Post-LOCA Long Term Cooling Evaluation Model

Technical Report

Non Proprietary

September 2012

Revision History

Revision	Page (Section)	Description
0	All	Issue for Standard

Abstract

This report establishes the adequacy of the long term cooling of the reactor vessel following the LOCA, loss of coolant accident, for the APR1400. The content of this document provides an overview of the applicable methodology and the description of specific model assumptions incorporated into the codes described below, which are used to analyze long term cooling of the reactor. In addition, this document provides a discussion of the bases for applying these codes and methods to the APR1400.

This report provides an overview of the applicable methodology and the description of specific assumptions incorporated into the codes used to analyze the LTC, long term cooling, as well as a discussion of the bases for applying these codes and methods to the APR1400. The validation of the principle models of these codes is presented through comparisons with computer codes that have been approved by the USNRC, United State Nuclear Regulatory Commission. The following codes are used in the LTC analysis:

• CEPAC	Used to calculate the secondary system temperature.
• NATFLOW	Used to calculate the RCS, reactor coolant system, core and loop natural circulation flow rates and temperatures after RCS has refilled for small breaks.
• CELDA	Used to calculate the long term depressurization and refill of the RCS for small breaks.
• BORON	Used to calculate the boric acid concentration in the core.

This report also provides the history of methodology changes for LTC codes. For the calculation of boric acid concentration, the new methodology adopts the mixing volume assumptions in the Westinghouse Long Term Cooling Analysis of Waterford 3 for the extended power uprate.

On the basis of the information in this technical report, it is concluded that the applied codes and methodologies are appropriate for the APR1400 safety analysis. In addition, it is concluded that the information provided in this technical report supports its purpose to provide key technical information related to the computer codes and methodologies. This information also supports the acceptance criteria

of the APR1400 related to representing LOCA safety analysis to the NRC, which will facilitate an efficient and timely review of the design certification license application.

Table of Contents

Abstract ··· i

Table of Contents ··· iii

List of Figures ··· iv

List of Tables ··· v

List of Acronyms ··· vi

1.0 INTRODUCTION ··· 1

2.0 BASIC LONG TERM COOLING PLAN ··· 2

- 2.1 Functional Requirement ··· 2
- 2.2 Operational Sequence ··· 2
- 2.3 Basis of Plan ··· 2
- 2.4 Emergency Core Cooling System Alignment ··· 4

3.0 ANALYTICAL APPROACH ··· 8

- 3.1 General Description ··· 8
- 3.2 Large Break Analysis Procedure ··· 9
- 3.3 Small Break Analysis Procedure ··· 9
- 3.4 Long Term Cooling Codes ··· 9
- 3.5 History of Methodology Changes ··· 10
  - 3.5.1 Interim approach used of Waterford 3 ··· 10
  - 3.5.2 Modification of BORON code for application of IRWST ··· 11
  - 3.5.3 Steam flow rate calculation using decay heat model (ANS 1971) ··· 11
  - 3.5.4 Core Flush Flow ··· 12
  - 3.5.5 Calculation method and result of the mixing volume ··· 13

4.0 RESULTS ··· 22

5.0 CONCLUSION ··· 25

6.0 REFERENCES ··· 26

Last Page ··· 27

List of Figures

Figure 2-1. RCS Refill Time vs. Break Area ········ 5
Figure 2-2. Overlap Range of Cold Leg Break Area ········ 6
Figure 2-3. RCS Pressure after Refill vs. Break Area ········ 7
Figure 3-1. Mixing Volume Changes ········ 20
Figure 3-2. Interim Methodology for Mixing Volume ········ 21
Figure 4-1. Inner Vessel Boric Acid Concentration vs. Time ········ 23
Figure 4-2. BORON Calculated Results for Mixing Volume ········ 24

List of Tables

Table 3-1. Major Variables 16

Table 3-2. Calculation of the Boil off Rate 16

Table 3-3. Calculation of α_B (Top of Region) 17

Table 3-4. Calculation of α_C at each Time Points 18

Table 3-5. Calculation Results of Mixing Volume Using the Interim Methodology 19

List of Acronyms

CE: Combustion Engineering

CFR: Code of Federal Regulation

DVI: Direct-Vessel Injection

ECCS: Emergency Core Cooling System

FAP: Fuel Alignment Plate

HF: Henry-Fauske

IRWST: In-containment Refueling Water Storage Tank

LOCA: Loss Of Coolant Accident

LTC : Long Term Cooling

NPP: Nuclear Power Plant

PWR: Pressurized Water Reactor

RCS: Reactor Coolant System

RWT: Refueling Water Tank

SBLOCA: Small Break LOCA

SCS: Shutdown Cooling System

SDC: Shutdown Cooling

SG: Steam Generator

SI: Safety Injection

SRP: Standard Review Plan

USNRC: United States Nuclear Regulatory Commission

1.0 INTRODUCTION

The purpose of this technical report is to present the LTC computer codes and methodologies for the analysis of LTC events in the SRP, standard review plan, Chapter 15, except for the dose evaluation, for advanced pressurized water reactors such as APR1400. The LTC methodology used for APR1400, which uses the following codes, is very similar to the conventional LTC methodology used for currently operating U.S. Combustion Engineering (CE)-fleet PWRs, Pressurized Water Reactors:

• CEPAC[1]	Used to calculate the secondary system temperature.
• NATFLOW[2]	Used to calculate the reactor coolant system core and loop natural circulation flow rates and temperatures after the RCS has refilled for small breaks.
• CELDA[3]	Used to calculate the long term depressurization and refill of the RCS for small breaks.
• BORON[4]	Used to calculate the boric acid concentration in the core.

This report describes :

- Section 2 - Basic Long Term Cooling Plan
- Section 3 - Analytical Approach
- Section 4 - Results
- Section 5 - Conclusion

2.0 BASIC LONG TERM COOLING PLAN

2.1 Functional Requirement

The basic function of the LTC is to maintain the core at safe temperature levels while avoiding the precipitation of boric acid in the RCS.

2.2 Operational Sequence

The LTC plan makes provision for maintaining core cooling and boric acid flushing by simultaneous hot leg and DVI, direct-vessel injection, line injection for large break LOCA or initiating shutdown cooling if the break is small enough that the successful operation is assured. The knowledge of pressurizer pressure gives the plant operator indication of the break size.

Major assumptions of operator behavior in CENPD-254[5] methodology are as follows.

- At the time of one hour after LOCA, the operator to start the operation of the steam generator cooldown.
- At the time of three hours after LOCA, the operator to start the simultaneous hot leg and DVI line injection.
- At the time of eight hours after LOCA, if RCS pressure has remained above 450 psia, the reactor coolant system is filled with liquid water.

