Evaluation of Loop Seal Reformation and Clearing for APR1400

Revision 0

Non-Proprietary

October 2016

Revision History

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ABSTRACT

This technical report is prepared for response to NRC RAI 143-8092 “Core Cooling during Small Break LOCA with Deep Loop Seal Design”. And this report presents the loop seal reformation analysis with small break loss of coolant accident (SBLOCA) analysis methodology that is used in Section 15.6.5 of the design certification document (DCD) Tier2 for the APR1400.

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The contents of this document include description of the computer code, analysis methodology, and results of the APR1400 loop seal reformation analysis.

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ACRONYMS AND ABBREVIATIONS

CFR	Code of Federal Regulations
CL	cold leg
DCD	design certification document
DVI	direct vessel injection
ECCS	emergency core cooling system
EDG	emergency diesel generator
HL	hot leg
HP	high pressure safety injection pump
LOCA	loss-of-coolant accident
LP	low pressure safety injection pump
LS	loop seal
NRC	Nuclear Regulatory Commission
PCT	peak clad temperature
RCS	reactor coolant system
SBLOCA	small break LOCA
SG	steam generator
SIP	safety injection pump
SIT	safety injection tank

1.0 INTRODUCTION

General Design Criterion (GDC) 35, “Emergency Core Cooling,” in 10 CFR Part 50, Appendix A, mandates the requirements for the emergency core cooling system (ECCS) that need to be satisfied by conforming to the ECCS acceptance criteria for light-water reactors given in 10 CFR 50.46 [4], “Acceptance Criteria for Emergency Core Cooling Systems for Light-water Nuclear Power Reactors.” 10CFR50.46(b)(1) identifies the peak cladding temperature (PCT) requirement; and 10CFR50.46(b)(5) requires that after any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time to prevent the core from being uncovered.

APR1400 DCD Section 15.6.5, “Loss-of-Coolant Accidents Resulting from the Spectrum of Postulated Piping Breaks within the Reactor Coolant Pressure Boundary,” and the referenced Technical Report APR1400-F-A-NR-14001-P, “Small Break LOCA Evaluation Model,” describe the analysis results of the small-break LOCA (SBLOCA) evaluation and core cooling with a deep loop seal, at a high level. This report provides the technical basis to establish that the analysis methodology and applied computer codes conservatively characterize the safety-significant phenomena of loop seal formation and clearing, and peak cladding temperature during a limiting SBLOCA, for potential core reheat and secondary cladding temperature rise.

CEFLASH-4AS node diagram for this analysis is shown in Figure 1-1. And general system parameters and initial conditions for SBLOCA are described in Table 1-1.

Figure 1-1 CEFLASH-4AS Node Diagram

Table 1-1 Major System Parameters and Initial Conditions for SBLOCA Analysis

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2.0 ACCEPTANCE CRITERIA

The core reheated temperature due to loop seal reformation and clearing phenomena should be below 800 °F in the APR1400 plants.

3.0 ASSUMPTIONS

In CEFLASH-4AS code, original input was modified for calculation of loop seal reformation.

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In PARCH/EM code, inputs transferred from CEFLASH-4AS are conservatively applied to fuel rod heatup code.

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Except above assumptions, other inputs for analysis are same with DCD SBLOCA analysis

3.1. Break Location and Size

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4.0 CALCULATION PROCEDURE

PCT calculation procedure for the loop seal clearing and reformation analysis is shown in Figure 4-1. CEFLASH-4AS code is used for finding the limit cases and PARCH/EM code calculates the conservative PCT. Specific calculation methodology for each code is introduced in this technical report.

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Figure 4-1 Loop Seal Reformation PCT Calculation Procedure in APR1400

4.1. Input Preparation for CEFLASH-4AS Calculation

There are CEFLASH-4AS input modifications for loop seal reformation.

