Attachment 2- Calculation DC00040-066, Rev 2

Subject Code 004	SOUTH CAROLINA ELECTRIC AND GAS COMPANY CALCULATION RECORD			Page 1 of 87
Calculation Title: Spray and Sump pH With Delta-75 SGs		Calculation Number: DC00040-068	Revision: 2	Status: A
Parent Document: ECR-71072	System: N/A	Safety Class: ☐ NN ☐ QR ☒ SR	☒ Partial Calc. Revision ☐ Complete Calc. Revision	
Originator: D. McCreary	Discipline: AE	Organization: SCE&G	Date: 4-21-09	XREF Number

CALCULATION INFORMATION

Content Description:

Calculates Post LOCA, Min/Max pH Values For RB Sprays and RB Sump Accounting For Use of Delta-75 SGs and Limiting Operating Conditions.

The sole purpose of Revision 2 is to replace Westinghouse proprietary information with non-proprietary information. No methodology, calculations, results, or conclusions have been changed.

Affected Components/Calculations/Documents:
DC000110-140, Equipment Qualification Zone Data
S-021-018

Piping Reconciliation Completed per QA-CAR-0089-18: ☐ This Revision ☐ Previous Revision ☒ N/A

Contains Preliminary Data/Assumptions: ☒ No ☐ Yes, Affected Pages: ______________

Computer Program Used: ☐ No
- ☐ Yes, Validated per ______________ (vendors name) computer program validation process (others)
- ☒ Yes, Validated in accordance with SAP-1040/ES-413 (ref. 3.4 & 3.5)
- ☐ Yes, Validated [ES-0412]
- ☐ Computer Program Validation Calculation

VERIFICATION ☐ Continued, Attachment

Scope:
Verify in accordance with ES-110 and ES-412.

Verifier: L. Cartin
Assigned by: B. Herwig

[signature] 4-21-09
Engineering Personnel /Date

[signature] 4-21-09
Verifier/Date

[signature] 4/22/09
Approval/Date

RECORDS

To Records Management: ______________
Initials/Date

Distribution: Calc File (Original)

Calculation Number
DC00040-066

Revision Number.	Summary Description
0	Min/Max pH for the RB spray and sump are calculated for post-LOCA conditions with the Delta-75 SGs.
1	The spray operability time, previously assumed to be 24 hours, is revised to 40 days. Calculated pH values are not changed.
2	Westinghouse proprietary information on RCS volume below the hot leg is replaced with non-proprietary information to support the Alternative Source Term (AST) submittal.
	Pages 10 through 17 are voided, and pages 5, 8, 9, 60, and 64 are revised.

ENGINEERS
TECHNICAL WORK RECORD

Serial 227-68-1864
Engineer L R Cartin
Date 24 Sept 1994

PROJECT-TITLE SPRAY/SUMP pH WITH DELTA-75 SGs TAB 163 PAGE 3

TABLE OF CONTENTS

1.0 PURPOSE

During RF-9, the current D3 SGs will be replaced with DELTA-75 SGs. The new SGs, described in Ref 1, have a larger tube bundle and thus result in a increase of approximately 787 ft3 (total) in RCS liquid volume.

RCS volume is one contributor to the pH of the solution recirculated within containment after a LOCA. An increase in the RCS volume, which can contain highly borated water (an acidic solution), would tend to make the sump solution more acidic or decrease the sump pH and spray pH during the recirculation period.

The bases section of the VCSNS Tech Spec (3/4.5.4 & 3/4.6.2.2 in Ref 6) currently states the following (changed per Ref 2):

> "The limits on NaOH volume and concentration ensure a pH value of between 7.5 and 11 for the solution recirculated within containment after a LOCA."

> "The limits on contained water volume and boron concentration of the RWST also ensure a pH value of between 7.5 and 11.0 for the solution recirculated within containment after a LOCA."

The limits (see enclosed Table 1) are based in part on the updated RB spray system/chemical drawdown pH analysis (G/C Calculation 2.6.1, Rev 1) described in Ref 4. This analysis is applicable to the current NSSS design which has D3 SGs.

G/C Calculation 2.6.1, Rev 1 also provides the basis for the spray pH assumptions used to qualify equipment. Current assumptions, per Ref 5, are outlined in Table 2. These are a subset of the Table 1 values. In general, higher spray pH's are utilized for qualification of electrical equipment inside containment since this is more limiting from an EQ standpoint.

This calculation will assess the impact of the Delta-75 SGs on Sump pH and Spray pH and determine if the current Tech Spec limits remains applicable and if current EQ assumptions regarding spray pH remain valid. A two part calculation will be performed.

> Part 1 will maintain the assumptions and methods utilized in the Ref 4 calculation except that the RCS volume will be updated to reflect the Delta 75 SGs. In general, a benchmark of the limiting Ref 4 calculation will be done followed by a new calculation with the

larger RCS volume. The part 1 calculation will determine the impact of the new SGs on the plant's current licensing basis. It is intended to show that the small increase in RCS volume will have a negligible change on sump and spray pH.

During conduct of the part 1 calculation, the input assumptions and methods used in the prior Ref 4 calculations were reviewed. Several inputs and assumptions were determined to not be bounding (i.e., not the most limiting value). In part 2, this review is documented and additional calculations are performed to assess potential impacts. Although the impact of the Delta-75 SGs will be included, Part 2 of this calculation goes beyond SG replacement. It will serve as a basis for recommendations concerning additional analyses or adjustment to spray/sump pH values.

The sole purpose of Revision 2 is to replace Westinghouse proprietary information with non-proprietary information. No methodology, calculations, results, or conclusions have been modified.

Specifically, Westinghouse correspondence that contained proprietary information were removed from the design inputs and placed into records that are referenced generally. The two instances where proprietary numbers are listed in the calculation body are replaced with generic discussions that do not affect the results of the calculation. Changes associated with revision 2 of this calculation are denoted by bold, italicized font with a revision bar. 2

TABLE 1

REACTOR BUILDING SPRAY SYSTEM pH
VANTAGE 5 CORE DESIGNS

DESCRIPTION	MINIMUM pH(1)	MAXIMUM pH(2)
Spray (Injection Phase)	8.8	10.1
Sump (@ end of Injection)	7.5	8.2
Spray (Recirculation Phase)	8.7	10.2
Sump (w/SHST empty)	8.1	8.3

Assumed Conditions:

1. Minimum pH Bases

   RWST = 2500 ppm Boron
   Accumulators = 2500 ppm Boron
   RCS = 2000 ppm Boron (nominal)
   SHST = 20 wt/% NaOH

2. Maximum pH Bases

   RWST = 2300 ppm Boron
   Accumulators = 2200 ppm Boron
   RCS = 2000 ppm Boron (nominal)
   SHST = 22 wt/% NaOH

DC00040-066, Rev 0
page 6

TABLE 2

EQUIPMENT QUALIFICATION pH ASSUMPTIONS

The chemical spray environment for which electrical equipment inside containment must be qualified is based upon the following post-accident operating periods and spray pH conditions:

Operating Period	Spray pH Range
0-2 hours (min)	8.7 - 10.2
2-24 hours (max)	8.1 - 8.3

Reference: Environmental Zone Data - General Notes
S-021-018, Sheet 2-2, Rev 6

2.0 REFERENCES

1. WCAP-13480, Westinghouse Delta-75 Steam Generator Design and Fabrication Information For the Virgil C. Summer Nuclear Station, August 1992.
2. SCE&G Letter, John L. Skolds to USNRC, "Revision to Technical Specification Bases 3/4.5.4 and 3/4.6.2.2 (TSP 900007-0).
3. CGGS-39100, "Post Accident Environmental Chemistry-Reactor Building", January 12, 1990.
4. G/C Calculation 2.6.1, Rev 1, "Post LOCA Environmental chemistry - Reactor Building.
5. Environmental Zone Data - General Notes S-021-018, Sheet 2-2, Rev 6.
6. VCSNS Technical Specifications, thru Adm 114.
7. LRC TWR 106, Serial 227-68-1864, Uprate Inputs.
8. STP-375.001, Rev 4, Change B, dated 9-11-90, Refueling Water Storage Tank Level Instrument (ILT00990) Calibration.
9. 1MS-18-002-1-4 3300 Gallon Sodium Hydroxide Storage Tank.
10. ECR-50328, RB Pressure & Temperature - LOCA
11. EQ / RG 1.97 DBD, Rev. 5 1
12. DC00020-005, Rev. 3, SG Replacement RB Temp/Press - LOCA
13. ***Westinghouse Letter CGE-93-0002SGUL, "VCSNS RSG/Uprating: NSSS Information for BOP Calculations."***
14. ***Westinghouse Letter CGE-93-0027SGUL, "VCSNS RSG/Uprating: Correction to Reactor Vessel Volume Data."*** 2

3.0 DESIGN INPUTS

1. RCS Liquid Volume With New Delta 75 SGs = 9383 ft3 per CGE-93-0002SGUL (***Reference 13***). 2

2. Increase in RCS volume due to Delta 75 SGs = 787 ft3 per CGE-93-0002SGUL ***(Reference 13)***.

3. Volume within the RV below the HL nozzles per CGE-93-0027SGUL (***Reference 14***). 2

4. G/C Calculation 2.6.1, Rev 1 for the overall approach and methodology of calculating the spray/sump pH (on microfilm: reel 1295, beginning on frame 1963).

5. RCS pH vs boron concentration per CP-614, Rev 9, Change B, Dated 2-15-94, "Reactor Coolant Chemistry Control" (figure enclosed).

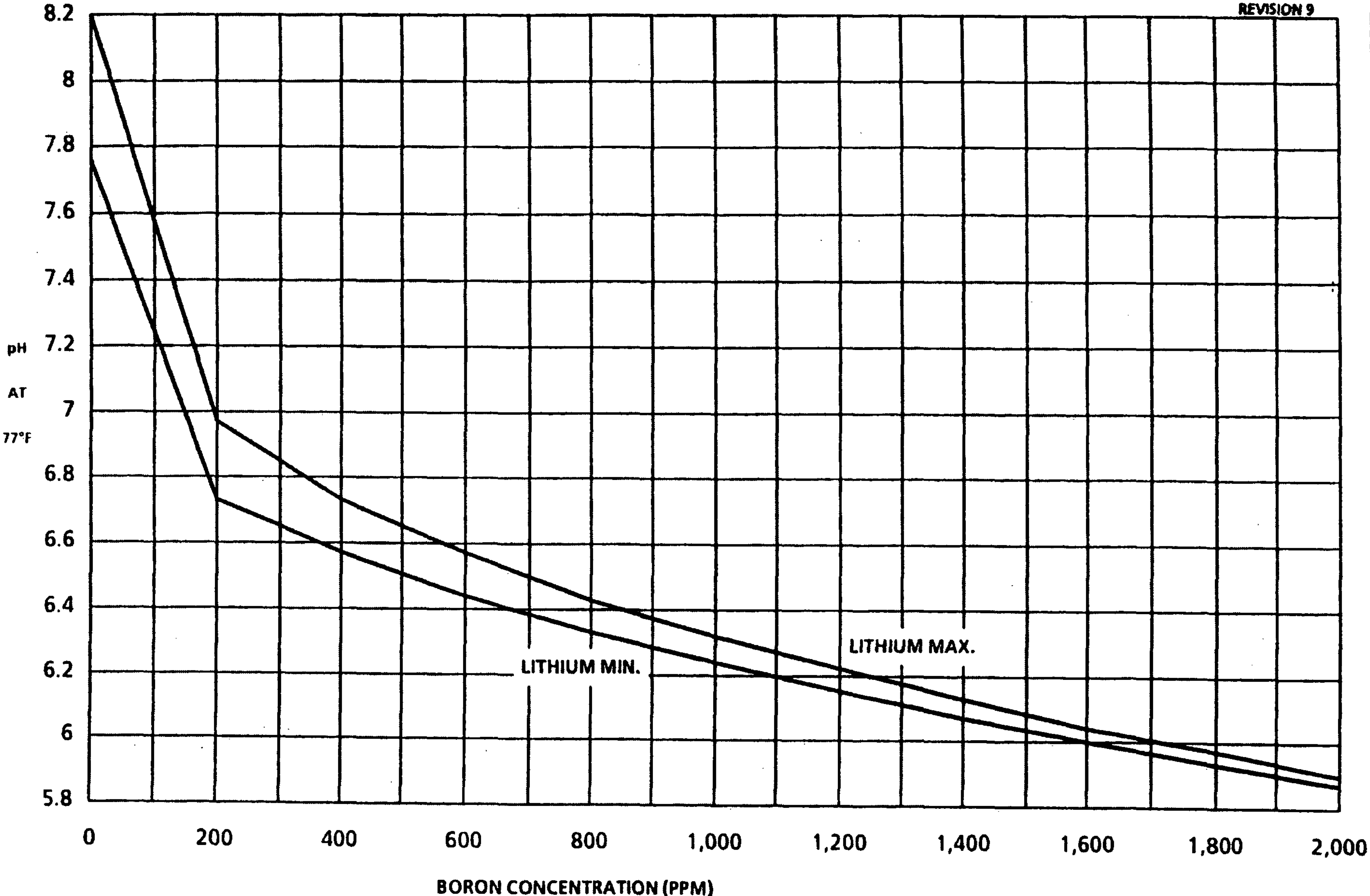
6. RCS Liquid Volume with current D3 SGs @ zero plugging = 8596 ft3 per CGE-93-002SGUL ***(Reference 13)***. 2