2.3 Basis of Plan

The LTC plan is based on the following reasons:

1) Small and large break LOCA's call for distinctly different responses in the long term cooling plan.
2) It is possible to determine from the pressurizer pressure whether the break is large or small.

The simultaneous hot leg and DVI line injection from the SI, safety injection, pumps is prescribed by the LTC plan following any LOCA. This simultaneous injection prevents boric acid precipitation for an extensive range of large and intermediate sized breaks, in either the hot leg or the DVI line. For extremely small breaks, where reactor coolant system pressure remains high, the simultaneous injection flow is too small to provide effective flushing of the boric acid however, with extremely small breaks the system refills and the boric acid concentration remains low due to the dispersal throughout the RCS by natural circulation.

In addition to boric acid precipitation, the cooling of the RCS must be considered. The SI pump injection is capable of adequate cooling of the RCS for all but the smallest breaks. For the smallest breaks, the steam generators are initially employed to cool the RCS, with subsequent activation of the SCS, shutdown cooling system. There is a range of break sizes for which the SI pump injection alone can cool the RCS after the initial period of steam generator heat removal, but which also yields system conditions such that eventual successful entry into shutdown cooling is assured. Therefore, there is an overlap in which either of the two different core cooling modes is satisfactory.

The LTC analysis predicts that the RCS will refill at various times depending on break size, as shown in Figure 2-1. As shown in the figure, for a break size as large as 0.04 ft^2, the RCS is refilled within 8 hours. In addition, the LTC analysis determines that longer than 14 hours is required to exhaust all of the auxiliary feedwater during cooldown of the RCS. Therefore, to allow a substantial time margin to avoid exhausting the auxiliary feedwater, a period of 8 to 9 hours is selected for the operator to decide whether the small break LTC procedure is appropriate. These results demonstrate that breaks as large as 0.04 ft^2 are able to use the SCS for the long-term cooling and flushing of the core. The LTC analysis determines that the large-break procedures can flush the core for break sizes down to 0.004 ft^2. The overlap in break sizes for which either the large-break or small-break procedures can be used is illustrated in Figure 2-2.

The operator chooses the appropriate procedure on the basis of the indicated RCS pressure between eight and nine hours. Figure 2-2 lists the RCS pressure at eight hours for a wide range of break sizes and Figure 2-3 presents this information graphically. The decision pressure is selected as 450 psia so that, with consideration of the maximum RCS pressure measurement error up to ± 300 psia, reasonable assurance is provided that the operator is able to select the proper procedure for any break size.

2.4 Emergency Core Cooling System Alignments

The different alignments of the ECCS, emergency core cooling system, which are used in the LTC plan, are as follows:

- Initial recirculation mode

The injection by SI pumps from the IRWST, in-containment refueling water storage tank, has been secured.

- Simultaneous injection mode

One or half of the SI pump flow has been realigned to the RCS hot legs. The LTC plan calls for a shift to this mode at about three hours after any LOCA.

- Shutdown cooling mode

A small break is indicated by a reactor coolant system pressure above 450 psia at about eight hours after a LOCA. In this case, the reactor coolant system is entirely refilled. The SI pumps maintain the system pressure, and the RCS liquid level is sufficient for entry into the SDC mode. The reactor coolant system temperature is then checked to assure that steam generator cooling has reduced it to the shutdown cooling entry value. Then, the SI pumps are realigned to be discharged entirely to the DVI line; they are then throttled to reduce the RCS pressure to the SDC entry value. The shift is then made to the SDC mode.

