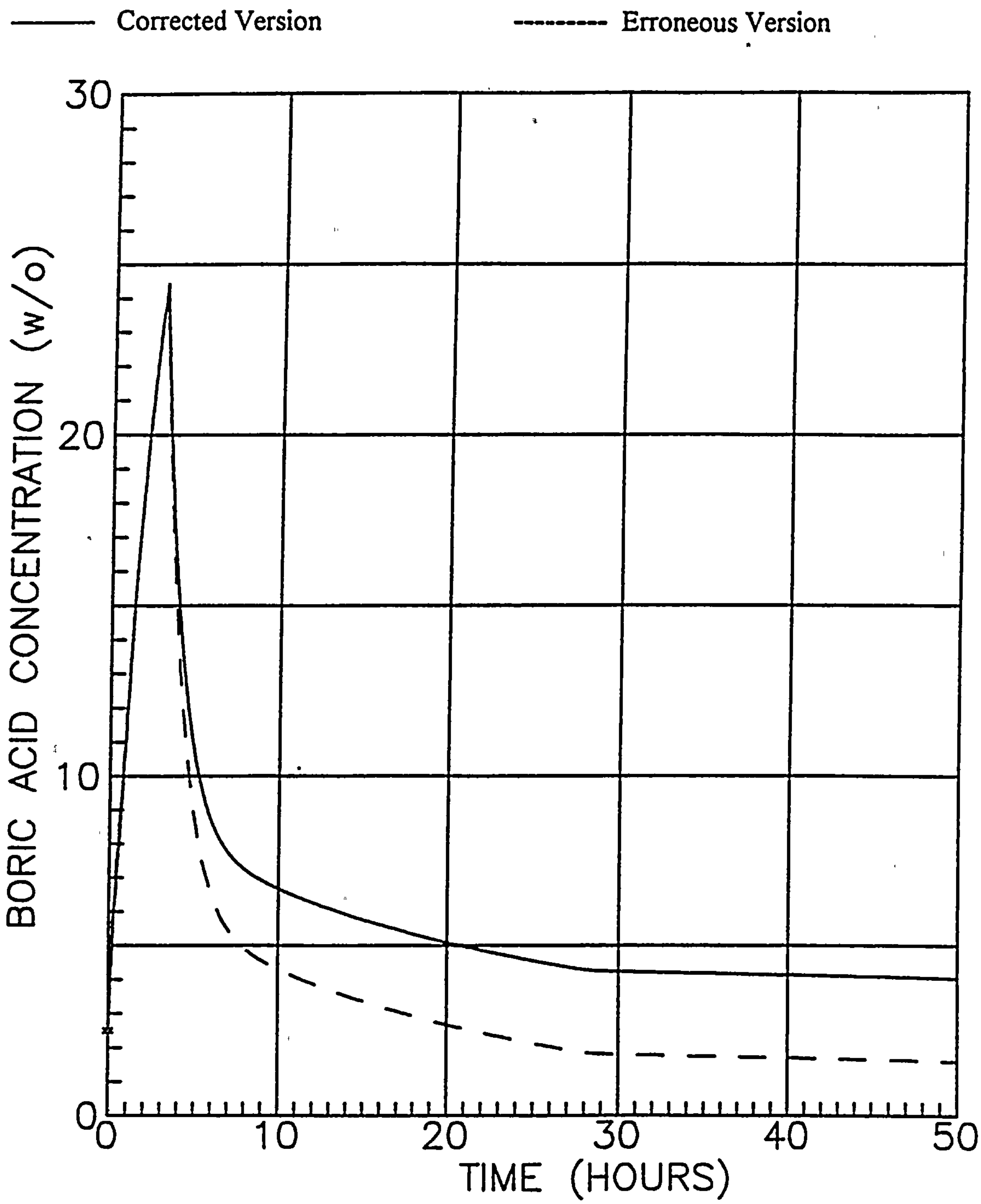
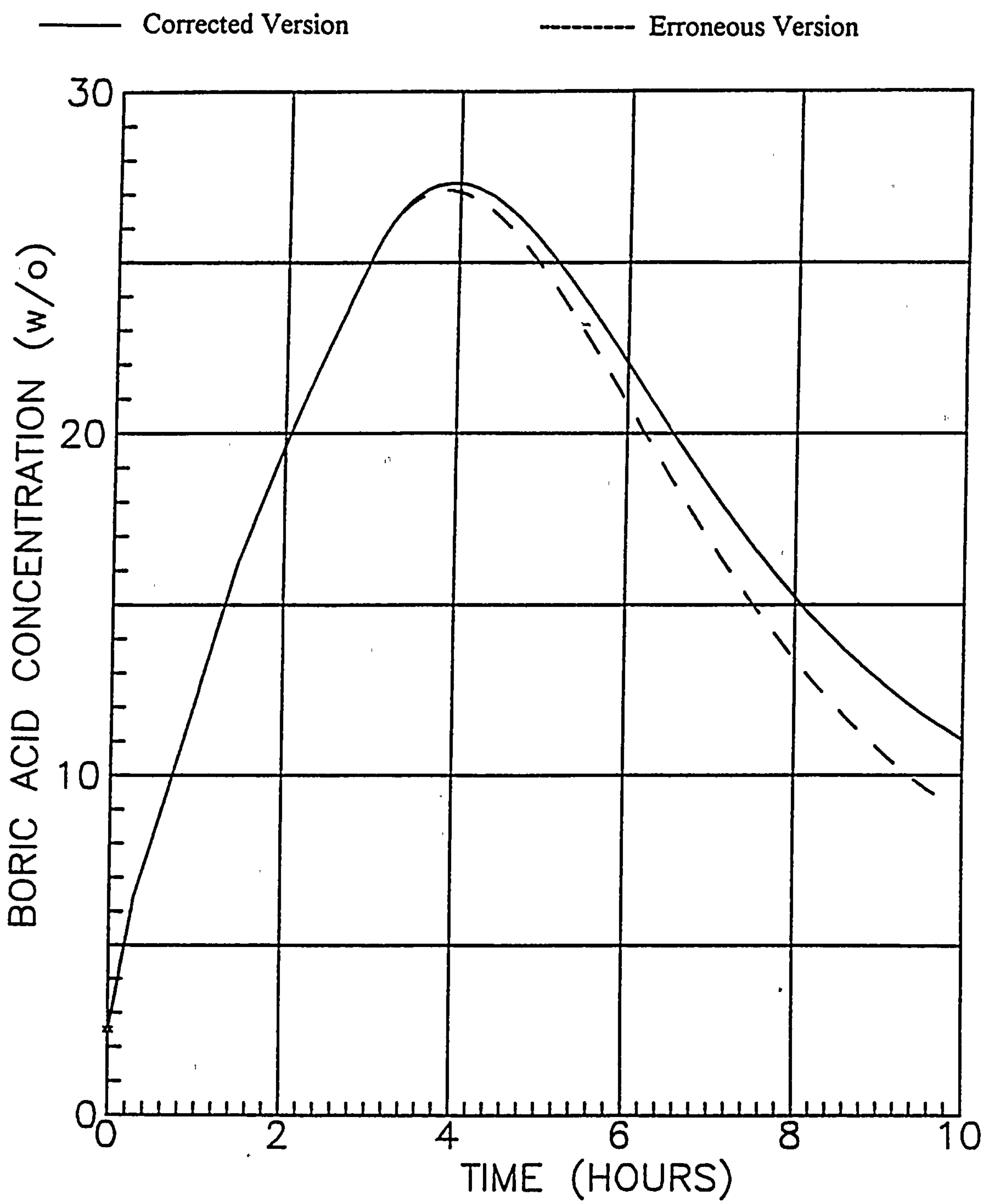