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4.2. CEFLASH-4AS Break Spectrum

CEFLASH-4AS break spectrum was performed to determine the limiting cases as Table 4-1. The results of break spectrum are shown in Table 4-1. It contains break sizes, calculation end time, core uncovery occurrence, minimum core mixture level, loop seal clearing information, and loop seal reformation occurrence & nodes information.

Table 4-1 CEFLASH-4AS Break Spectrum result **TS**

Table 4-2 Loop Seal Behavior Summary in CEFLASH-4AS Break Spectrum TS

4.3. The Limiting Case Selection for Fuel Rod Heatup Calculation

The limiting cases from break spectrum calculation were selected with below conditions.

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The limiting cases are selected as Table 4-3, Figure 4-2 and Figure 4-3 with above requirements.

Table 4-3 Limiting cases from CEFLASH-4AS break spectrum calculation

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Figure 4-2 CEFLASH-4AS Result for limiting cases –Inner-vessel Core Mixture Level

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Figure 4-3 CEFLASH-4AS Result for limiting cases – Loop Seal Mixture Level

Core uncovery is occurred in Figure 4-2 due to the loop seal reformation phenomena as shown in Figure 4-3. And the PCT analysis will be performed using PARCH/EM code for the above liming cases.

4.4. Input Preparation for PARCH/EM Calculation

PARCH/EM basedeck is prepared with below modification.

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Each PARCH/EM input for the limiting cases in CEFLASH-4AS is prepared with below three modifications applied to PARCH/EM basedeck from each CEFLASH-4AS result.

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- Conservative PARCH/EM Input Assumptions for 0.040 ft^2 CL break

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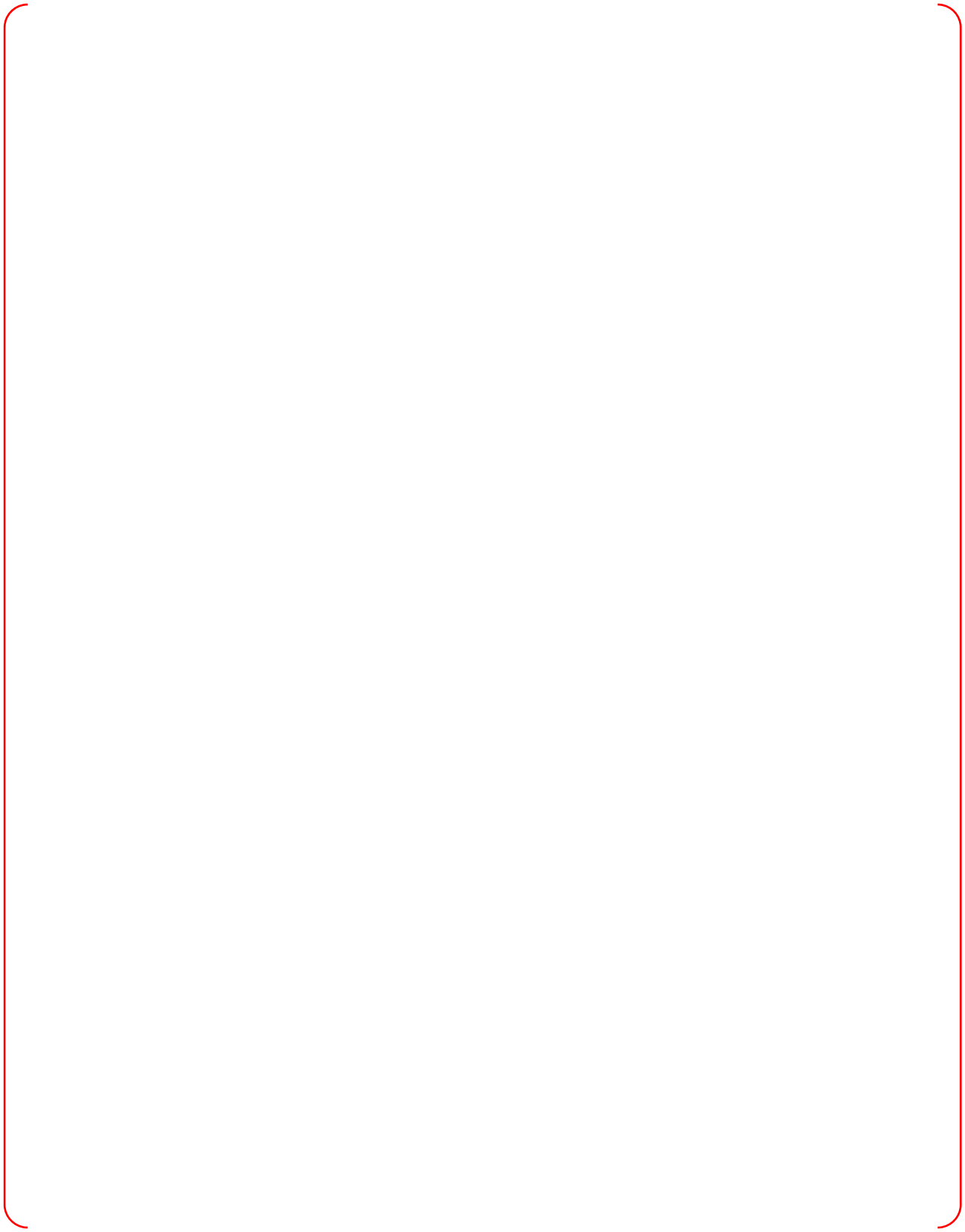