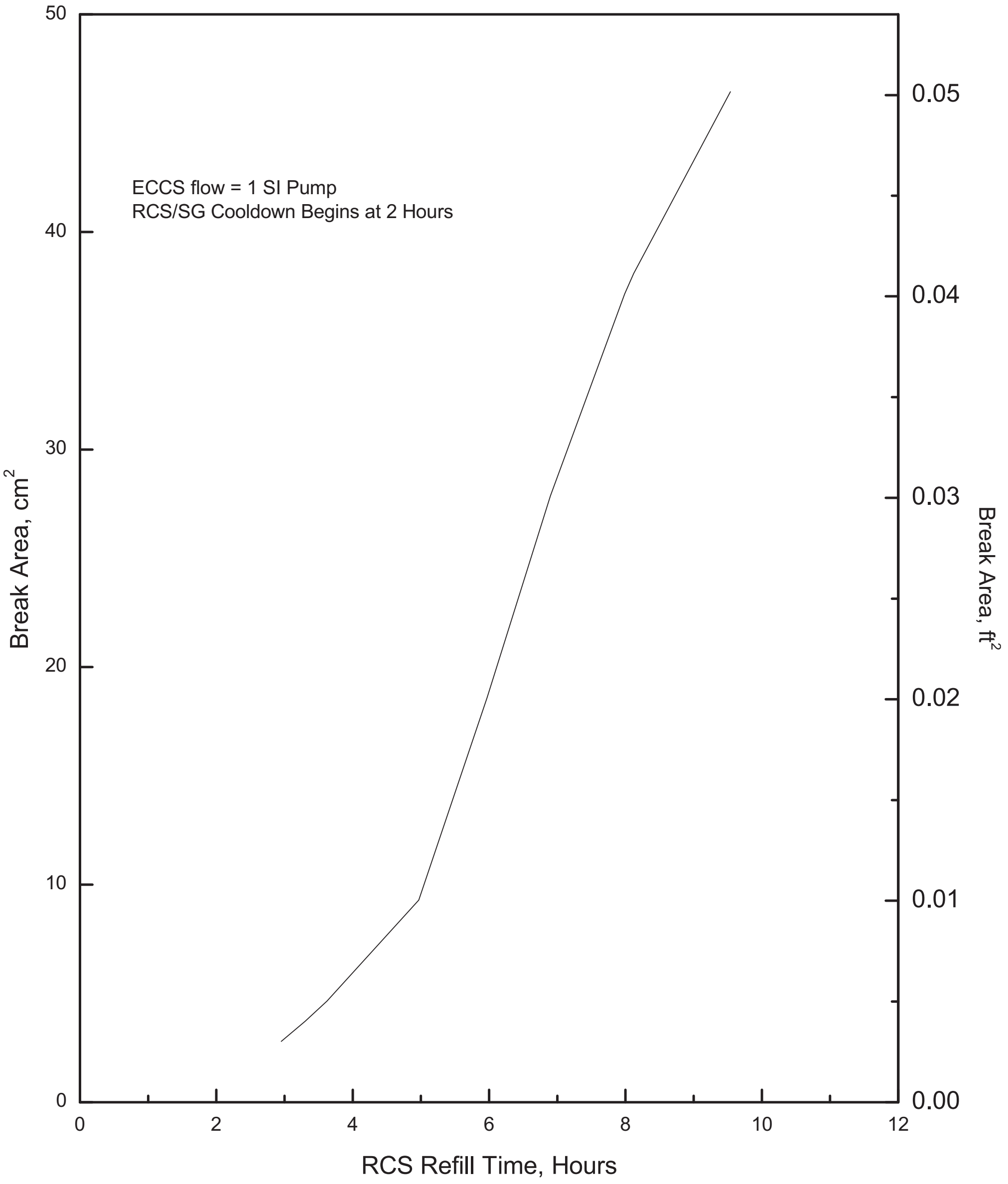
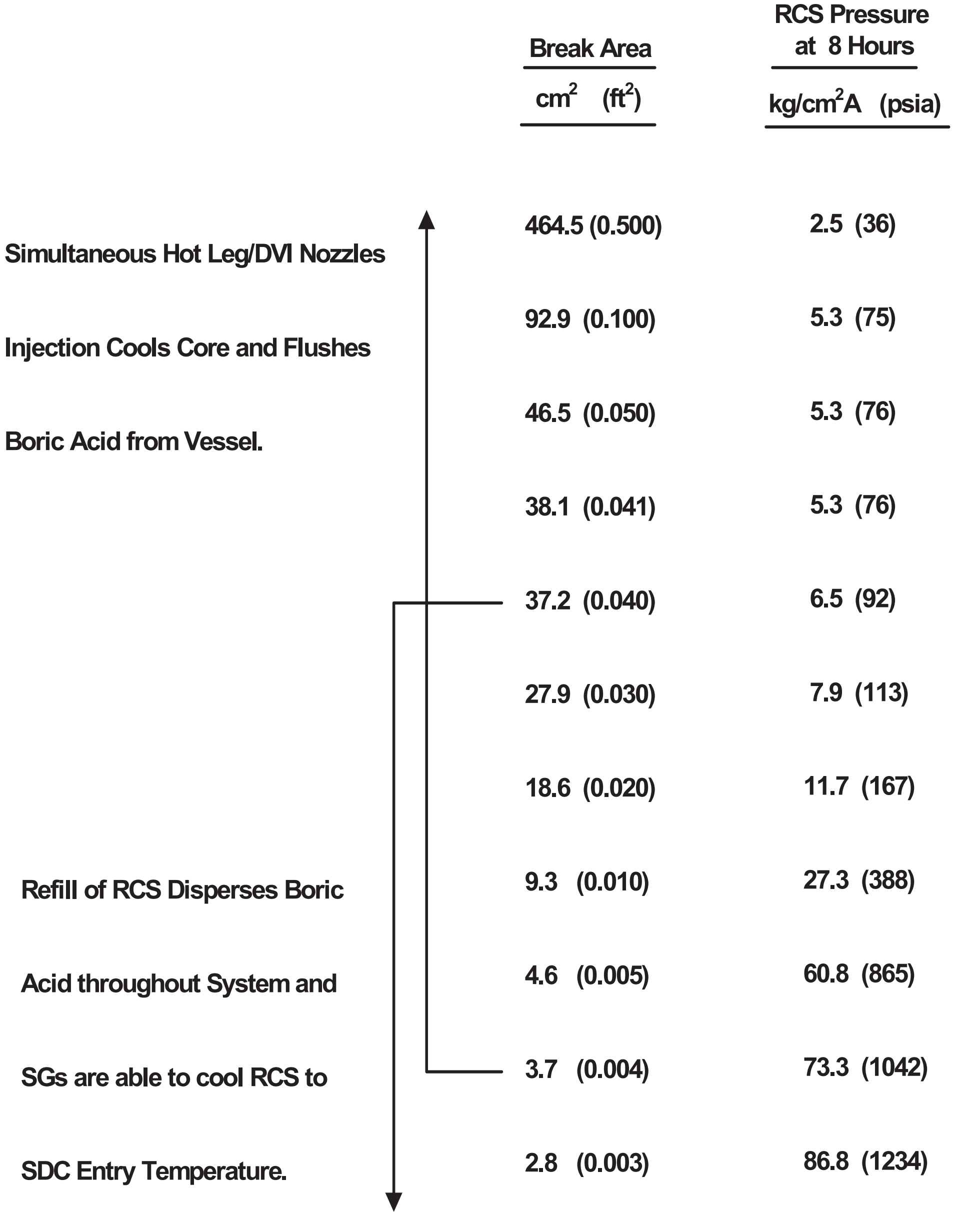


Figure 2-1. RCS Refill Time vs. Break Area



Break Area cm^2 (ft^2)	RCS Pressure at 8 Hours kg/cm^2A (psia)
464.5 (0.500)	2.5 (36)
92.9 (0.100)	5.3 (75)
46.5 (0.050)	5.3 (76)
38.1 (0.041)	5.3 (76)
37.2 (0.040)	6.5 (92)
27.9 (0.030)	7.9 (113)
18.6 (0.020)	11.7 (167)
9.3 (0.010)	27.3 (388)
4.6 (0.005)	60.8 (865)
3.7 (0.004)	73.3 (1042)
2.8 (0.003)	86.8 (1234)