7. Station Curve Book Figure II-1.1, Critical Boron Concentration Versus Cycle Burnup Equilibrium Xenon and Samarium, Cycle 8, dated 4-20-93 (enclosed). (Typical Boron Letdown Curve)

8. Per App. B to Ref. 11, the post accident operating time corresponds to the time required to fulfill the intended safety function when subjected to any extremes of the environmental conditions. Per Ref. 10, the RB spray operating time in the LOCA RB P&T analysis (Ref. 12) is 40 days. 1

This page followed by page 18. 2

CALCULATED pH AT 77°F FOR THE COORDINATED LI/B CONTROL BAND

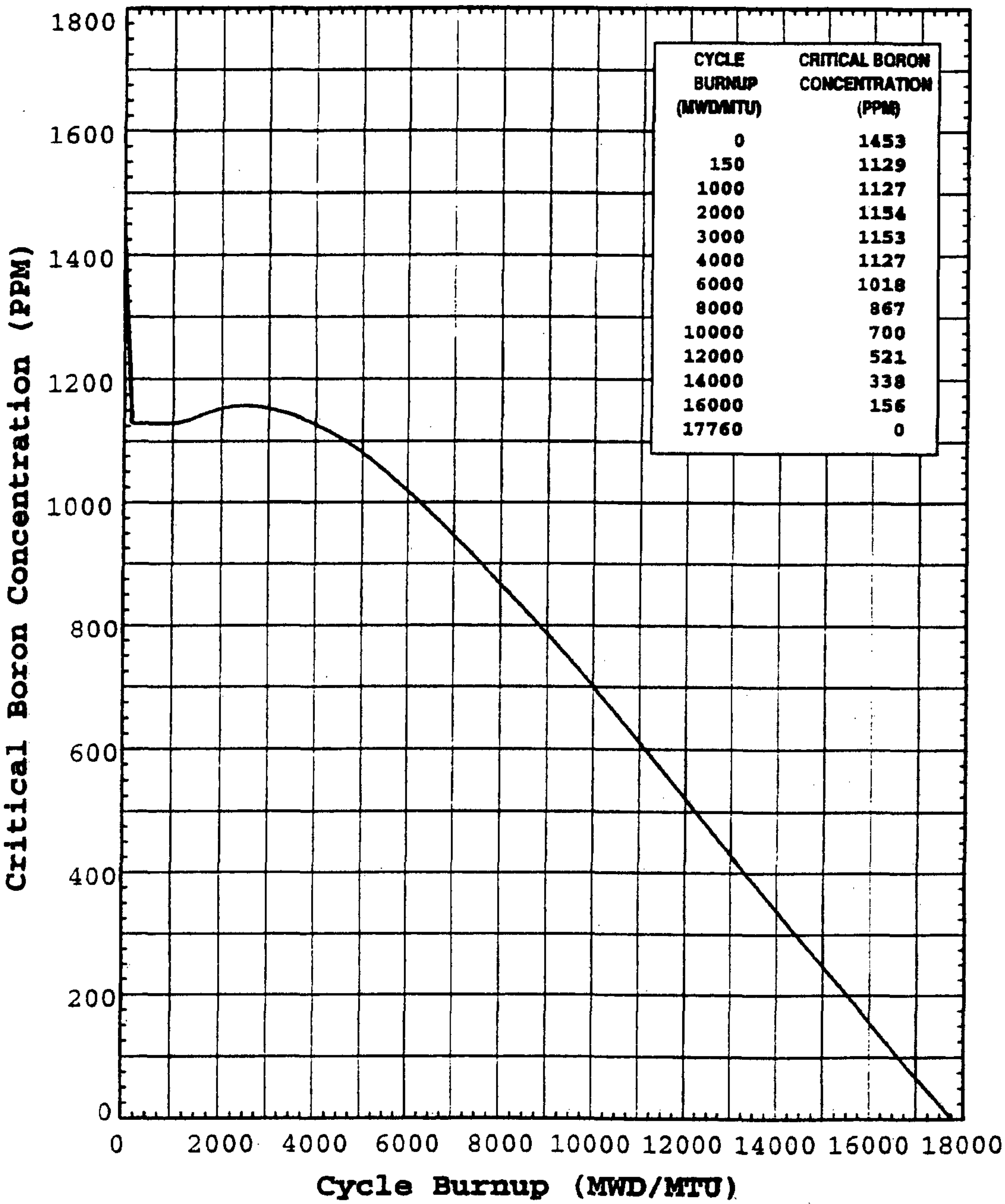


DC00040-066, REV 0 page 18

CP-614, REV 9, Change B, DATED 2-15-94
"REACTOR COOLANT CHEMISTRY CONTROL"
JRC
5-17-94

Figure II-1.1
Revision Date: 4-20-93
Prepared By: R L Harris
Verified By: John J Woods
Approved By: Will Haltiwanger

Critical Boron Concentration Versus Cycle Burnup
Equilibrium Xenon and Samarium
Cycle 8



CYCLE BURNUP (MWD/MTU)	CRITICAL BORON CONCENTRATION (PPM)
0	1453
150	1129
1000	1127
2000	1154
3000	1153
4000	1127
6000	1018
8000	867
10000	700
12000	521
14000	338
16000	156
17760	0

Tech. Spec. Ref.: N/A Procedure Ref.: REP-109.001 STP-201.001 Figure Ref.: Desn. Calc. DC0020A-025

DC0040-066, Rev 0
page 19

4.0 SYSTEM OPERATING CONDITIONS

Four significant operating combinations of the RB Spray pumps and ECCS pumps were evaluated in the Ref 4 calculation. They are as follows:

Ref 4 Calc Case #	Mode Designation	Spray Pump	RHR Pump	Chg/SI Pump
1	Design	1	1	1
2	Normal	2	2	3
3	Sp Pump Inoperable	1	2	3
4	RHR Pump Inoperable	2	1	3

A drawdown analysis for each of the above cases were evaluated for minimum (20 w/o) and maximum (22 w/o) NaOH in the Rev 0 calculation. The output (time response of tank levels) is a key input to the pH calculation. Key assumptions within the drawdown analysis were as follows:

1.The injection phase (i.e., spray suction from RWST) continues until the RWST Lo-LO Level setpoint @ 18% is reached. At that time, the recirculation phase with spray suction from the sump is assumed to begin.

2.The SHST continues to drain during the recirculation phase until all usable volume (i.e., level at centerline of the outlet nozzle) is depleted.

The calculated SHST levels at the end of injection are shown below for easy reference. The amount of NaOH injected to the sump during the injection phase is derived from the change in tank level and the tank's initial concentration.

SHST LEVEL @ THE END OF INJECTION

Ref 4 Calc Case #	Min NaOH Conditions @ 20 w/o With Initial Level of 37'	Max NaOH conditions @ 22 w/o with Initial Level of 38'
#1 - Design	8.7	8.92
#2 - Normal	8.95	6.8
#3 - Sp Pump Inoperable	14.2	14.8
#4 - RHR Pump Inoperable	2	2.5

5.0 KEY ANALYSIS INPUTS

The key assumptions/inputs from the Ref 4 calculations which will be utilized to analyze the impact of the new SGs are summarized below. These represent the plant's current basis of analysis.

BASE REF 4 ANALYSIS ASSUMPTIONS & INPUTS

Component	Input	Value for Max pH Calculations	Value for Min pH Calculations
RWST	Boron, ppm	2300	2500
	Initial Level, ft	49	51.15
	Level @ Lo-Lo Setpoint, ft	8.92	8.92
	Level Change, ft	40.08	42.23
	gal/ft	9399.6	9399.6
	Amount to Sump	Level Change To Lo-Lo Level	Level change to Lo-Lo Level
Accumulator	Boron, ppm	2200	2500
	Capacity, ft3	1001.1	1014.2
	Amount to Sump	All	All
RCS	Boron, ppm	2000	2000
	Liq Volume, ft3	8430	8430
	Vol below top of Core, ft3	1400	1400
	Density, lb/ft3	45.57	45.57
	Amount to Sump	Vol above top of Core (7030 ft3)	Vol above top of Core (7030 ft3)
SHST	w/o	22	20
	Density, lb/ft3	77.411	76.046
	Weight, lb/gal	10.35	10.17
	Initial Level, ft	38	37

SHST	Gal/ft	82.6	82.6
	Level @ end of injection	Per drawdown analysis - See Section 4.0	Per drawdown analysis - See Section 4.0
	Amount to Sump	All Usable Volume-Drained Empty to Outlet Centerline	All Usable Volume-Drained Empty to Outlet Centerline
RB Sprays	Flow Per Pump, gpm	2500	2500
	Inj Phase Boron, ppm	RWST @ 2300	RWST @ 2500
	Recirc Phase Boron, ppm	Sump @ 2300	Sump @ 2500

6.0 METHODOLOGY

The calculational methods utilized in the Ref 4 calculation will be applied. Basically, three types of pH calculations are performed:

Spray Header pH During Injection

Sump pH

Spray Header pH During Recirculation

The general methodology for these evaluations is outlined below.

6.1 Spray Header pH During Injection

The injection phase is assumed to last until the RWST Lo-Lo level setpoint @ 18% is reached. During the injection phase the spray header pH is controlled by the spray flow rate, boron concentration within the RWST, the flow rate from the SHST, and NaOH concentration within the SHST. In general, the following is done to calculate the spray header pH.

1. Spray flow is assumed constant at 2500 gpm per pump and is made up of flow from the RWST and flow from the SHST.

2. Initial conditions of the spray solution sources are assumed to either minimize\maximize pH (see Section 5.0).

3. The flow rates from the SHST into the spray header is taken from the drawdown analysis. From this flow and assumed NaOH concentration, the rate at which water and NaOH is added to the spray header from the SHST is determined.

4. The spray flow from the RWST is taken as the total flow (2500 gpm) minus the flow from the SHST.

5. Given the spray flow from the RWST, the amount of boric acid being added to the spray header is determined.

6. Assuming the flow streams from the RWST and SHST are perfectly mixed, the NaOH and H_3BO_3 molarities of the spray header solution is calculated.

7. Given the NaOH and H_3BO_3 molarities, the pH of the spray header solution is determined from ORNL data (see Section 6.4).

The methodology is outlined in Ref 4. Since the micro-film copy of the calculation is difficult to read, the basis inputs & equations utilized from the Ref 4 calculation will be restated to aid in the review of this Design Calculation.

Calculate the H_3BO_3 Molarity of the RWST

Using the CRC Handbook of Chemistry & Physics, the atomic weights of the elements comprising H_3BO_3 are:

Boron	= 10.82
Hydrogen	= 1.0
Oxygen	= 16

Molecular Weight of H_3BO_3 = 3 + 10.82 + 48 = 61.82

$$\text{Molarity} = M = \frac{\text{g-mole of solute}}{\text{liter of solution}}$$

$$M_{H3BO3} = \frac{\dfrac{\text{ppm x g-Boron}}{10^6\ \text{g-RWST Sol}} \times \dfrac{61.82\ \text{g-}H_3BO_3}{10.82\ \text{g-Boron}} \times \dfrac{1\ \text{g-mole}\ H_3BO_3}{61.82\ \text{g-}H_3BO_3}}{\text{liters of RWST solution}}$$

$$M_{H3BO3} = \frac{\text{ppm x (1/10.82) g-mole}\ H_3BO_3}{10^6\ \text{g-RWST Sol} \times \dfrac{1\ \text{liter}}{10^3\ \text{g-water}} \times \dfrac{1}{\text{sp gr}}\ \dfrac{\text{g-water}}{\text{g-RWST Sol}}}$$

$$M_{H3BO3} = \frac{\text{ppm x (1/10.82) g-mole}\ H_3BO_3}{10^3\ \text{liters}}$$

$$M_{H3BO3} = \frac{\text{ppm}}{1000} \times 0.0924 \times \text{sp-gr}$$

Assuming a specific gravity of 1.0 for RWST water, the boric acid molarity of the RWST solution becomes:

$$M_{H3BO3} = \frac{\text{ppm}}{1000} \times 0.0924,\quad \frac{\text{g-mole}\ H_3BO_3}{\text{liters RWST solution}}$$

Calculate the H_3BO_3 Molarity of the Spray

$$^{SP}M_{H3BO3} = {}^{RWST}M_{H3BO3} \times \frac{\text{liters of RWST}}{\text{liters of Spray}}$$

liters of spray = liters of RWST + liters of SHST

$$\frac{\text{liters of RWST}}{\text{liters of spray}} = \frac{\text{liters of spray} - \text{liters of SHST}}{\text{liters of spray}}$$

Treating the liter ratios in terms of flow

$$\frac{\text{liters-RWST}}{\text{liters-spray}} = \frac{2500 - SHST_{gpm}}{2500}$$ Where spray flow is 2500 gpm

The boric acid molarity of the spray flow then becomes:

$$^{SP}M_{H3BO3} = \frac{ppm}{1000} \times 0.0924 \times \frac{2500 - SHST_{gpm}}{2500}$$

Calculate the NaOH Molarity of the Spray Solution

The NaOH spray molarity can be calculated from the SHST flow and the total spray flow rate.