- Conservative PARCH/EM Input Assumptions for 0.044 ft^2 CL break

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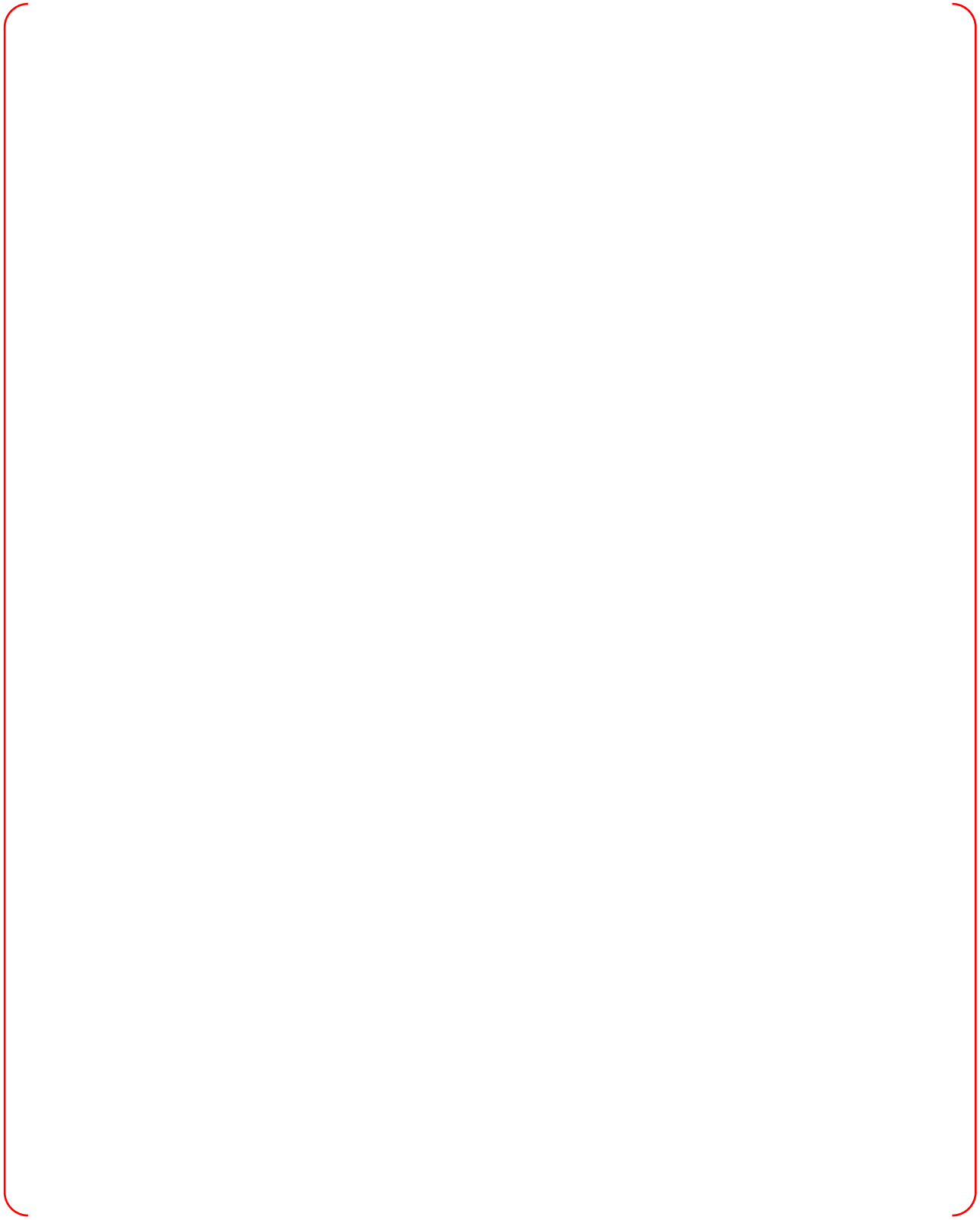