Figure 2-2. Overlap Range of Cold Leg Break Area

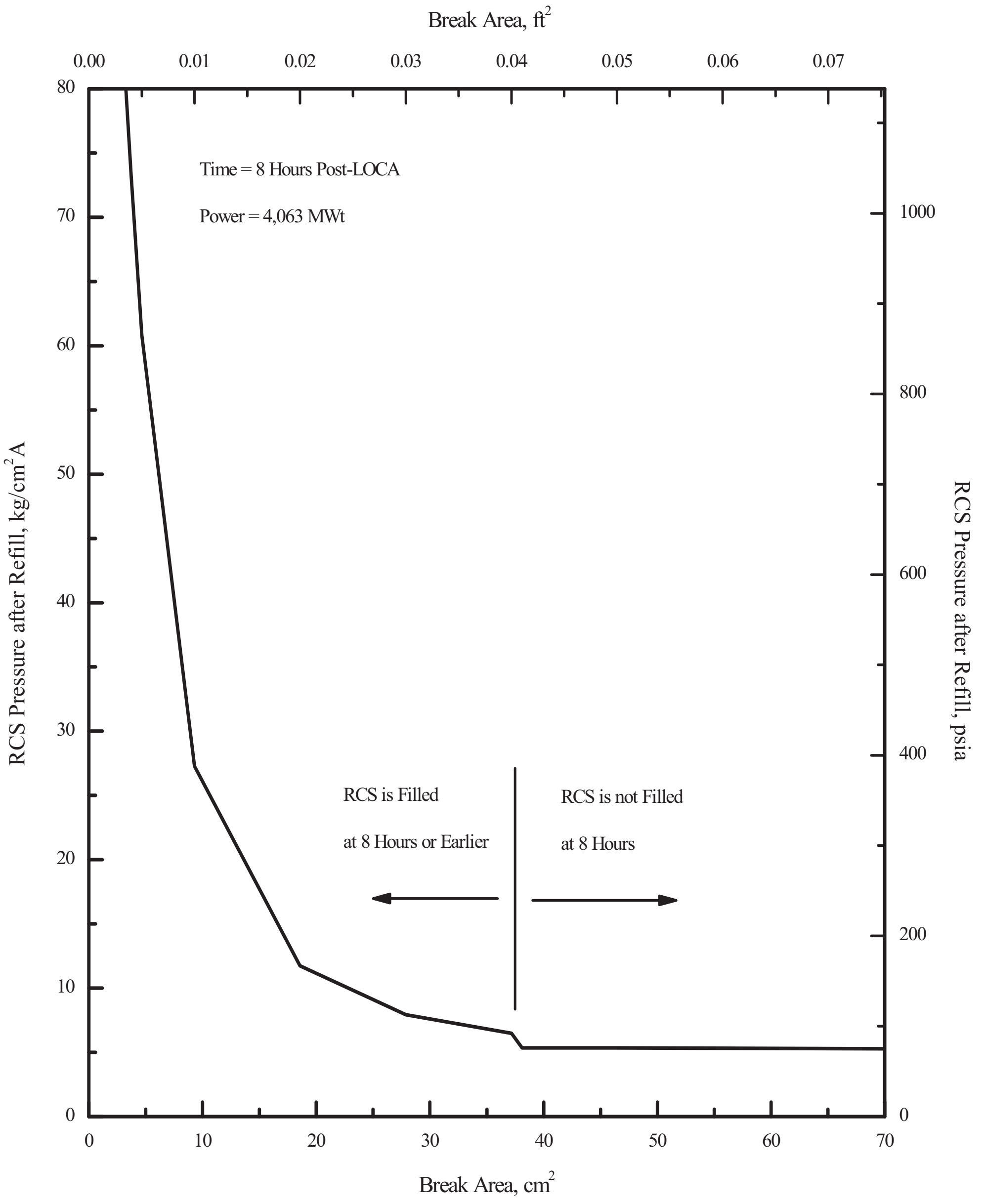


Figure 2-3. RCS Pressure after Refill vs. Break Area

3.0 ANALYTICAL APPROACH

3.1 General Description

The basic objective of the LTC analysis is to demonstrate the long term coolability of the core. The analysis procedures account for single-failures to assure that the performance objectives are even with this assumption.

It is important to recognize the behavioral difference between large and small break LOCAs in long term cooling. The difference is that the RCS will remain at high pressure for small breaks and the injection flow rate will be too low for effective cooling; thus, small breaks require the SGs to cool the RCS until SDC can be initiated. Large breaks, on the other hand, are adequately cooled by the injection flow because this flow is large due to the low RCS pressure; however, large breaks must utilize simultaneous hot leg and DVI line injection to flush boric acid from the vessel. Thus, the LTC large break and small break analyses are different from each other.

Another issue to be considered is the effect of the break location. For any large hot leg break, the short term DVI line ECCS injection flow will fill the annulus and provide the elevation head necessary to force flow through the core and out of the hot leg break. The liquid flow which is in excess of the core boil-off will provide a substantial flushing flow through the core, and will decrease and maintain the core boric acid concentration similar to that of the low levels at initial IRWST.

For large cold leg breaks, however, boric acid concentrates in the core as long as the cold side injection is continued. If it is easily determined that the break occurred in the cold leg (and hot side injection is possible.), the ECCS injection flow would be switched to hot side injection only. When sufficient elevation head builds up in the hot side, the core flushing flow will flow down through the core and up through the annulus to the break.

In case of the slot break at the top of the cold leg, the margin will be reduced due to the fact that loop seal refilling will increase the value of the core-to-break steam flow pressure drop. However, water in the cold leg can be credited when a slot break occurs at the top of the cold leg. So, the margin will be increased due to the fact that crediting water in the cold leg will increase the hydrostatic head of the downcomer. The additional pressure drop will be covered by this margin. Therefore, the long term loop seal refilling with a slot break at the cold leg does not significantly affect the boric acid precipitation analysis

Since the break location may not be easily determined, the long term ECCS alignment should be able to cope with breaks in either location. This ability is achieved by converting from the short term cold side ECCS injection to long term simultaneous DVI and hot leg injection. The intact side of the RCS will build up the elevation head necessary to send flow through the core and out of the break. The cold side injection flow will continue through the normal cold leg ECCS injection nozzles while the hot side injection point will be through the hot leg suction lines of the shutdown cooling system.

3.2 Large Break Analysis Procedure

The LTC analysis for large break LOCAs is chiefly concerned with the control of boric acid concentration. The timely initiation of simultaneous DVI line/hot side SI pump injection enables the intact side of the vessel to accumulate liquid elevation head. Once sufficient head has been established, a liquid flushing flow through the core and out through the break will be provided thereby both cooling the core and removing boric acid.

3.3 Small Break Analysis Procedure

The post-LOCA procedures for LTC following a small break resemble those used during a normal cooldown to a cold shutdown condition.

Long term cooling of the core can be performed by the SDC system since the RCS will be refilled for small breaks for which the simultaneous DVI/hot side injection is unable to cool and flush the core.

3.4 Long Term Cooling Codes

1) CELDA : Computer code that is used to determine the long term depressurization and refill of the RCS.

2) NATFLOW : Computer code that is used, for small breaks, to determine the RCS core and loop natural circulation flow rates and temperatures after the RCS has refilled.

3) BORON : Computer code that calculates the transient boric acid concentration in the RCS.

4) CEPAC : Computer code that determines the SG cooldown performance.

3.5 History of Methodology Changes

3.5.1 Interim approach used in Waterford 3

Some non-conservatism has been identified in the previous methodology, and as a result, in 2005, the USNRC suspended the approval of CENPD-254, which is the old LTC methodology for CE-designed nuclear power plants. The major reasons for such suspension are described below. :

1. Void effect − The mixing volume must be justified and the void fraction must be taken into account when computing the boric acid concentration.

2. Time-varying mixing volume − The analysis to determine boric acid concentration needs to account for the variation in the mixing region while considering the pressure drop in the loop.

3. Decay heat − The decay heat model in appendix K with a multiplier of 1.2 has to be used at all times.

4. Boric acid solubility limit - The solubility limit must be justified.

The 'interim approach' is to reflect the four issues above to CENPD-254, and the methodology applying such interim approach is the 'interim methodology'. The updated analysis utilized the post-LOCA LTC methodology using the interim approach. The following three items are described in more detail as mentioned above for issue 1 and issue 2.

(1) The mixing volume used for computing the boric acid concentration was changed to include the additional volume in the core outlet plenum located between the bottom and top elevations of the hot leg piping at the exit of the vessel. The previously approved model consisted only of the portion of the upper plenum below the bottom elevation of the hot leg piping. The core was also included in the mixing volume, as originally approved by USNRC regarding the use of the CENPD-254 methodology.