Using the CRC Handbook of Chemistry & Physics, the atomic weights of the elements comprising NaOH are:

Sodium = 23
Hydrogen = 1.0
Oxygen = 16

Molecular Weight of NaOH = 23 + 16 + 1 = 40

$$^{sp}M_{NaOH} = \frac{gpm_{shst}}{gpm_{spray}}\left(1000\frac{g_{H2O}}{l_{H2O}}\right)\left(SG\frac{\frac{g_{shst}}{l_{shst}}}{\frac{g_{H2O}}{l_{H2)}}}\right)\left(\frac{w\%}{100}\frac{g_{NaOH}}{g_{shst}}\right)\left(\frac{1}{40}\frac{g\text{-}mole_{NaOH}}{g_{NaOH}}\right)$$

$$^{sp}M_{NaOH} = \frac{1}{4}\left(\frac{gmp_{shst}}{gpm_{spray}}\right)w\% * SG\frac{g\text{-}mole_{NaOH}}{l_{shst}}$$

Given the following from the Ref 4 calculation:

Density of water @ 70°F = 62.305 lb/ft3 per Crane Paper 410

Density of 20 w/o NaOH sol = 76.046 lb/ft3

Density of 22 w/o NaOH sol = 77.4114 lb/ft3

The SHST solution specific gravity becomes:

@ 20 w/o, sp gr = 76.046/62.305 = 1.2205

@ 22 w/o, sp gr = 77.4114/62.305 = 1.2425

With a constant spray flow rate of 2500 gpm, the NaOH molarity for a 20 w/o solution in the SHST becomes:

@ 20 w/o, $^{sp}M_{NaOH} = \frac{1}{4} * 20 * 1.2205 * \frac{gpm_{shst}}{2500}$

@ 20 w/o, $^{sp}M_{NaOH} = 0.002441 \times gpm_{SHST}$

With a constant spray flow rate of 2500 gpm, the NaOH molarity for a 22 w/o solution in the SHST becomes:

@ 22 w/o, $^{sp}M_{NaOH} = \frac{1}{4} * 22 * 1.2425 * \frac{gpm_{shst}}{2500}$

@ 22 w/o, $^{sp}M_{NaOH} = 0.002734 \times gpm_{SHST}$

Within the Ref 4 calculation, these basis equations were coded into a LOTUS spreadsheet. This spreadsheet is not available. Therefore, a new spread sheet will be developed to do the subset of calculations of interest herein. An example is enclosed with comments added to explain the approach. This spreadsheet evaluates the spray pH at one point in time given the SHST flow tank and SHST/RWST initial conditions. Fluid properties are consistent with the Ref 4 calculations.

Calculation of - Maximum Spray pH- During Injection Phase

Example Case

Initial Conditions		Case Dependent Inputs	
RWST @	2500 ppm boron	SHST Flow =	35.3 gpm
SHST @	20 w/o		

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations of Molarities of the Spray Solution

H3BO3 Molarity = 0.0000924 x ppm x (2500 - SHST Flow)/2500

H3BO3 Molarity = 0.227738

NaOH Molarity = 0.002441 x SHST Flow

NaOH Molarity = 0.086167

Calculate the Spray pH using the ORNL Data

Spray pH = __________

```
A:A1: 'Calculation of - Maximum Spray pH- During Injection Phase
A:A2: '
A:A4: 'Example Case
A:A6: 'Initial Conditions
A:E6: 'Case Dependent Inputs
A:A8: 'RWST @
A:B8: 2500
A:C8: 'ppm boron
A:E8: 'SHST Flow =
A:G8: 35.3
A:H8: 'gpm
A:A9: 'SHST @
A:B9: 20
A:C9: 'w/o
A:A13: 'Constant Inputs
A:A15: 'Spray Train Flow = 2500 gpm total of spray solution
A:A19: 'Calculations of Molarities of the Spray Solution
A:A21: 'H3BO3 Molarity = 0.0000924 x ppm x (2500 - SHST
A:F21: 'ST Flow)/2500
A:A23: 'H3BO3 Molarity =
A:C23: 9.24E-05*B8*(2500-G8)/2500
A:A26: 'NaOH Molarity = 0.002441 x SHST Flow
A:A28: 'NaOH Molarity =
A:C28: 0.002441*G8
A:A31: 'Calculate the Spray pH using the ORNL Data
A:A33: 'Spray pH = __________
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DC00040-066, REV 0
page 28

6.2 Sump pH Calculations

In general terms, the following is done to determine the sump pH:

1. Sump solution sources are identified: RWST, SI Accumulators, RCS, and SHST.

2. Initial conditions of the sump solution sources are assumed to either minimize\maximize pH (see Section 5.0).

3. The amount of water, boric acid and NaOH added to the sump from each water source is then determined from the volume added and assumed density.

4. The NaOH and boric acid molarity of the sump solution is then calculated assuming perfect mixing.

5. Given the NaoH and boric acid molarity of the solution, the pH of the sump solution is determined from ORNL data (see Section 6.4).

This methodology is outlined in Ref 4. Since the micro-film copy of the calculation is difficult to read, the basis inputs and equations that are needed will be restated to aid in the review of this revision.

To convert ppm boron to w/o boric acid H_3BO_3:

Using the CRC Handbook of Chemistry & Physics, the atomic weights of the elements comprising H_3BO_3 are:

Boron	= 10.82
Hydrogen	= 1.0
Oxygen	= 16

Molecular Weight of H_3BO_3 = 3 + 10.82 + 48 = 61.82

$$1 \text{ w/o Boric Acid} = \frac{1 \text{ \# boric Acid}}{100 \text{ \# solution}}$$

$$\text{Boron} = \frac{10.82}{61.82} \text{ of boric acid}$$

$$1 \text{ w/o boric acid} = \frac{1 \text{ lbm } (10.82/61.82)}{100 \text{ lbm solution}} = \frac{0.175 \text{ lbm boron}}{100 \text{ lbm solution}}$$

$$= \frac{0.175 \times 10^4}{100 \times 10^4} = \frac{1750}{1000000} = 1750 \text{ ppm}$$

Therefore, for ppm level of 2000, 2300, 2500

2000 ppm = 2000/1750 = 1.143 w/o boric acid
2300 ppm = 2300/1750 = 1.314 w/o boric acid
2500 ppm = 2500/1750 = 1.428 w/o boric acid

To find the pounds of boric acid in a solution of ppm boron:

For water @ 70 F, v_f = 0.01605 ft3/lbm per ASME Steam Tables

$$\text{lbm/gal} = \frac{1}{(0.01605\ \text{ft3/lbm})(7.48\ \text{gal/ft3})} = 8.329$$

$$\text{lbm } H_3BO_3 = (\text{total gallons})(8.329\ \text{lbm/gal})\left(\frac{\text{ppm}}{1750 \times 100}\right)$$

To find pounds of NaOH in the solution added by the SHST:

@ 20 w/o v_f @ 70F = 0.01315 ft3/lbm per Met-Ed Data

$$1\ \text{gal} = \frac{1\ \text{gal}}{(0.01315\ \text{ft3/lbm})(7.48\ \text{gal/ft3})} = 10.17\ \text{lbm}$$

lbm of NaOH = (gallons from SHST)(10.17 lbm/gal)(0.2 lbm-Naoh/lb-SHST Solution)

@ 22 w/o v_f @ 70F = 0.012918 ft3/lbm per Met-Ed Data

$$1\ \text{gal} = \frac{1\ \text{gal}}{(0.012918\ \text{ft3/lbm})(7.48\ \text{gal/ft3})} = 10.35\ \text{lbm}$$

lbm of NaOH = (gallons from SHST)(10.35 lbm/gal)(0.22 lbm-Naoh/lb-SHST Solution)

To calculate the molarity of H_3BO_3 solution in the sump:

$$M_{H3BO3} = \frac{(\text{lbm of } H_3BO_3)(453.59\ \text{g/lbm})(1\ \text{g-mole}/61.82\ \text{g})}{(\text{lbs of solution})(453.59\ \text{g/lbm})(1\ \text{liter}/1000\ \text{g})}$$

$$= \frac{(\text{lbm of } H_3BO_3) \times (16.176 \text{ g-mole/liter})}{(\text{lbm of solution})}$$

To calculate the molarity of NaOH solution in the sump:

Using the CRC Handbook of Chemistry & Physics, the atomic weights of the elements comprising NaOH are:

Sodium	=	23
Hydrogen	=	1.0
Oxygen	=	16

Molecular Weight of NaOH = 23 + 16 + 1 = 40

$$M_{NaOH} = \frac{(\text{lbm of NaOH})(453.59 \text{ g/lbm})(1 \text{ g-mole/40 g})}{(\text{lbm of solution})(453.59 \text{ g/lbm})(1 \text{ liter/1000 g})}$$

$$= \frac{(\text{lbm of NaOH}) \times (25 \text{ g-mole/liter})}{(\text{lbm of solution})}$$

Within the Ref 4 calculation, these basis equations were coded into a LOTUS spreadsheet. This spreadsheet is not available. Therefore, a new spread sheet will be developed to do the subset of calculations of interest herein. An example is enclosed with comments added to explain the approach. Fluid properties are consistent with the Ref 4 calculations.

Calculation of Minimum Sump pH at the End of Injection

Case R2-1 Benchmark of Rev 1 Calculation

Base Assumptions

RWST @	2500	ppm boron with initial level at high level alarm
SI ACC @	2500	ppm boron with initial level at high level alarm
RCS @	2000	ppm boron
SHST @	20	w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	8430	ft3
Vol Below Top of C	1400	ft3

Net Water to Sump	7030	ft3
	320374.1	lbs
Mass Boric Acid	3661.418	
Water Mass	316712.6	

RWST @ 9399.6 gal/ft

Level Change	42.23	ft
Mass of Solution	3305850.	
Mass Boric Acid	47226.44	lbs
Water Mass	3258624.	lbs

SHST @ 82.6 gal/ft

Level Change	22.8	ft
Density	76.046	lb/ft3
Mass of Solution	19145.23	lb
Mass NaOH	3829.046	lb
Water Mass	15316.18	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	3661.418	0	316712.6	320374.1
RWST	47226.44	0	3258624.	3305850.
SHST	0	3829.046	15316.18	19145.23
Total	53630.72	3829.046	3779911.	3837371.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.024945

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.225948

Calculate the pH using the ORNL data

Sump pH =__________

DC00040-066, REV 0

page 32

```
A:A1: 'Calculation of Minimum Sump pH at the End of Injection
A:A3: 'Case R2-1   Benchmark of Rev 1 Calculation
A:A5: 'Base Assumptions
A:A6: 'RWST @
A:B6: 2500
A:C6: 'ppm boron with initial level at high level alarm
A:A7: 'SI ACC @
A:B7: 2500
A:C7: 'ppm boron with initial level at high level alarm
A:A8: 'RCS @
A:B8: 2000
A:C8: 'ppm boron
A:A9: 'SHST @
A:B9: 20
A:C9: 'w/o NaOH with level initially at 37 ft
A:A11: 'SI Accumulators
A:E11: 'RWST @
A:F11: 9399.6
A:G11: 'gal/ft
A:A13: '# of Tanks
A:C13: 3
A:E13: 'Level Change
A:G13: 42.23
A:H13: 'ft
A:A14: 'Vol per Tank
A:C14: 1027.3
A:D14: 'ft3
A:E14: 'Mass of Solution
A:G14: +F11*G13/7.4805*62.29934
A:A15: 'Density
A:C15: 62.2995
A:D15: 'lb/ft3
A:E15: 'Mass Boric Acid
A:G15: +B6/(1750*100)*G14
A:H15: 'lbs
A:A16: 'Mass of Solution
A:C16: +C13*C14*C15
A:D16: 'lbs
A:E16: 'Water Mass
A:G16: +G14-G15
A:H16: 'lbs
A:A17: 'Mass Boric Acid
A:C17: +B7/(1750*100)*C16
A:D17: 'lbs
A:E17: '
A:A18: 'Water Mass
A:C18: +C16-C17
A:D18: 'lbs
A:A20: 'Reactor Coolant System
A:E20: 'SHST @
A:F20: 82.6
A:G20: 'gal/ft
A:A22: 'Density
A:C22: 45.57242
A:D22: 'lb\ft3
A:E22: 'Level Change
```

DC00040-066, REV 0