Figure 2

Initial Boil-off Rate Exceeds Hot-Side Injection Rate



4.0 CONCLUSIONS

All of the codes used in the ABB CE ECCS performance evaluation model were converted to HP workstations operating under the HP/UX operating system and one change in the application of the evaluation model for SBLOCA occurred in 1997. In addition, two errors were identified -- one for post-LOCA long term cooling and one for LBLOCA.

The change in computers used to run the ABB CE ECCS performance analysis computer codes produced no changes in the PCT for LBLOCA, SBLOCA, or post-LOCA long term cooling. Excluding plant specific effects due to the error in ERF, the sum of the absolute magnitude of the changes in PCT calculated using the ABB CE ECCS evaluation models, including those from previous annual reports, References 2-10, remains less than 1°F for LBLOCA. The total LBLOCA PCT impact for a given plant is 1°F plus the plant specific effect of the ERF error given in Appendices A through E.

The change in the application of the SBLOCA model combined with the effects from previous annual reports, References 2-10, produce a cumulative change in maximum cladding temperature for SBLOCA of less than 3°F. This change in the application of the SBLOCA model was not applied to any Analysis of Record (AOR) in 1997.

An error was discovered and corrected in the computer codes that calculate the post-LOCA boric acid concentration in the core. The error has minimal or no impact on the margin between the maximum calculated boric acid concentration for ABB CE plants and the associated solubility limit. Correction of the error in boric acid concentration has no effect on the PCT.