(2) The liquid volume in the core and upper plenum mixing volumes (based on the void fraction) identified in item (1) above was calculated by applying the CEFLASH-4AS phase separation model to this region. The phase separation model used in CEFLASH-4AS was originally approved by USNRC for computing the mixture level in the core following all SBLOCAs. This model was shown to accurately predict the void fraction and, hence, the two-phase level in regions experiencing high rates of heat addition following SBLOCAs.

(3) The mixing volume was increased to also include 50 percent of the lower plenum. Mitsubishi Heavy Industries’ BACCHUS test employed to simulate post-LOCA boric acid mixing in the lower plenum and core of a Westinghouse and CE-designed PWR was cited as justification for expanding the mixing volume to also include a portion of the lower plenum. The tests showed that the entire lower plenum volume contributed to the mixing. Hence, crediting only 50 percent of this volume is conservative.

3.5.2 Modification of the BORON code for application of IRWST.

APR1400 adopts IRWST instead of the refueling water tank (RWT) used in previous CE-type plants. In CE-type plants, ECC is injected from the RWT for a certain amount of time and is changed to the sump when the RWT is emptied. In APR1400, however, ECC is injected from IRWST from the beginning. Therefore, the BORON code for APR1400 was modified to model the IRWST.

3.5.3 Steam flow rate calculation using the decay heat model (ANS 1971)

The decay heat fraction (DHF) at one hour post-LOCA is determined using the BORON computer code decay heat model described in CENPD-254-P-A, which is reproduced below.

[ ]

where

DECAY = normalized decay heat fraction including 1.1 conservative multiplier
T = time (seconds)

When using a time of 1 hour or 3600 seconds, the DHF is:

$$\mathrm{DECAY} = 0.75 \times 10^{(0.75\times\log(3600)-0.778)}/3600 = 0.016143$$

Consistent with NRC imposed restrictions on the acceptability of the boric acid precipitation methodology, a decay heat multiplier of 1.2 was applied as shown below:

Decay Heat Fraction (Including 1.2 decay heat multiplier)
Decay Heat Fraction = 0.016143 * 1.2 / 1.1
Decay Heat Fraction = 0.01761

The core power level including power measurement uncertainty is 4063 MWt. Therefore, using the above data, the core boil-off rate (WBO) at 1 hour post-LOCA is equal to the core power times the decay heat fraction divided by the heat of vaporization, as shown below:

WBO = 4063 MWt * 948.04 Btu/sec-MWt * 0.01761 / (1150.28 - 180.18) Btu/lbm
WBO = 69.95 lbm/sec

Table 3-2 summarizes the core boil-off for 13 times points.

3.5.4 Core flush flow

Core flush begins three hours after the ECCS is realigned in accordance with the LTC plan for DVI/hot side at three hours post LOCA. Core flushing flow is 1 SI pump flow or 1/2 SI pump flow for both cold leg break and DVI line break. This report used the core flushing flow as 1/2 SI pump flow for conservatism. The obtained core flushing flow is shown below.

$$W_{flush} = 1/2\ W_{SI} - W_{boiloff}$$

The BORON code is applied to calculate the boric acid concentration of double-ended guillotine breaks. Thus, the RCS pressure is decreased down to the containment pressure. But, 0.4 W_{SI} was used instead of 1/2 W_{SI} for analytical flexibility.

$$W_{flush} = 0.4\ W_{SI} - W_{boiloff}$$

3.5.5 Calculation method and result of the mixing volume

The major variables for mixing volume calculation are shown in Table 3-1. The each part of the mixing volume is shown in Figure 3-2. The atmospheric conditions assumed for LTC were used to perform the following calculations (14.7 psia, 212 °F).

A flat axial power shape was selected as a reasonably conservative representation of the axial power distribution. So, this report used multiple core regions as shown in Table 3-3. The void fraction of each core region was calculated using the equations below and the results are shown in Table 3-3 and Table 3-4. This report used the average void fraction shown in Table 3-4 to calculate the mixing volume.

The mixing volume used in the interim methodology was calculated by applying the CEFLASH-4AS phase separation model to this region, using the following equation:

$$\left[\qquad\qquad\qquad\qquad \right] \qquad\qquad (1)$$

where, $\dot{P}_N$ = bubble production rate = $\left(\frac{Q}{h_{fg}} + \dot{W}_{flashing}\right) 1/Z_N$

W_N = flow bubbles from the lower subregion

V_D = drift velocity = $3.0EXP^{-0.75\frac{P}{1000.0}}$

$\boxed{?}(Z) = \frac{\dot{P}_N(Z_{20}-Z_N)+W_N}{\dot{P}(Z_{20}-Z_N)+V_D\rho_V A_N+W_N}$

α_B and α_C can be obtained from equation (1)

$$\alpha_B = \rho_g A_N \int_{Z_1}^{Z_{20}} \alpha(Z)dZ = \int_{Z_1}^{Z_{20}} \frac{\dot{P}_N Z_N + W_N}{\dot{P}_N Z_N + (V_D \rho_g A_N) + W_N} dz \tag{2}$$

$$= \rho_g A_N [Z_N - \frac{V_D \rho_g A_N}{\dot{P}_N} \ln\left(\frac{\dot{P} Z_N + V_D \rho_g A_N + W_N}{V_D \rho_g A_N + W_N}\right)] \tag{3}$$

and, equation (3) is divided by $\rho_g A_N Z_N$

$$\alpha_B = 1 - \frac{k}{\dot{P}_N Z_N} \ln\left(\frac{\dot{P} Z_N + k + W_N}{k + W_N}\right) \tag{4}$$

If we assume the condition is subcooled, $W_N = 0,\ W_{\text{flashing}} = 0$

$$\alpha_B = 1 - \frac{k}{\dot{P}_N Z_N} \ln\left(\frac{\dot{P} Z_N + k}{k}\right) \tag{5}$$

$$\therefore\ \alpha_B = 1 - \frac{k}{\dot{m}} \ln\left(\frac{\dot{m} + k}{k}\right)$$

where, $k = V_D \rho_g A_N$

$$\dot{P}_N = \left(\frac{Q}{h_{hg}} + \dot{W}_{\text{flashing}}\right) {}^{1}/{}_{Z_N} \gg \dot{P}_N Z_N = \frac{Q}{h_{fg}} = \dot{m}$$

$$\frac{V_D}{1-\alpha_C} \rho_f A_C \alpha_C = \dot{P}_N Z_N + W_N \tag{6}$$

$$\frac{k \alpha_C}{1-\alpha_C} = \dot{m} \tag{7}$$

$$\therefore\ \alpha_C = \frac{\dot{m}}{k + \dot{m}} \tag{8}$$

Summarized results of the void fraction (α) are as follows

$\alpha_A = 0$

$$\alpha_B = 1 - \frac{k}{\dot{m}(t)} \ln \frac{\dot{m}(t)+k}{k}$$

$$\alpha_C = \frac{\dot{m}(t)+k}{k}$$

The variables used in the above equations are summarized in Table 3-1 and, time dependent boil off rate values are calculated in Table 3-2. This report assumed that the core is ten regions. The mixture height vs. time and the core and upper plenum void distributions at three points of time are shown in Table 3-3 and Table 3-4.