```
A:G22: 22.8
A:H22: 'ft
A:E23: 'Density
A:G23: 76.046
A:H23: 'lb/ft3
A:A24: 'RCS Liq Vol
A:C24: 8430
A:D24: 'ft3
A:E24: 'Mass of Solution
A:G24: +G22*F20*1/7.4805*G23
A:H24: 'lb
A:A25: 'Vol Below Top of Core
A:C25: 1400
A:D25: 'ft3
A:E25: 'Mass NaOH
A:G25: +B9/100*G24
A:H25: 'lb
A:C26: '----------
A:E26: 'Water Mass
A:G26: +G24-G25
A:H26: 'lb
A:A27: 'Net Water to Sump
A:C27: +C24-C25
A:D27: 'ft3
A:C28: +C27*C22
A:D28: 'lbs
A:A30: 'Mass Boric Acid
A:C30: +C28*(B8/175000)
A:A31: 'Water Mass
A:C31: +C28-C30
A:B35: 'lbs
A:C35: 'lbs
A:D35: 'lbs
A:E35: 'lbs
A:A36: 'Source
A:B36: 'H3BO3
A:C36: 'NaOH
A:D36: 'Water
A:E36: 'Solution
A:A37: '--------
A:B37: '--------
A:C37: '--------
A:D37: '--------
A:E37: '--------
A:A38: 'Accum
A:B38: +C17
A:C38: 0
A:D38: +C18
A:E38: +C16
A:A39: 'RCS
A:B39: +C30
A:C39: 0
A:D39: +C31
A:E39: +C28
A:A40: 'RWST
A:B40: +G15
```

```
A:C40: 0
A:D40: +G16
A:E40: +G14
A:A41: 'SHST
A:B41: 0
A:C41: +G25
A:D41: +G26
A:E41: +G24
A:A42: '--------
A:B42: '--------
A:C42: '--------
A:D42: '--------
A:E42: '--------
A:A43: 'Total
A:B43: +B38+B39+B40+B41
A:C43: +C38+C39+C40+C41
A:D43: +D38+D39+D40+D41
A:E43: +E38+E39+E40+E41
A:A45: 'Calculate Molarity per the G/C Method
A:A47: 'NaOH Molarity  = (Total lbs NaOH)(25)/(Total lbs Solution)
A:A48: '               =
A:C48: +C43*25/E43
A:A50: 'H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
A:A51: '               =
A:C51: +B43*16.167/E43
A:A54: 'Calculate the pH using the ORNL data
A:A56: 'Sump pH =
A:B56: '__________
```

TC00040-066, REV0

Page 35

6.3 Spray Header pH During Recirculation

The pH in the spray header during recirculation is evaluated in the Ref 4 calculation assuming the RB pressure is 0.0 psig and the SHST continues to drain. This is noted as a conservative approach since it leads to max pH values. The general approach taken in the Ref 4 calculation will be applied. Key elements are:

1. Sump solution sources are identified: RWST, SI Accumulators, RCS, and SHST.

2. Initial conditions of the sump solution sources are assumed to either minimize\maximize pH (see Section 5.0).

3. The makeup of the sump solution (amount of solution & amount of NaOH) are assumed constant and equal to those at the end of the injection phase. No adjustment in the sump conditions during recirculation is made even though NaOH is being gravity feed into the spray as the SHST empties.

4. The sump boron level is set equal to the RWST value and held constant (i.e., at 2500 ppm boron when min pH is being evaluated and 2300 ppm when max pH is being evaluated).

5. Spray flow is assumed constant at 2500 gpm and is made up of flow from the sump and flow from the SHST.

6. The flow rate from the SHST into the spray header is taken from the drawdown analysis. From this flow and assumed NaOH concentration, the rate at which water and NaOH is added to the spray header from the SHST is determined.

7. The spray flow from the sump is taken as the total flow (2500 gpm) minus the flow from the SHST.

8. Given the spray flow rate from the sump & the amount of NaOH in the sump, the rate at which NaOH is added to the spray header from the sump is calculated assuming the sump solution is homogeneously mixed.

9. Given the spray flow from the sump & assumed boron concentration, the rate at which H_3BO_3 is added to the spray header from the sump is calculated assuming the sump solution is homogeneously mixed.

10. Assuming the flow streams from the sump and SHST are perfectly mixed, the NaOH and H_3BO_3 molarities of the spray header solution are calculated.

11. Given the NaOH and H_3BO_3 molarities, the pH of the spray header solution is determined from ORNL data (see Section 6.4).

The methodology is outlined in Ref 4. Since the micro-film copy of the calculation is difficult to read, the basis inputs and equations that are needed will be restated to aid in the review of this revision.

In min-mode with NaOH @ 20 w/o

Calculate lbm/min of NaOH injected into the spray header from SHST given SHST tank flow in gpm from the drawdown analysis:

$$\text{NaOH Injected} = \frac{\text{gal SHST Inj}}{\text{min}} \times 10.17\,\frac{\text{lbm NaOH Soln}}{\text{gal NaOH Soln}} \times \frac{0.2\ \text{lbm NaOH}}{\text{lbm Soln NaOH}}$$

$$= (\text{gpm})_{SHST} \times 2.034,\ \text{lbm-NaOH/min}$$

Given the lbm of NaOH in the sump, the total lbm of sump solution, and a constant spray flow rate of 2500 gpm, calculated the lbm/min of NaOH injected into the spray header by the spray pump upstream of the SHST addition point.

$$\text{NaOH Sprayed} = \frac{\text{lbm-NaOH in sump}}{\text{lbm soln in sump}} \times 8.329\,\frac{\text{lbm sump soln}}{\text{gal sump soln}} \times (2500 - \text{gpm}_{SHST})\,\frac{\text{gal sump soln}}{\text{min}},\ \frac{\text{lbm NaOH}}{\text{min}}$$

The total NaOH into the spray header then becomes the sum of the NaOH injected from the SHST and from the sump by the spray pump.

$$\text{Header NaOH} = \text{NaOH Injected} + \text{NaOH Sprayed},\ \frac{\text{lbm-NaOH}}{\text{min}}$$

Knowing the mass addition rate to the header, the NaOH molarity of the header solution is calculated:

$$M_{NaOH} = \frac{\left(\text{Header NaOH}, \frac{\text{lbm-NaOH}}{\text{min}}\right) \times 453.59\,\frac{\text{g}}{\text{lbm}}}{2500\,\frac{\text{gal-soln}}{\text{min}} \times 3.785\,\frac{\text{l}}{\text{gal}} \times 40\,\frac{\text{g}}{\text{g-mole}}}$$

$$= 0.001198 \times (\text{Header NaOH}),\ \frac{\text{g-mole}}{\text{l}}$$

where Header NaOH = lbm-NaOH/min

In preparation to calculate the boric acid molarity, the lbm/min of H_3BO_3 added to the spray header from the sump is calculated given the gpm flow of sump solution and ppm level of the sump solution.

$$H_3BO_3 \text{ Sprayed} = \frac{\text{gal } H_3BO_3 \text{ soln}}{\text{min}} \times 8.329 \frac{\text{lbm } H_3BO_3 \text{ soln}}{\text{gal } H_3BO_3 \text{ soln}} \times \frac{\text{ppm}}{1750 \times 100}$$

$$= (\text{ppm})(4.7594 \text{ X } 10^{-5})\ \text{gpm}_{\text{sump-H3BO3 soln}},\ \frac{\text{lbm-}H_3BO_3}{\text{min}}$$

where $\text{gpm}_{\text{sump-H3BO3 soln}} = 2500 - (\text{gpm})_{\text{SHST}}$

The molarity then becomes:

$$MH_3BO_3 = \frac{(H_3BO_3 \text{ Sprayed}, \frac{\text{lbm-}H_3BO_3}{\text{min}})}{2500 \frac{\text{gal soln}}{\text{min}}} \times 453.59 \frac{\text{g}}{\text{lbm}} \times \frac{1 \text{ gal}}{3.785 \text{ l}} \times \frac{1 \text{ g-mole}}{61.82 \text{ g}}$$

$$= (7.754 \times 10^{-4}) \times H_3BO_3 \text{ Sprayed},\ \frac{\text{g-mole}}{\text{l}}$$

where $H_3BO_3 \text{ Sprayed} = \frac{\text{lbm-}H_3BO_3}{\text{min}}$

In max mode where NaOH is 22 w/o

use $\frac{0.22 \text{ lbm NaOH}}{\text{lbm soln NaOH}}$ & $10.35 \frac{\text{lbm NaOH soln}}{\text{gal Naoh soln}}$

$$\text{NaOH Injected} = \frac{\text{gal NaOH Soln Inj}}{\text{min}} \times 10.35 \frac{\text{lbm NaOH Soln}}{\text{gal NaOH Soln}} \times \frac{.22 \text{ lbm NaOH}}{\text{lbm Soln NaOH}}$$

$$= 2.277 \times (\text{gpm})_{\text{SHST}},\ \frac{\text{lbm-NaOH}}{\text{min}}$$

With the above change the remaining equations remain the same.

The above equation were also programmed in a Lotus spreadsheet which calculated the spray header pH for one point in time. An example is enclosed and comments are provided to illustrate the method.

Calculation of -Minimum Spray pH- During
Recirculation Prior to Emptying The SHST

Case R2-5: Benchmark of Rev 1 Calculation

Initial Conditions		Case Dependent Inputs	
RWST @	2500 ppm boron	SHST Flow =	21.5 gpm
SI ACC @	2500 ppm boron	NaOH in Sump =	3829.04 lbm
RCS @	2000 ppm boron	Total Sump Soln =	3837370. lbm
SHST @	20 w/o NaOH	Sump ppm =	2500 ppm

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations

NaOH Injected = 2.034 x NaOH Flow

= 43.731 lbm/min

NaOH Sprayed = $\frac{\text{NaOH in Sump}}{\text{Total Sump Soln}}$ x 8.329 x (2500 - NaOH Flow)

= 20.59861 lbm/min

Total NaOH Into Hrd = NaOH Injected + NaOH Sprayed

= 64.32961 lbm/min

NaOH Molarity = 0.001198 x (Total NaOH Into Hrd)

= 0.077066 g-mole/l

H3BO3 Sprayed = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)

= 294.9043 lbm/min

H3BO3 Molarity = 7.754E-04 x H3BO3 Sprayed

= 0.228668

Calculate the pH using the ORNL Data

Spray pH = __________

DC00040-066, REV 0
Page 39

```
A:A1: 'Calculation of -Minimum Spray pH- During
A:A2: 'Recirculation Prior to Emptying The SHST
A:A4: 'Case R2-5: Benchmark of Rev 1 Calculation
A:A6: 'Initial Conditions
A:E6: 'Case Dependent Inputs
A:A8: 'RWST @
A:B8: 2500
A:C8: 'ppm boron
A:E8: 'SHST Flow =
A:G8: 21.5
A:H8: 'gpm
A:A9: 'SI ACC @
A:B9: 2500
A:C9: 'ppm boron
A:E9: 'NaOH in Sump =
A:G9: 3829.04
A:H9: 'lbm
A:A10: 'RCS @
A:B10: 2000
A:C10: 'ppm boron
A:E10: 'Total Sump Soln =
A:G10: 3837370.18
A:H10: 'lbm
A:A11: 'SHST @
A:B11: 20
A:C11: 'w/o NaOH
A:E11: 'Sump ppm =
A:G11: 2500
A:H11: 'ppm
A:A13: 'Constant Inputs
A:A15: 'Spray Train Flow = 2500 gpm total of spray solution
A:A19: 'Calculations
A:A21: 'NaOH Injected = 2.034 x NaOH Flow
A:B22: '
A:B23: '     =
A:C23: 2.034*G8
A:D23: 'lbm/min
A:A26: 'NaOH Sprayed      =   NaOH in Sump    x 8.329 x (2500 - NaOH Flow)
A:C27: '  ---------------
A:C28: '  Total Sump Soln
A:C30: '=
A:D30: +G9/G10*8.329*(2500-G8)
A:E30: 'lbm/min
A:A33: 'Total NaOH        = NaOH Injected + NaOH Sprayed
A:A34: 'Into Hrd
A:C35: '=
A:D35: +C23+D30
A:E35: 'lbm/min
A:A38: 'NaOH Molarity     = 0.001198 x (Total NaOH Into Hrd)
A:C40: '=
A:D40: 0.001198*D35
A:E40: 'g-mole/l
A:A43: 'H3BO3 Sprayed     = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)
A:B45: '
A:C45: '=
A:D45: (4.7594E-05)*(2500-G8)*G11
```

DC00040-066, REV 0
Page 40