- Conservative PARCH/EM Input Assumptions for 0.047 ft^2 CL break

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- Conservative PARCH/EM Input Assumptions for 0.054 ft^2 CL break

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- Conservative PARCH/EM Input Assumptions for 0.055 ft^2 CL break

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- Conservative PARCH/EM Input Assumptions for 0.058 ft^2 CL break

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4.5. PARCH/EM Calculation Results

PARCH/EM calculation is performed for the limiting cases and clad surface temperature results are described in Figure 4-22 ~ Figure 4-27.

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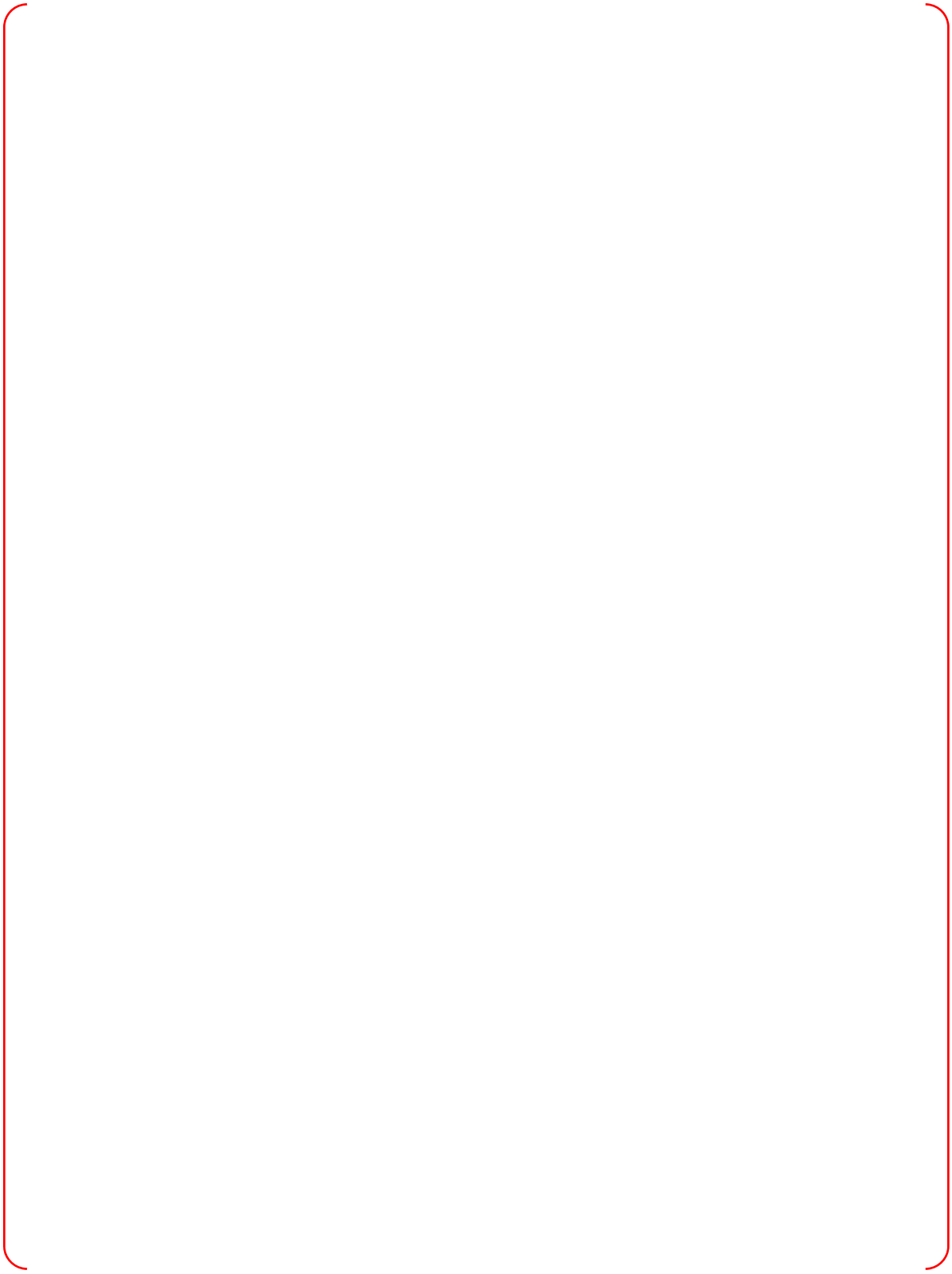

5.0 PCT CALCULATION RESULT

Clad surface summary result of Figure 4-22 ~ Figure 4-27 is as shown in Figure 5-1. Clad temperature increase before 1,200 sec stems from initial loop seal clearing, not related to the loop seal reformation phenomena.

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For each break, PCTs by loop seal reformation are described in Table 5-1.

Table 5-1 PARCH/EM Clad Surface Temperature Result – PCT by Loop Seal Reformation TS