The final mixing volume based on a void fraction that corresponds to the above three points of time is shown in Table 3-5. Void fraction α_C was calculated by considering core area to outlet plenum ratio. The result of α_C is shown in Table 3-4.

Table 3-1. Major Variables

	Value	Reference
Power (Q)		
Enthalpy (h_{fg})		
A_{core}		
$A_{Outlet\ Plenum}$		
ρ_g		
V_D		
$K=(V_{D*}\ \rho_{g\ *}A_{core})$		

Table 3-2. Calculation of the Boil off Rate

Time (hr)	Decay Heat	□ (lbm/sec)
0.0083	0.058345	231.74
0.56	0.020358	80.86
1.0	0.017611	69.95
1.39	0.016219	64.42
1.5	0.015913	63.20
2.0	0.014809	58.82
2.78	0.013638	54.17
3.0	0.013381	53.15
4.0	0.012453	49.46
5.0	0.011777	46.78
8.0	0.010471	41.59
13.0	0.009274	36.84
24.0	0.007956	31.60

Table 3-3. Calculation of α_B (Top of Region)

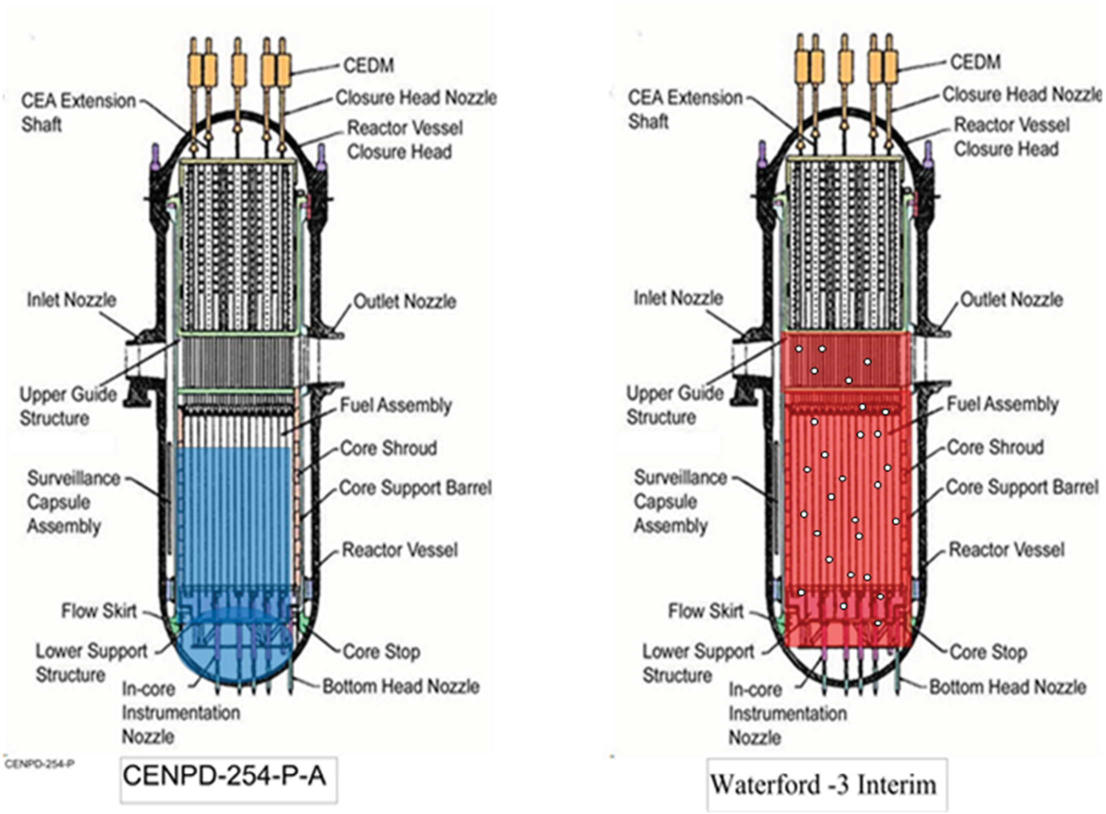
Mixing Volume Region	Height, ft	Calculated Boil Off rate for each Region, lbm/sec			Void Fractions		
		1 hours	2 hours	3 hours	α_B (at 1 hours)	α_B (at 2 hours)	α_B (at 3 hours)
1	1.25						
2	1.25						
3	1.25						
4	1.25						
5	1.25						
6	1.25						
7	1.25						
8	1.25						
9	1.25						
10	1.25						

Table 3-4. Calculation of α_C at each Time Points

Time (hr)	α_C
0.0083	
0.56	
1.0	
1.39	
1.5	
2.0	
2.78	
3.0	
4.0	
5.0	
8.0	
13.0	

Table 3-5. Calculation Results of Mixing Volume using the Interim Methodology

Region		Volume (ft^3)	Void Fraction	Final Volume (ft^3)	
Lower Plenum (A)	Bottom inactive core (top of lower support structure to bottom of active core)				Crediting 50% participation of the lower plenum volume is conservative relative to the BACCHUS tests results.
	Flow skirt to top of lower support structure				Only liquid
Core (B)	Core, guide tube, core shroud				The void fraction in the core is calculated using the CEFLASH-4AS phase separation model.
Outlet Plenum (C)	Bottom of FAP to top of hot leg				The liquid volume in the outlet plenum is calculated by applying the core-to-outlet plenum area ratio to the core exit void fraction
	Top inactive core (top of active core to bottom of FAP)				
Total Volume, ft^3					