```
A:E45: 'lbm/min
A:A48: 'H3BO3 Molarity    = 7.754E-04 x H3BO3 Sprayed
A:C50: '=
A:D50: (0.0007754)*D45
A:A53: 'Calculate the pH using the ORNL Data
A:A55: 'Spray pH = __________
```

DC00040-066, REV 0

Page 41

6.4 Reference pH Data

The RB spray and sump pH conditions are determined, given the NaOH and H_3BO_3 molarities, from data in ORNL-2984 based on 25°C or 77°F. The reference figures are contained in Ref 4. They are also enclosed, for information only, to help facilitate review of this calculation.

The enclosed curves are viewed as "crude" for the desired resolution of the these calculation. However, they are the basis for the current analysis and do represent the best information available.

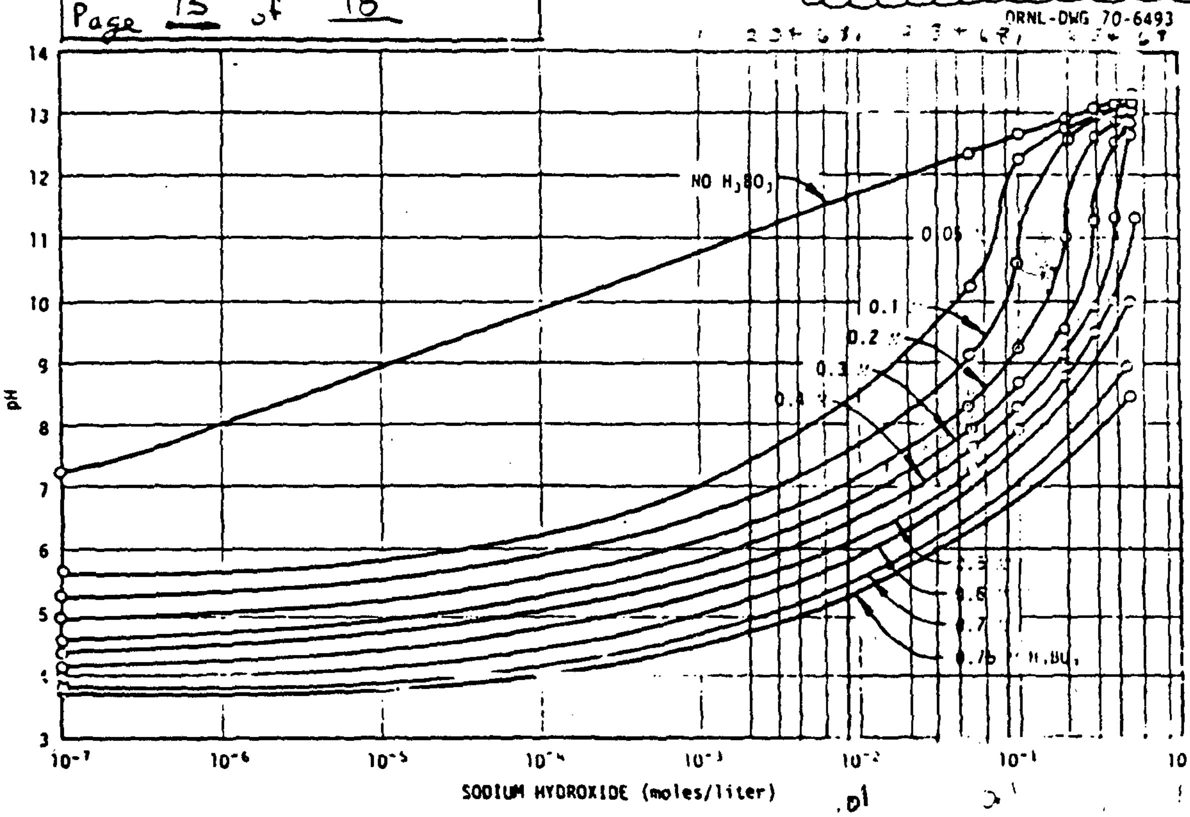
SP SYSTEM

DB Stauffer 01/11/90
SP-13.1 Rev 2
Page 15 of 18

From ORNL 2104 per
copy from K. R. Conn copy -
10-27-76, AL
page 6A of 7
W.O. 04446100
containment building spray system

21

Ref 4.1



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JM 9-28-94

Fig. 4.1. pH Values for H_3BO_3-NaOH Solutions. [From data supplied by Stone and Webster Engineering Corporation and obtained from the following references:

a. *Kirk-Othmer Encyclopedia of Chemical Technology*, 2nd ed., Interscience, New York, 1969.

b. S. J. Kiehl and R. D. Loucks, Systemic pH Values of Some Solutions in the Alkaline Range, *Trans. Electrochem. Soc.*, 67: 81–100 (1935).

c. I. M. Kolthoff and W. Bosch, The Abnormal pH Change in Boric Acid-Soda Liquor Mixtures of Different Dilutions and Temperatures, *Rec. Trav. Chim.*, 46: 180–188 (1927).]

Per Ken Conn, all data hereon were evaluated at 25°C.
∴ data listed on page 6 of 7 is at 25°C

Jim Neeley

5683

DC00040-066, REV0
Page 43

1147

0.21
0.22
0.23
0.24

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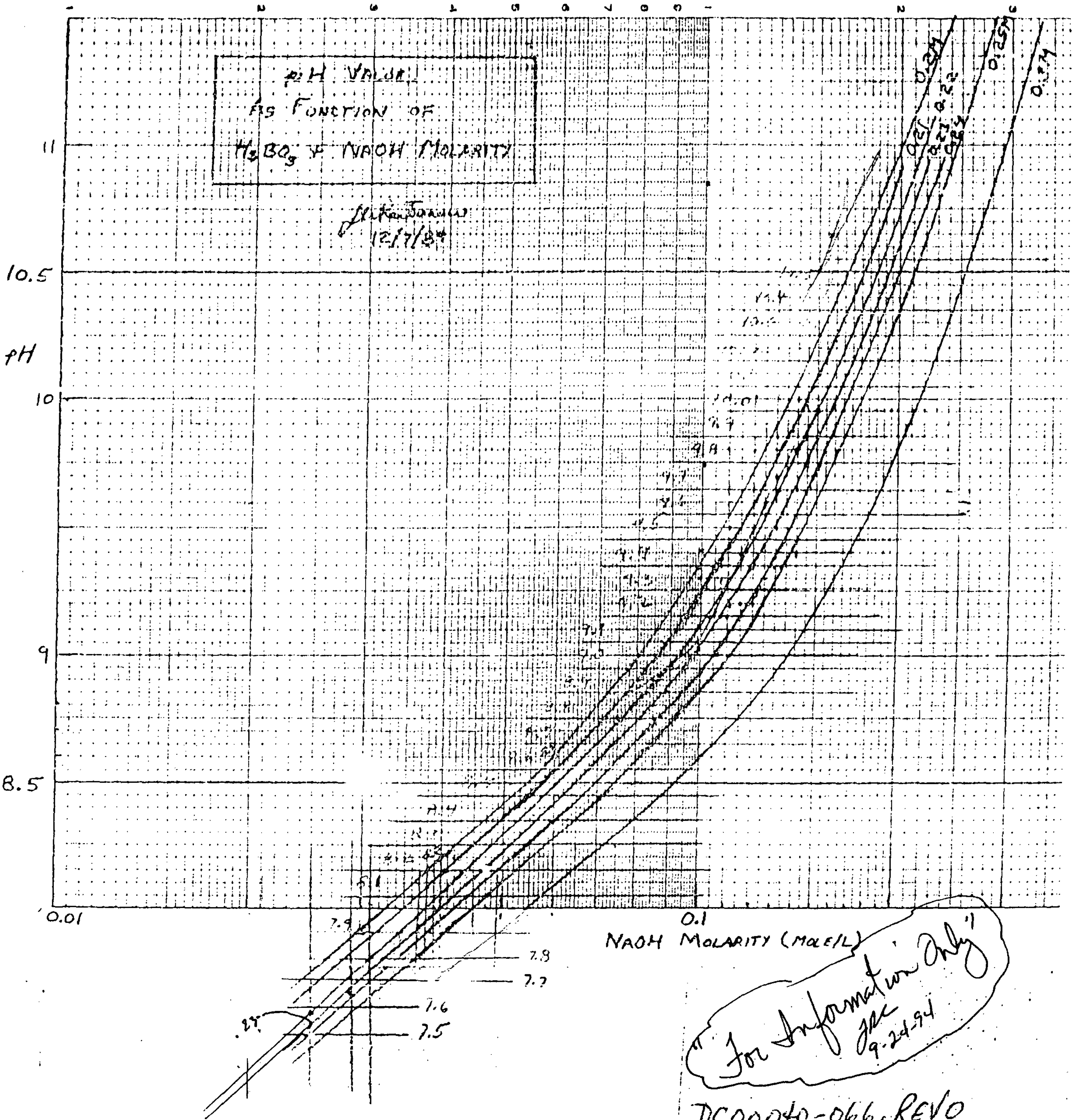

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DC00040-066, REV0
Page 44

7.0 CALCULATIONS

A two part calculation will be performed as described in Section 1.0.

7.1 Part 1 - Impact of Delta-75 SGs

The increase in RCS volume due to the Delta-75 SGs will have no effect on the spray pH during the injection phase since it is totally dependent on the spray flow off the RWST and drawdown of the SHST. At the end of the injection phase, the spray suction is transferred to the sump. The additional mass of the Delta-75 SG will tend to decrease the sump pH at the onset of sump recirculation. The lower sump pH will in-turn decrease the spray pH until the SHST empties and, and in the long term the equilibrium sump/spray pH will also be lower. Therefore, the increase in RCS volume due to the Delta 75 SGs will challenge the following minimum pH limits defined in Table 1:

Sump (@ end of Injection)	7.5
Spray (Recirculation Phase)	8.7
Sump (w/SHST empty)	8.1

The maximum pH limits in Table 1 are conservative for the increase in RCS volume due to the Delta-75 SGs and are therefore not challenged.

7.1.2 Assumptions

The input assumptions made in the Ref 4 calculation will be maintained. Major inputs and assumptions are itemized in Section 4.0 and 5.0.

7.1.3 Calculational Methods

The calculation method utilized in the Ref 4 calculation, as outlined in Section 6.0, will be maintained. Correct application of the methodology is verified via conduct of a benchmark to the limiting pH condition from the Ref 4 calculation. During the course of the benchmarking activity, several errors were discovered. These are corrected, assessed for impact, and documented.

7.1.4 Computer Calculations

Lotus based worksheets were developed for these calculation as outlined in Section 6.0 based on the Ref 4 methodology. These worksheets are automated "hand calculations" easily verified with a calculator. Their accuracy is cross-checked against the Ref 4 calculations via the benchmark activities.

7.1.5 Min Sump pH - @ the End of Injection

Within the Ref 4 calculation, the min sump pH (7.5) is calculated to occur at the onset of sump recirculation prior to the depletion of the SHST. This occurs for min NaOH initial conditions, maximum boron initial conditions in the RWST and SI Accumulators, with one spray pump operating and corresponds to Case 3 of the Ref 4 calculation.

The limiting Ref 4 calculation is repeated in the enclosed Lotus spreadsheet entitled Case R2-1. The Case R2-1 results are essentially identical (small roundoff differences only) to those in the Ref 4 calculation. Case R2-1 is thus considered a good benchmark.

The Lotus spreadsheet entitled Case R2-2 repeats the Case R2-1 calculation except that the RCS volume of 8430 ft3 is increased to 9383 ft3 to reflect the impact of the Delta 75 SGs. Using the ORNL data of Section 6.4 and the calculated molarities, the sump solution pH is estimated to remain approximately 7.5. Therefore, the increase in RCS volume due to the larger SGs has a negligible impact on prior calculations performed to determine the minimum sump pH at the end of the injection phase.

Calculation of Minimum Sump pH at the End of Injection

Case R2-1 Benchmark of Rev 1 Calculation

Base Assumptions

RWST @	2500 ppm boron with initial level at high level alarm
SI ACC @	2500 ppm boron with initial level at high level alarm
RCS @	2000 ppm boron
SHST @	20 w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

RWST @ 9399.6 gal/ft

Level Change	42.23	ft
Mass of Solution	3305850.	
Mass Boric Acid	47226.44	lbs
Water Mass	3258624.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	8430	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7030	ft3
	320374.1	lbs
Mass Boric Acid	3661.418	
Water Mass	316712.6	

SHST @ 82.6 gal/ft

Level Change	22.8	ft
Density	76.046	lb/ft3
Mass of Solution	19145.23	lb
Mass NaOH	3829.046	lb
Water Mass	15316.18	lb

DC00040-066, REV 0
Page 47

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	3661.418	0	316712.6	320374.1
RWST	47226.44	0	3258624.	3305850.
SHST	0	3829.046	15316.18	19145.23
Total	53630.72	3829.046	3779911.	3837371.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.024945

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.225948

Calculate the pH using the ORNL data

Sump pH ≈ 7.5

Calculation of Minimum Sump pH at the End of Injection

Case R2-2: Update to Case R2-1 To Reflect Delta-75 SGs

Base Assumptions

RWST @	2500 ppm boron with initial level at high level alarm
SI ACC @	2500 ppm boron with initial level at high level alarm
RCS @	2000 ppm boron
SHST @	20 w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

RWST @ 9399.6 gal/ft

Level Change	42.23	ft
Mass of Solution	3305850.	
Mass Boric Acid	47226.44	lbs
Water Mass	3258624.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	9383	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7983	ft3
	363804.6	lbs
Mass Boric Acid	4157.767	
Water Mass	359646.8	

SHST @ 82.6 gal/ft

Level Change	22.8	ft
Density	76.046	lb/ft3
Mass of Solution	19145.23	lb
Mass NaOH	3829.046	lb
Water Mass	15316.18	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	4157.767	0	359646.8	363804.6
RWST	47226.44	0	3258624.	3305850.
SHST	0	3829.046	15316.18	19145.23
Total	54127.07	3829.046	3822845.	3880801.

DC00040-066, REV 0

Page 48

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.024666

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.225487

Calculate the pH using the ORNL data

Sump pH ≅ 7.5

7.1.6 Min Sump Equilibrium pH (w/SHST Empty)

The Ref 4 calculation assumes that the SHST continues to drain during the recirculation period in order to maximize the sump/spray pH (i.e., conservative from a EQ standpoint). A value of 8.1 is calculated in the Ref 4 calculation for min NaOH initial conditions in the SHST and maximum boron initial conditions in the RWST and SI Accumulators.

The limiting Ref 4 calculation is repeated in the enclosed Lotus spreadsheet entitled Case R2-3. The Case R2-3 results do not agree with the Ref 4 calculation. The breakdown of mass of solution, mass of boric acid, water mass and NaoH mass of the individual sources of sump solution are essentially identical (small roundoff differences only) to those in the Ref 4 calculation; however, when the individual components were summed, it appears that the spreadsheet in the Ref 4 calculation has an error. The calculations agree on the lbm of NaOH from the SHST, lbm H_3BO_3 from RWST and the total lbm of solution in the sump. However, differences are present for the total H_3BO_3 in the sump and total lbs of water in the sump. The error in the Ref 4 calculation is due to use of the wrong lbs of H_3BO_3 from the RWST being used in the summation to calculate the total amount of boric acid in the sump. The lbs of boric acid from the RWST was based on the calculated value assuming an initial level of 49 ft as opposed to 51.15 feet:

Total H_3BO_3 = SI Acc + RCS + RWST
= 2642.87+3661.42+44822.05
= 51226.34

Without the spread sheet, I cannot be certain how the total lbm of water in the sump was calculated in the Ref 4 calculation since the correct total lbm of sump solution was calculated. It can, however, be derived as follows:

lbm sump water = Total lbm Sump Solution - lbm H_3BO_3 - lbm NaOH
= 3849293.94-51226.34-6213.79
= 3791853.81 lbm

Nonetheless, the Case R2-3 calculation corrects this discrepancy and the sump pH is calculated to be 8.0 as opposed to 8.1 in the Ref 4 calculation. Since the intent of the ref 4 calculation was to maximize the pH for EQ consideration, the use of 8.1 would continue to be conservative..

The Lotus spreadsheet entitled Case R2-4 repeats the Case R2-3 calculation except that the RCS volume of 8430 ft3 is increased to 9383 ft3 to reflect the impact of the Delta 75 SGs. Using the ORNL data and the calculated molarities, the sump solution pH is estimated to remain approximately 8.0. Therefore, the increase in RCS volume due to the larger SGs has a negligible impact on prior calculations performed to determine the minimum equilibrium sump pH after the SHST empties.

Calculation of Minimum Equilibrium Sump pH After The SHST Empties

Case R2-3 - Benchmark of the Rev 1 Calculation

Base Assumptions

RWST @	2500	ppm boron with initial level at high level alarm
SI ACC @	2500	ppm boron with initial level at high level alarm
RCS @	2000	ppm boron
SHST @	20	w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

RWST @ 9399.6 gal/ft

Level Change	42.23	ft
Mass of Solution	3305850.	
Mass Boric Acid	47226.44	lbs
Water Mass	3258624.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	8430	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7030	ft3
	320374.1	lbs
Mass Boric Acid	3661.418	
Water Mass	316712.6	

SHST @ 82.6 gal/ft

Level Change	37	ft
Density	76.046	lb/ft3
Mass of Solution	31069.01	lb
Mass NaOH	6213.803	lb
Water Mass	24855.21	lb

DC00040-066, REV 0
Page 51

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	3661.418	0	316712.6	320374.1
RWST	47226.44	0	3258624.	3305850.
SHST	0	6213.803	24855.21	31069.01
Total	53630.72	6213.803	3789450.	3849294.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.040356

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.225248

Calculate the pH using the ORNL data

Sump pH = >8.0