A generic statement applicable to all plants for the impact of the ERF error on PCT is not possible. The approximate increase in PCT for the lattices and range of pin-to-box ratios reported in the table in Section 3.4 is 28 to 52°F but the results depend on the lattice and the pin-to-box factor. A 0.2 kW/ft reduction in the PLHGR or other compensatory actions could support the existing AOR. Plant specific information about the PCT impact of the error in ERF and the actions taken by each plant licensee to address the error is given in Appendices A through E.

5.0 REFERENCES

1. "Acceptance Criteria for Emergency Core Cooling Systems for Light Water Nuclear Power Reactors," Code of Federal Regulations, Title 10, Part 50, Section 50.46.

2. "Annual Report on C-E ECCS Codes and Methods for 10CFR50.46," CENPD-279, April, 1989.

3. "Annual Report on C-E ECCS Codes and Methods for 10CFR50.46," CENPD-279, Supplement 1, February, 1990.

4. "Annual Report on C-E ECCS Codes and Methods for 10CFR50.46," CENPD-279, Supplement 2, April, 1991.

5. "Annual Report on C-E ECCS Codes and Methods for 10CFR50.46," CENPD-279, Supplement 3, April, 1992.

6. "Annual Report on C-E ECCS Codes and Methods for 10CFR50.46," CENPD-279, Supplement 4, April, 1993.

7. "Annual Report on C-E ECCS Codes and Methods for 10CFR50.46," CENPD-279, Supplement 5, February, 1994.

8. "Annual Report on ABB C-E ECCS Performance Evaluation Models," CENPD-279, Supplement 6, February, 1995.

9. "Annual Report on ABB C-E ECCS Performance Evaluation Models," CENPD-279, Supplement 7, February, 1996.

10. "Annual Report on ABB C-E ECCS Performance Evaluation Models," CENPD-279, Supplement 8, February, 1997.

11. "Post-LOCA Long Term Cooling Evaluation Model," CENPD-254-P-A, June 1980.

12. "Potential Error in the Energy Redistribution Factor Used in LOCA Analysis," Combustion Information Bulletin 97-04, Rev. 01, July 11, 1997.

13. "Report Pursuant to 10CFR21 Regarding Error in the Energy Redistribution Factor Used in LOCA Analysis," LD-97-024, August 14, 1997.

14. "Calculative Methods for the C-E Large Break LOCA Evaluation Model," CENPD-132P, August 1974.

APPENDIX A

ARIZONA PUBLIC SERVICE COMPANY

Effect of ERF Error on PCT for Palo Verde Units 1, 2 and 3

Introduction

As described in Section 3.4, a non-conservative error in the decay heat energy redistribution factor (ERF) which could lead to an underprediction of peak cladding temperature (PCT) was discovered and corrected. Persuant to the requirements of 10CFR 21, the NRC was notified of the error in the ERF by Reference 1 which stated that the peak cladding temperature could be underestimated by 20 to 60°F. Licensees using the ABB CE LBLOCA evaluation model were informed that the validity of their analyses of record (AOR) would be maintained provided that the margin to the peak linear heat generation rate (PLHGR) is at least 0.2 kW/ft.

Effect

In Reference 2 APS notified the NRC that preliminary calculations by ABB CE showed that the effect of the error in ERF would be an increase in the PCT of 30°F for the PVNGS units. Reference 2 also said that the allowable peak linear heat generation rate (PLHGR) for the PVNGS units was reduced by 0.2 kW/ft which would make the resulting calculated PCT, including the ERF error, less than the licensing limit of 2200°F. Subsequent ABB CE calculations specific to the PVNGS units confirmed that decreasing the PLHGR from 13.3 to 13.1 kW/ft produced a PCT less than 2200°F. These calculations were forwarded to PVNGS to support final resolution of the ERF error.

Conclusion

A PVNGS specific analysis using the corrected ERF and a 0.2 kW/ft reduction in PLHGR demonstrates conformance to the 10CFR50.46 acceptance criteria.

References:

1. Letter from I. C. Rickard (ABB-CE) to Document Control Desk (USNRC), "Report Pursuant to 10CFR21 Regarding Error in the Energy Redistribution Factor Used in LOCA Analysis," LD-97-024, August 14, 1997.
2. Letter, S. A. Bauer (APS) to Document Control Desk (USNRC), "Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2 and 3, Docket Nos. STN 50-528/529/530, Error in Energy Redistribution Factors Used in LOCA/ECCS Performance Evaluation Models, 30 Day 10CFR50.46 Report," 102-04011 - WEI/SAB/RMW, September 14, 1997.