CENPD-254-P-A

Waterford -3 Interim

Figure 3-1. Mixing Volume Changes

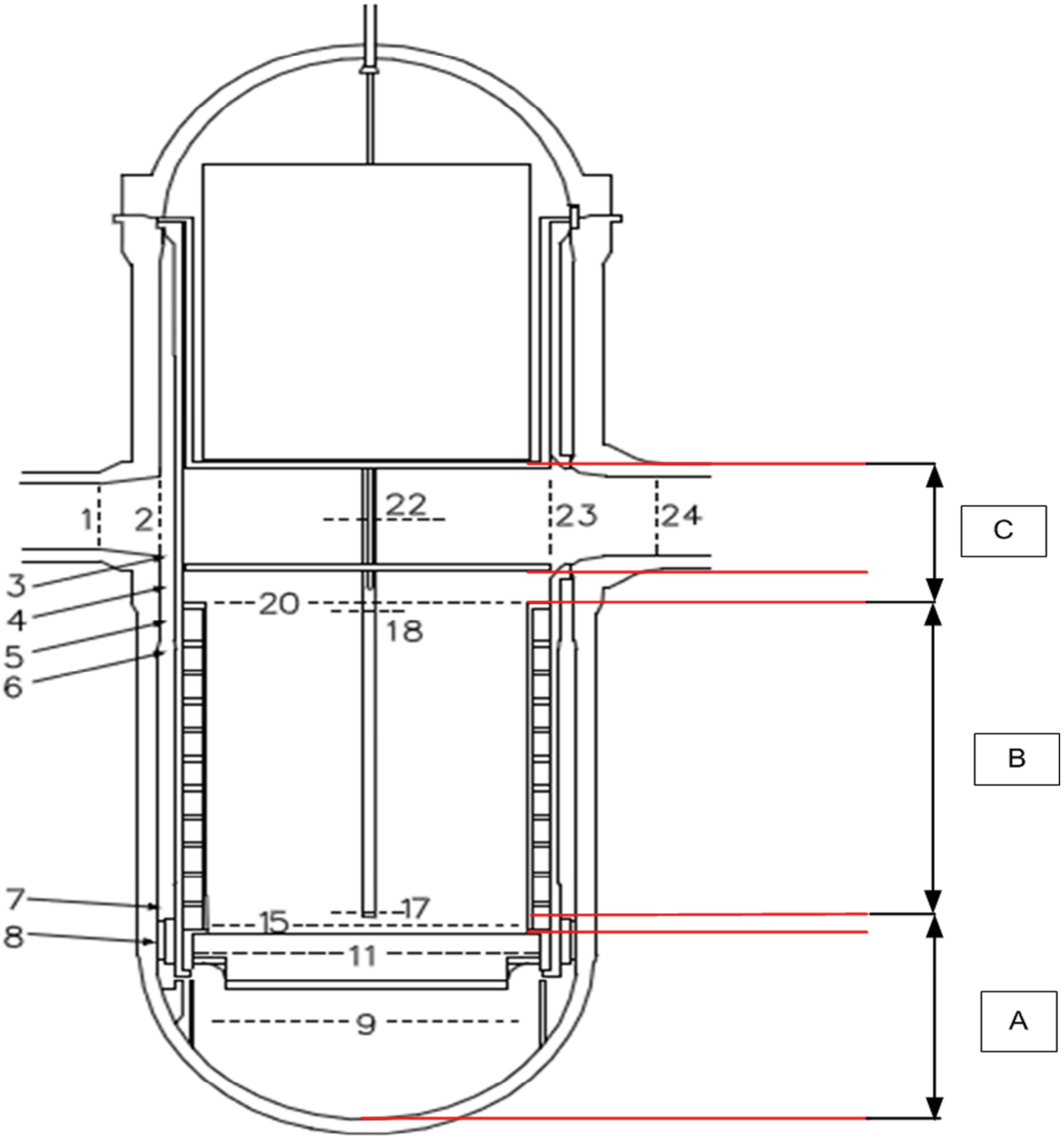


Figure 3-2. Interim Methodology for Mixing Volume

4.0 RESULTS

The objective of this technical report is to describe improvement of methodology changes in LTC codes. For the calculation of boric acid concentration, new mixing volume calculation methodology which is the same as Westinghouse LTC analysis of Waterford 3 [6] at extended power uprate is used.

The BORON code calculates the transient boric acid concentration in the RCS. The results are shown in Figure 4-1. As shown in the figure, boric acid precipitation does not occur when simultaneous injection is started three hours after the accident. Also, as shown in Figure 4-2, the interim methodology is more conservative compared to the traditional CENPD-254 methodology.

In summary, this technical report demonstrates the key analytical methods and specialized models are appropriate for APR1400 LTC analyses.