Calculation of Minimum Equilibrium Sump pH After The SHST Empties

Case R2-4: Update of Case R2-3 Calculation To Reflect Delta 75 SGs

Base Assumptions

RWST @	2500 ppm boron with initial level at high level alarm
SI ACC @	2500 ppm boron with initial level at high level alarm
RCS @	2000 ppm boron
SHST @	20 w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

RWST @ 9399.6 gal/ft

Level Change	42.23	ft
Mass of Solution	3305850.	
Mass Boric Acid	47226.44	lbs
Water Mass	3258624.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	9383	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7983	ft3
	363804.6	lbs
Mass Boric Acid	4157.767	
Water Mass	359646.8	

SHST @ 82.6 gal/ft

Level Change	37	ft
Density	76.046	lb/ft3
Mass of Solution	31069.01	lb
Mass NaOH	6213.803	lb
Water Mass	24855.21	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	4157.767	0	359646.8	363804.6
RWST	47226.44	0	3258624.	3305850.
SHST	0	6213.803	24855.21	31069.01
Total	54127.07	6213.803	3832384.	3892725.

DC00040-066, REV 0

Page 52

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.039906

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.224796

Calculate the pH using the ORNL data

Sump pH = >8.0

7.1.7 Min Spray pH - Recirculation (W/O SHST Empty)

The SHST does not empty during the injection period. Within the Ref 4 calculation, the SHST is assumed to drain until empty. During the drain period, the spray pH is controlled primarily by the flow rate from the SHST. The drawdown analysis shows that the SHST drain flow slowly decreases thus resulting in a similar decrease in spray pH. The minimum value occurs just prior to emptying the SHST. A min spray pH of 8.7 is calculated for cases 2a, 2b, and 3 within the Ref 4 calculation. Cases 3 and 2a will be evaluated.

The Ref 4 calculation for case 3 is repeated in the enclosed Lotus spreadsheet entitled Case R2-5. The Case R2-5 results are essentially identical (small roundoff differences only) to those in the Ref 4 calculation. Case R2-5 is thus considered a good benchmark. It is noted that the amount of sump solution is assumed to remain constant and equal to that calculated at the end of the injection phase and that the boron concentration of the sump solution is set equal to 2500 ppm. Both assumptions would tend to minimize the spray pH.

The Lotus spreadsheet entitled Case R2-6 repeats the Case R2-5 calculation to reflect the impact of the Delta 75 SGs. The larger RCS volume will increase the amount of sump solution and its boron level. However, since the sump solution boron level is assumed constant at 2500 ppm, the impact of the larger SGs will be limited to an increase in the total amount of sump solution. Per the Case R2-2 calculation, the new total amount of sump solution is 3,880,801 lbs (an increase of 43431 lbm). Case R2-6 reflects this change. Using the ORNL data and the calculated molarities, the sump solution pH is estimated to remain approximately 8.7.

The Ref 4 calculation for case 2a is repeated in the enclosed Lotus spreadsheet entitled Case R2-7. The Case R2-7 results are essentially identical (small roundoff differences only) to those in the Ref 4 calculation. Case R2-7 is thus considered a good benchmark. The Lotus spreadsheet entitled Case R2-8 repeats the Case R2-7 calculation to reflect the impact of the Delta 75 SGs. The total amount of sump solution is increase by 43431 lbm to 3,885,209.61 lbm in the Case R2-8 calculation. Using the ORNL data and the calculated molarities, the sump solution pH is estimated to remain approximately 8.7.

Therefore, based on the calculation described above, it is concluded that the increase in RCS volume due to the larger SGs has a negligible impact on prior calculations performed to determine the minimum spray pH during the recirculation period prior to emptying the SHST.

Calculation of -Minimum Spray pH- During
Recirculation Prior to Emptying The SHST

Case R2-5: Benchmark of Rev 1 Calculation

Initial Conditions		Case Dependent Inputs	
RWST @	2500 ppm boron	SHST Flow =	21.5 gpm
SI ACC @	2500 ppm boron	NaOH in Sump =	3829.04 lbm
RCS @	2000 ppm boron	Total Sump Soln =	3837370. lbm
SHST @	20 w/o NaOH	Sump ppm =	2500 ppm

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations

NaOH Injected = 2.034 x NaOH Flow

= 43.731 lbm/min

NaOH Sprayed = $\frac{\text{NaOH in Sump}}{\text{Total Sump Soln}}$ x 8.329 x (2500 - NaOH Flow)

= 20.59861 lbm/min

Total NaOH Into Hrd = NaOH Injected + NaOH Sprayed

= 64.32961 lbm/min

NaOH Molarity = 0.001198 x (Total NaOH Into Hrd)

= 0.077066 g-mole/l

H3BO3 Sprayed = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)

= 294.9043 lbm/min

H3BO3 Molarity = 7.754E-04 x H3BO3 Sprayed

= 0.228668

Calculate the pH using the ORNL Data

Spray pH ≃ 8.7

DC0040-066, REV 0
Page 54

Calculation of -Minimum Spray pH- During
Recirculation Prior to Emptying The SHST

Case R2-6: Update to Case R2-5 to Reflect Delta-75 SGs

Initial Conditions		Case Dependent Inputs	
RWST @	2500 ppm boron	SHST Flow =	21.5 gpm
SI ACC @	2500 ppm boron	NaOH in Sump =	3829.04 lbm
RCS @	2000 ppm boron	Total Sump Soln =	3880801 lbm
SHST @	20 w/o NaOH	Sump ppm =	2500 ppm

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations

NaOH Injected = 2.034 x NaOH Flow

= 43.731 lbm/min

NaOH Sprayed = $\frac{\text{NaOH in Sump}}{\text{Total Sump Soln}}$ x 8.329 x (2500 - NaOH Flow)

= 20.36809 lbm/min

Total NaOH Into Hrd = NaOH Injected + NaOH Sprayed

= 64.09909 lbm/min

NaOH Molarity = 0.001198 x (Total NaOH Into Hrd)

= 0.076790 g-mole/l

H3BO3 Sprayed = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)

= 294.9043 lbm/min

H3BO3 Molarity = 7.754E-04 x H3BO3 Sprayed

= 0.228668

Calculate the pH using the ORNL Data

Spray pH ≅ 8.7

DC00040-066, REV 0
Page 55

Calculation of -Minimum Spray pH- During
Recirculation Prior to Emptying The SHST

Case R2-7: Benchmark of Rev 1 Calculation Case 2a

Initial Conditions		Case Dependent Inputs	
RWST @	2500 ppm boron	SHST Flow =	19 gpm
SI ACC @	2500 ppm boron	NaOH in Sump =	4710.72 lbm
RCS @	2000 ppm boron	Total Sump Soln =	3841778. lbm
SHST @	20 w/o NaOH	Sump ppm =	2500 ppm

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations

NaOH Injected = 2.034 x NaOH Flow

= 38.646 lbm/min

NaOH Sprayed = $\frac{\text{NaOH in Sump}}{\text{Total Sump Soln}}$ x 8.329 x (2500 - NaOH Flow)

= 25.33813 lbm/min

Total NaOH Into Hrd = NaOH Injected + NaOH Sprayed

= 63.98413 lbm/min

NaOH Molarity = 0.001198 x (Total NaOH Into Hrd)

= 0.076652 g-mole/l

H3BO3 Sprayed = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)

= 295.2017 lbm/min

H3BO3 Molarity = 7.754E-04 x H3BO3 Sprayed

= 0.228899

Calculate the pH using the ORNL Data

Spray pH ≅ 8.7

DC00040-066, REV 0
Page 56

Calculation of ~Minimum Spray pH- During
Recirculation Prior to Emptying The SHST

Case R2-8: Update of Case R2-7 to Reflect the Delta-75 SGs

Initial Conditions		Case Dependent Inputs	
RWST @	2500 ppm boron	SHST Flow =	19 gpm
SI ACC @	2500 ppm boron	NaOH in Sump =	4710.72 lbm
RCS @	2000 ppm boron	Total Sump Soln =	3885209. lbm
SHST @	20 w/o NaOH	Sump ppm =	2500 ppm

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations

NaOH Injected = 2.034 x NaOH Flow

= 38.646 lbm/min

NaOH Sprayed = $\frac{\text{NaOH in Sump}}{\text{Total Sump Soln}}$ x 8.329 x (2500 - NaOH Flow)

= 25.05488 lbm/min

Total NaOH Into Hrd = NaOH Injected + NaOH Sprayed

= 63.70088 lbm/min

NaOH Molarity = 0.001198 x (Total NaOH Into Hrd)

= 0.076313 g-mole/l

H3BO3 Sprayed = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)

= 295.2017 lbm/min

H3BO3 Molarity = 7.754E-04 x H3BO3 Sprayed

= 0.228899

Calculate the pH using the ORNL Data

Spray pH ≅ 8.7

7.1.8 Summary of Part 1 Calculations

Rev 2 Calc Case #	pH Limit	Conditions		Comment
		H_3BO_3	NaOH	
R2-1	Min Sump pH @ End of Injection	Max	Min	Benchmark of the Ref 4 Case 3 Calculation
R2-2		Max	Min	Same as Case R2-1 except RCS volume is increased to 9383 ft3 to reflect Delta-75 SGs
R2-3	Min Sump Equilibrium pH	Max	Min	Benchmark of the Ref 4 Limiting Calculation
R2-4		Max	Min	Same as Case R2-3 except RCS volume is increased to 9383 ft3 to reflect Delta-75 SGs
R2-5	Min Spray pH During Recirculation (Prior to Emptying the SHST)	Max	Min	Benchmark of the Ref 4 Case 3 Calculation
R2-6		Max	Min	Same as Case R2-5 except RCS volume is increased to 9383 ft3 to reflect Delta-75 SGs
R2-7		Max	Min	Benchmark of the Ref 4 Case 2a Calculation
R2-8		Max	Min	Same as Case R2-7 except RCS volume is increased to 9383 ft3 to reflect Delta-75 SGs

7.2 Part 2 Calculations

In this section a review of the Ref 4 analysis assumptions will be performed. These will be followed by some more bounding calculations to assess the impact on min/max sump pH limits when more conservative assumptions are used. The Ref 4 methodology and Lotus spreadsheets, developed in Section 6.0, will be applied with modifications as described herein. A computer run summary is provided in Section 7.2.10.

7.2.1 Additional Checks Of The Ref 4 Inputs

The drawdown analysis is an integral input to the sump/spray pH calculation. This calculation is based on the major assumptions outlined in the enclosed G/C memo.

Select Major inputs used in the G/C calculation were checked. The results were as follows:

Item	G/C Value	Check Result
Limits on Boron in RWST	Max = 2500 ppm Min = 2300 ppm	Verified via Tech Spec 3.5.4
Limits on Boron in Accumulators	Max = 2500 ppm Min = 2200 ppm	Verified via Tech Spec 3.5.1
Accumulator water volume	Max = 7684.74 gal Min = 7488.75 gal	Verified via Tech Spec 3.5.1 min/max vol of 7489/7685 gals
RWST Vol per ft	9399.6 gal/ft	In Ref 7 this was calculated as 104.7197 ft3/in which corresponds to 9399.6 gal/ft.
Max Change in RWST level	42.23 ft at low-low level	Verified per STP-375.001 (Ref 8) where HL Alarm @ 97% & LL Alarm @ 18% & Span of 642" (.97-.18)642=507.18" or 42.26 ft
Min Change in RWST level	40.08 ft at low-low level	Ref 4 calculation was based on a Nom Min Full setpoint of 93% which, per the above methodology, gives (.93-.18)642=481.5" or 40.13 ft. This is viewed as a reasonable assumption and will be maintained to ensure consistancy with the drawdown analysis. However, the current low level setpoint is 90% per Ref 8, giving a Max error of approximately 1.56', where: (.90-.18)642=462.24" or 38.52 ft.
SHST NaOH Concentration	22 w/o Max 20 w/o Min	Verified per Tech Spec 3.6.2.2.
NaOH Vol per ft	82.6 gal/ft	Verified per Ref 9 where Tank ID=3'-9" which gives area of 11.0447 ft2 and vol of 82.61 gal/ft @ 7.48 gal/ft3

Min NaOH Level	**37 ft**	**This represents the min height above the centerline of the outlet nozzle. Verified via Tech Spec 3.6.2.2 which requires min vol of 3140 gals & DWG 1MS-18-002 (Ref 9) which shows the outlet elevation to be 1-ft above the bottom of the tank. Min level is thus:** $\frac{3140\ gal}{82.61\ gal/ft} - 1' = 37.01'$
Max NaOH Level	**38 ft**	**This represents the max height above the centerline of the outlet nozzle. Verified via Tech Spec 3.6.2.2 which requires max vol of 3230 gals & DWG 1MS-18-002 (Ref 9) which shows the outlet elevation to be 1-ft above the bottom of the tank. Max level is thus:** $\frac{3230\ gal}{82.61\ gal/ft} - 1' = 38.09'$