Additionally, Cladding Oxidation for each case are summarized in Table 5-2.

Table 5-2 PARCH/EM Calculation Result for Cladding Oxidation TS

6.0 CONCLUSIONS

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7.0 REFERENCES

1. "Calculative Methods for the C-E Small Break LOCA Evaluation Model," CENPD-137P, August 1974 (Proprietary).

   "Calculative Methods for the C-E Small Break LOCA Evaluation Model," CENPD-137, Supplement 1-P, January 1977 (Proprietary).

2. "CEFLASH-4AS, A Computer Program for Reactor Blowdown Analysis of the Small Break Loss-of-Coolant Accident," CENPD-133P, Supplement 1, August 1974 (Proprietary).

   "CEFLASH-4AS, A Computer Program for the Reactor Blowdown Analysis of the Small Break Loss-of-Coolant Accident," CENPD-133, Supplement 3-P, January 1977 (Proprietary).

3. "PARCH, A FORTRAN-IV Digital Program to Evaluate Pool Boiling, Axial Rod and Coolant Heatup," CENPD-138P, August 1974 (Proprietary).

   "PARCH, A FORTRAN-IV Digital Program to Evaluate Pool Boiling, Axial Rod and

   Coolant Heatup (Modifications)," CENPD-138P, Supplement 1, February 1975 (Proprietary).

4. 10CFR50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light Water-Cooled Nuclear Power Reactors," October 1988.