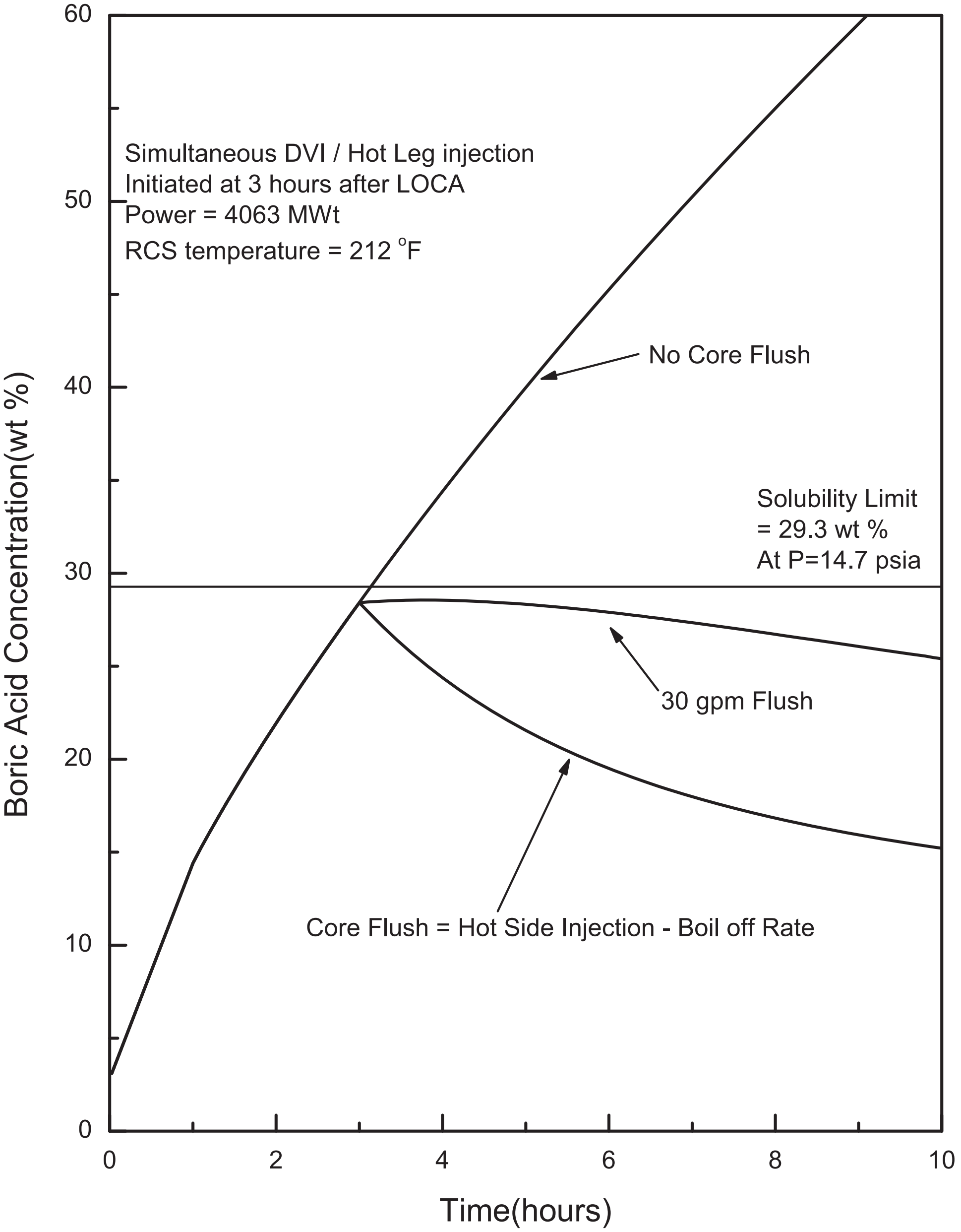


Figure 4-1. Inner Vessel Boric Acid Concentration vs. Time

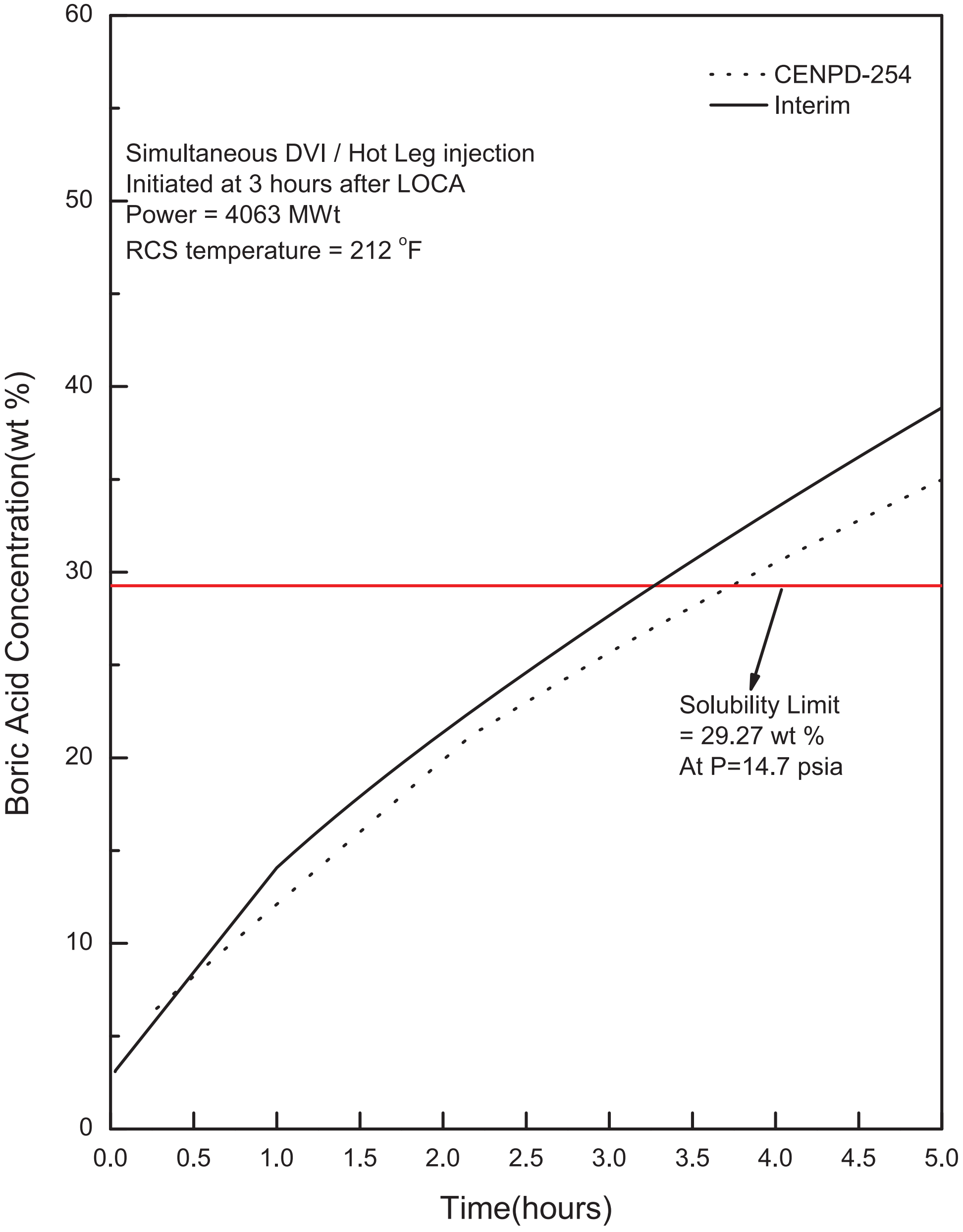


Figure 4-2. BORON Calculated Results for Mixing Volume.

5.0 CONCLUSION

The regulatory requirement for the LTC is provided in 10 CFR 50.46(b)(5), which states "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 required by the long-lived radioactivity remaining in the core." Although the SRP (NUREG-0800) provides some guidance, it essentially repeats the regulatory requirement.

On the basis of the information in this technical report, the mixing volume is evaluated by applying interim methodology. The boric acid precipitation does not occur when simultaneous injection is started three hours after the accident. Also, it was concluded that the existing codes and methodologies are appropriate for the APR1400 LTC analyses. In addition, it is concluded that the information provided in this technical report supports its purpose to provide key technical information related to the computer codes, methods and models are applicable to the regulatory requirements

6.0 REFERENCES

[1]. DR-97-C018, Rev. 2, "Computer Code Approval Form for CEPAC Version, CEP.1.3", B. S. Park, 1999. 8. 20.

[2]. DR-97-C017, Rev. 2, "Computer Code Approval Form for CELDA Version, CEL.1.2", B. S. Park, 1999. 8. 20.

[3]. DR-97-C029, Rev. 2, "Computer Code Approval Form for NATFLOW Version, NAT.1.2", B. S. Park, 1999. 8. 20.

[4]. DR-97-C013, Rev. 2, "Computer Code Approval Form for BORON Version, BOR.1.3", B. S. Park, 1999. 8. 20. (Proprietary).

[5]. CENPD-254-P-A, "Post-LOCA LTC Evaluation Model", 1980. 6.

[6]. W3F1-2005-0012, “Supplement to Amendment Request NPF-38-249 Extended Power Uprate Waterford Steam Electric Station, Unit 3”, 2005. 2. 16.

Last Page

of

APR1400-F-A-NR-12002-NP (Revision 0)