RCS Liq Vol	**8430 ft3**	**This appears low based on design inputs 1 & 2. A more representative value would be 8596 ft3. Use of 8430 ft3 is not bounding for min sump pH calculations but is bounding for max pH calculations. The use of a larger volume will be assessed when the impact of the new SGs is evaluated.**
RCS Boron concentration	**2000 ppm**	**Based on current core designs, this is a conservative high value for RCS boron concentration for Mode 1/2 at BOC per Design Input 7. EOC values will approach 0 ppm. Use of 2000 ppm is bounding for min pH calculations.**
RCS Vol below top of the core	**1400 ft3**	**Appears reasonable per comparison to Design Input 3 Reference. This is treated as RCS water (2000 ppm) which is conservative for min sump pH calculation. When it is conservative to assume residual water exists in the RV, *Design Input 3*, which represents the volume below the HL nozzle, would be more bounding.** 2

The RWST drawdown was assumed to terminate at the low-low level setpoint. Since the Chg/SI pumps would continue to take suction off the RWST until the operators switch their suction to the discharge of the RHR pumps, more water can be added to the RB sumps after the low-low level. The current assumption, which minimizes the RWST volume, is conservative for max sump pH calculations. For minimum sump pH calculation, a more conservative assumption would be to assume that RWST volume to the current 6% empty level alarm makes it way to the sump. At this point operator action would be taken to terminate any operating pumps with suction off the RWST.

During the recirculation period, the Ref 4 calculation assumes that the RB is depressurized thus allowing the SHST to continue to drain until empty. This would maximize the resulting spray and equilibrium sump pH. For minimum pH calculations, however, it would be more conservative to assume that no additional NaOH is added from the SHST following the switchover from the injection to recirculation phase.

During the recirculation period prior to emptying the SHST, the spray pH is calculated. In these calculations, several assumptions are made:

1. Sump Boron Level: is set at either the min or max ppm level of the RWST depending on if max or min spray pH calculations are being done. This is conservative for min spray pH calculations. However, since both the RCS and ECCS accumulators can be at a lower boron level than the RWST, a mixed mean sump boron level would be more appropriate for max spray pH calculations.

2. Sump NaOH Level: a constant value equal to the amount drained from the SHST during the injection phase is assumed. The sump NaOH levels are not updated even though the SHST is assumed to continue to drain. This is conservative for min spray pH calculations especially when noting that the boron levels in the sump are set at the max RWST levels. This would, however, not be bounding for max spray pH calculations. However, since the max spray pH during this period occurs at the onset of recirculation, this maximum predicted pH value will not be affected.

3. Sump Solution Level: a constant value equal to the additions from the RCS, RWST, and SHST at the end of the injection phase is assumed. For min spray pH calculation, it would be more conservative to track the additional solution added to the sump. However, since the period of time required to empty the SHST is so short (minutes), use of a constant sump solution volume is a reasonable assumption.

When calculating the long term equilibrium sump pH (after the RWST and NaOH drawdown is complete), the Ref 4 calculation also took credit for 1400 ft3 of water (volume within the RV below the top of the core) of RCS water not being in the sump. During recirculation, it is more conservative to assume that the water in the RV is also at the equilibrium sump pH since is it recirculated continuously.

It is noted that nominal RWST levels are assumed as initial conditions; measurement errors are not considered. This is viewed as appropriate since the level change, not the absolute magnitude of the level, is of more importance.

7.2.2 Min Spray pH - Injection Phase

This calculation evaluates the spray header pH as the SHST drains during the injection period. It is controlled by the spray flow, RWST boron level, the initial conditions within the SHST, drain rates from the SHST, and the duration of the injection phase. The new SGs have not impact on this calculation and, during the course of this review, no inputs or assumptions were identified which were unconservative. This calculated value of 8.8 is thus judged to remain bounding.

7.2.3 Max Spray pH - Injection Phase

This calculation evaluates the spray header pH as the SHST drains during the injection period. It is controlled by the spray flow, RWST boron level, the initial conditions within the SHST, drain rates from the SHST, and the duration of the injection phase. The new SGs have not impact on this calculation and, during the course of this review, no inputs or assumptions were identified which were unconservative. This calculated value of 10.1 is thus judged to remain bounding.

7.2.4 Min Sump pH - @ End of Injection

This calculation evaluates the sump pH at the end of the injection phase. This calculation is impacted by the additional volume added by the new SGs; however, as shown in Section 7.1.5, the change in pH is negligible. During the course of this review, no inputs or assumptions were identified which were unconservative. Thus, the calculated value of 7.5 remains bounding.

7.2.5 Max Sump pH - @ End of Injection

This calculation evaluates the max sump pH at the end of the injection phase. During the course of this review, several assumptions were identified which are not bounding and a error in the Ref 4 calculation was found. As a result, three additional calculations were performed to assess the impact on the Ref 4 calculated value of 8.2. These are discussed below:

In the Ref 4 calculation, the max sump pH occurred for case 4 with maximum NaOH conditions. Within the Ref 4 calculation, a mass balance error exists for the RWST components. The lbs of boric acid and water are shown as 43448.32 lbs and 3262401.84 lbs respectively; calculations indicate that they are based on a assumed 42.23 ft change in RWST level during the injection phase. However, the total lbs of solutions, which is equal to the sum of the boric acid and water, is stated as 3137543.79 lbs (which is less than the amount of water); calculations indicate that this total amount of sump solution is based on a 40.08 ft change in

RWST level during the injection phase. Thus two benchmark calculations are performed:

Case R2-9: benchmarks the Ref 4 calculation assuming a RWST level change of 42.23 ft. The resulting pH is approximately 8.2.

Case R2-10: benchmarks the Ref 4 calculation assuming a RWST level change of 40.08 ft. This benchmark is judged to be the intended assumption in the Ref 4 calculation since a min change in RWST level would tend to maximize the resulting sump pH. The resulting pH is approximately 8.25 which is slightly higher than the Ref 4 calculation.

The above benchmarks indicate that the mass balance error in the Ref 4 calculation results in a minor impact on the calculated max sump pH level at the end of injection.

An additional error also exists in the Ref 4 calculation and is also present in Cases R2-9 & R2-10. This error is associated with the mass of NaOH. In converting the SHST level change to mass of NaOH added, the wrong SHST fluid density was used. For these max NaOH conditions, a density corresponding to 20 w/o (76.046 lb/ft3) as opposed to 22 w/o (77.411 lb/ft3) was utilized. This is evident in the benchmark calculations which match the Ref 4 results. This error is corrected in Case R2-11 below.

During the course of this review, several more limiting assumptions were identified which could lead to a high sump pH at the end of injection. These are:

1. The RCS could be End of Cycle conditions with boron level which approach 0 ppm. With a zero ppm boron, the max RCS volume should be considered; thus, the larger RCS volume with the new SGs should be considered.

2. Within the Ref 4 calculation, the water volume below the top of the core (1400 ft3) is not added to the sump. This was treated as RCS volume (@2000 ppm) within the Ref 4 calculation. Is it more conservative to assume that all of the RCS volume @ 0 ppm boron is added to the sump and that the water below the top of the core is from the RWST @ 2300 ppm boron. To incorporate this change into the LOTUS spreadsheet, the volume below the top of the core will be set to zero, thus forcing all RCS volume to be added to the sump, and the RWST level change will be decreased to effectively not allow the volume below the RV nozzles ***(Design Input 3)*** to be added to the sump. This volume ***below the RV nozzles*** is equal to approximately 1.86 ft ***of RWST level***. Thus, within the LOTUS spreadsheet, the change in RWST level will be specified as (40.08 - 1.86) = 38.22 ft. 2

3.The RCS volume will be increased to 9383 ft3 to reflect the new SGs.

Case R2-11 reflect the above changes and utilized the SHST fluid density of 77.411 lb/ft3 corresponding to 22 w/o. The changes result in a maximum sump pH @ the end of injection of approximately 8.5, which is 0.3 higher than the Ref 4 calculation.

Calculation of Max Sump pH at the End of Injection

Case R2-9: Benchmark of G/C Calculation with 42.23' RWST Level Change

Base Assumptions

RWST @	2300 ppm boron with initial level at 51.15 ft
SI ACC @	2200 ppm boron with initial level at low level alarm
RCS @	2000 ppm boron
SHST @	22 w/o NaOH with level initially at 38 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1001.1	ft3
Density	62.2995	lb/ft3
Mass of Solution	187104.0	lbs
Mass Boric Acid	2352.165	lbs
Water Mass	184751.9	lbs

RWST @ 9399.6 gal/ft

Level Change	42.23	ft
Mass of Solution	3305850.	
Mass Boric Acid	43448.32	lbs
Water Mass	3262402.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	8430	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7030	ft3
	320374.1	lbs
Mass Boric Acid	3661.418	
Water Mass	316712.6	

SHST @ 82.6 gal/ft

Level Change	35.5	ft
Density	76.046	lb/ft3
Mass of Solution	29809.46	lb
Mass NaOH	6558.081	lb
Water Mass	23251.38	lb

DC00040-066, REV 0
Page 66

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2352.165	0	184751.9	187104.0
RCS	3661.418	0	316712.6	320374.1
RWST	43448.32	0	3262402.	3305850.
SHST	0	6558.081	23251.38	29809.46
Total	49461.91	6558.081	3787118.	3843138.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.042660

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.208072

Calculate the pH using the ORNL data

Sump pH ≅ 8.2

Calculation of Max Sump pH at the End of Injection

Case R2-10 - Benchmark of the G/C Calculation
With 40.08' RWST Level Change

Base Assumptions

RWST @	2300 ppm boron with initial level at 49.00 ft
SI ACC @	2200 ppm boron with initial level at low level alarm
RCS @	2000 ppm boron
SHST @	22 w/o NaOH with level initially at 38 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1001.1	ft3
Density	62.2995	lb/ft3
Mass of Solution	187104.0	lbs
Mass Boric Acid	2352.165	lbs
Water Mass	184751.9	lbs

RWST @ 9399.6 gal/ft

Level Change	40.08	ft
Mass of Solution	3137544.	
Mass Boric Acid	41236.30	lbs
Water Mass	3096308.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	8430	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7030	ft3
	320374.1	lbs
Mass Boric Acid	3661.418	
Water Mass	316712.6	

SHST @ 82.6 gal/ft

Level Change	35.5	ft
Density	76.046	lb/ft3
Mass of Solution	29809.46	lb
Mass NaOH	6558.081	lb
Water Mass	23251.38	lb

DC00040-066, REV 0
Page 67

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2352.165	0	184751.9	187104.0
RCS	3661.418	0	316712.6	320374.1
RWST	41236.30	0	3096308.	3137544.
SHST	0	6558.081	23251.38	29809.46
Total	47249.88	6558.081	3621024.	3674832.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.044614

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.207870

Calculate the pH using the ORNL data

Sump pH ≃ 8.25

Calculation of Max Sump pH at the End of Injection

Case R2-11: Update to Case R2-10 with new SG, 0 ppm in RCS, all RCS vol to the sump, RV vol below nozzle at RWST ppm

Base Assumptions

RWST @	2300	ppm boron with initial level at 49.00 ft
SI ACC @	2200	ppm boron with initial level at low level alarm
RCS @	0	ppm boron
SHST @	22	w/o NaOH with level initially at 38 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1001.1	ft3
Density	62.2995	lb/ft3
Mass of Solution	187104.1	lbs
Mass Boric Acid	2352.166	lbs
Water Mass	184751.9	lbs

RWST @ 9399.6 gal/ft

Level Change	38.22	ft
Mass of Solution	2991940	
Mass Boric Acid	39322.64	lbs
Water Mass	2952617	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	9383	ft3
Vol Below Top of C	0	ft3

Net Water to Sump	9383	ft3
	427606	lbs
Mass Boric Acid	0	
Water Mass	427606	

SHST @ 82.6 gal/ft

Level Change	35.5	ft
Density	77.411	lb/ft3
Mass of Solution	30344.53	lb
Mass NaOH	6675.797	lb
Water Mass	23668.74	lb

DC00040-066, REV0
Page 68

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2352.166	0	184751.9	187104.1
RCS	0	0	427606	427606
RWST	39322.64	0	2952617	2991940
SHST	0	6675.797	23668.74	30344.53
Total	41674.81	6675.797	3588644	3636995

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.045888

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.185251

Calculate the pH using the ORNL data

Sump pH ≅ 8.5

7.2.6 Max Equilibrium Sump pH (w/SHST empty)

This calculation evaluates the maximum sump pH after the SHST empties. The volume & ppm levels of the borated water sources are minimized whereas the volume and NaOH concentration within the SHST is maximized in order to achieve the maximum equilibrium sump pH.

Case R2-12 benchmarks the Ref 4 calculation. The results are essentially identical. A maximum sump pH of approximately 8.3 is predicted.

During the course of this review, several more limiting assumptions were identified which could lead to a higher equilibrium sump pH after the SHST empties. These are:

1.The RCS could be End of Cycle conditions with boron level which approach 0 ppm. With a zero ppm boron, the max RCS volume should be considered; thus, the larger RCS volume with the new SGs should be considered.

2.Within the Ref 4 calculation, the water volume below the top of the core (1400 ft3) is not added to the sump. This was treated as RCS volume (@2000 ppm) within the Ref 4 calculation. Is it more conservative to assume that all of the RCS volume @ 0 ppm boron is added to the sump, and it is judged to be more appropriate to assume that the volume below the core is essentially an extension of the sump due to the recirculation of ECCS fluid.

3.Since the RCS will be assumed to be at 0 ppm boron, its volume will be increased to 9383 ft3 to reflect the new SGs.

Case R2-13 repeats Case R2-12 with the above changes and the maximum equilibrium sump pH is calculated to be approximately 8.5, which is approximately 0.2 higher than the Ref 4 calculated result.

Calculation of Max Sump pH During Recirculation with SHST Empty

Case R2-12: Benchmark of G/C Calculation

Base Assumptions

RWST @	2300	ppm boron with initial level at 49 ft
SI ACC @	2200	ppm boron with initial level at low level alarm
RCS @	2000	ppm boron
SHST @	22	w/o NaOH with level initially at 38 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1001.1	ft3
Density	62.2995	lb/ft3
Mass of Solution	187104.0	lbs
Mass Boric Acid	2352.165	lbs
Water Mass	184751.9	lbs

RWST @ 9399.6 gal/ft

Level Change	40.08	ft
Mass of Solution	3137544.	
Mass Boric Acid	41236.30	lbs
Water Mass	3096308.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	8430	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7030	ft3
	320374.1	lbs
Mass Boric Acid	3661.418	
Water Mass	316712.6	

SHST @ 82.6 gal/ft

Level Change	38	ft
Density	77.411	lb/ft3
Mass of Solution	32481.47	lb
Mass NaOH	7145.923	lb
Water Mass	25335.54	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2352.165	0	184751.9	187104.0
RCS	3661.418	0	316712.6	320374.1
RWST	41236.30	0	3096308.	3137544.
SHST	0	7145.923	25335.54	32481.47
Total	47249.88	7145.923	3623108.	3677504.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.048578

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.207719

Calculate the pH using the ORNL data

Sump pH ≅ 8.3

DC00040-066, REV 0
Page 70

Calculation of Max Sump pH During Recirculation with SHST Empty

Case R2-13: Updated Case R2-12 with New SGs, RCS @ 0ppm,
All Sources Mixed

Base Assumptions

RWST @	2300	ppm boron with initial level at 49 ft
SI ACC @	2200	ppm boron with initial level at low level alarm
RCS @	0	ppm boron
SHST @	22	w/o NaOH with level initially at 38 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1001.1	ft3
Density	62.2995	lb/ft3
Mass of Solution	187104.0	lbs
Mass Boric Acid	2352.165	lbs
Water Mass	184751.9	lbs

RWST @ 9399.6 gal/ft

Level Change	40.08	ft
Mass of Solution	3137544.	
Mass Boric Acid	41236.30	lbs
Water Mass	3096308.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	9383	ft3
Vol Below Top of C	0	ft3
Net Water to Sump	9383	ft3
	427606.0	lbs
Mass Boric Acid	0	
Water Mass	427606.0	

SHST @ 82.6 gal/ft

Level Change	38	ft
Density	77.411	lb/ft3
Mass of Solution	32481.47	lb
Mass NaOH	7145.923	lb
Water Mass	25335.54	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2352.165	0	184751.9	187104.0
RCS	0	0	427606.0	427606.0
RWST	41236.30	0	3096308.	3137544.
SHST	0	7145.923	25335.54	32481.47
Total	43588.46	7145.923	3734001.	3784736.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.047202

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.186193

Calculate the pH using the ORNL data

Sump pH ≅ 8.5

DC00040-066, REV 0

7.2.7 Min Equilibrium Sump pH

Within the ref 4 calculation, the minimum equilibrium sump pH is evaluated assuming that the SHST continues to drain. Within Section 4.1.5, this calculation was benchmarked (Case R2-3) and the effect of the larger RCS volume was assessed in Case R2-4. In both cases, the minimum equilibrium sump pH was assessed to be approximately 8.0.

During the course of this review, several more limiting assumptions were identified which could lead to a lower equilibrium sump pH. These are:

1. The RB can be assumed to remain pressurized thus preventing further draining of the SHST. The amount of NaOH within the sump solutions would thus be limited to that calculated at the end of the injection phase.
2. Drawdown of the RWST could continue past the low-low level setpoint of 18% due to continued operation of the Chg/SI pumps until a manual transfer is accomplished. It would be more conservative to assume that the RWST continues to drain to the 6% empty alarm (per Ref 8). At this point, the EOP directs the operator to terminate Chg/SI flow by stopping the pumps if the manual transfer to the recirculation alignment has not been accomplished. The RWST level change for this condition would be (0.97 - 0.06)(642/12) = 48.685 ft.
3. All of the RCS volume should be assumed to be mixed with the sump because of the continuous recirculation of the sump solution.

The impact of these changes are evaluated below in Cases R2-14 through R2-16.

Case R2-14: Repeats Case R2-4. This reflects the impact of the new SGs and limits the change in the SHST level 22.8 ft which corresponds to the level change which occurred during the injection period. For Case R2-14, the calculated pH is approximately 7.5 (the same as that predicted for the min sump pH at the end of injection).

Case R2-15: Updates Case R2-14 assuming the RWST drains to the 6% empty alarm (i.e., level change of 48.685') and all of the RCS volume mixes with the sump solution (i.e., volume below the core is zero in the LOTUS spread sheet). For Case R2-15, the calculated pH is approximately 7.4.

The Case R2-15 result is of some concern in that it is less than the current min limit of 7.5 stated in the bases of the Technical Specifications.

During normal operation, the pH within the RCS is controlled via addition of Lithium as illustrated by Design Input 5. At 2000 ppm boron, a pH of approximately 5.9 at 77°F would be expected. Within Case R2-16, the RCS pH control will be credited to determine if the 7.5 pH limit in the Tech Spec can be shown to be adequate. Within Case R2-16, the effect of the lithium within the RCS fluid will be credited by calculating an equivalent boron concentration to maintain the initial RCS pH. This equivalent level of boron is approximated in the following manner:

1. Assume initial RCS pH of 5.85 to 5.9 per Design Input 5 for an RCS boron concentration of 2000 ppm.
2. Using the ORNL Data, the boric acid molarity for this pH range, with essentially zero NaOH (molarity of 10^{-7}, is approximate 0.04.
3. Based on a molarity of 0.04, an equivalent boron concentration in the RCS is calculated.

Per Section 6.2:

$$M_{H3BO3} = \frac{(\text{lbm of } H_3BO_3)(453.59 \text{ g/lbm})(1 \text{ g-mole}/61.82 \text{ g})}{(\text{lbs of solution})(453.59 \text{ g/lbm})(1 \text{ liter}/1000 \text{ g})}$$

$$= \frac{(\text{lbm of } H_3BO_3) \times (16.176 \text{ g-mole/liter})}{(\text{lbm of solution})}$$

$$\text{lbm } H_3BO_3 = (\text{lbm of RCS fluid}) \left(\frac{\text{ppm}}{1750 \times 100}\right)$$

Therefore,

$$(\text{lbm of } H_3BO_3) = \frac{(0.04)(427606 \text{ lbm in RCS})}{16.176} = 1057.38 \text{ lbm}$$

where 427606 is the RCS mass with the new SG calculated in the LOTUS spread sheet for a RCS liquid volume of 9383 ft3.

$$\text{RCS ppm} = \frac{(1057.38)(1750 \times 100)}{427606} = 432.738 \text{ ppm}$$

With the above changes incorporated, Case R2-16 shows that the sump pH will approach 7.6 and thus remain above the Tech Spec min value of 7.5.

Calculation of Minimum Equilibrium Sump pH With No Drawdown of SHST After The Injection Phase

Case R2-14: Update of Case R2-4 With SHST Level Change of 22.8 ft

Base Assumptions

RWST @	2500	ppm boron with initial level at high level alarm
SI ACC @	2500	ppm boron with initial level at high level alarm
RCS @	2000	ppm boron
SHST @	20	w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

RWST @ 9399.6 gal/ft

Level Change	42.23	ft
Mass of Solution	3305850.	
Mass Boric Acid	47226.44	lbs
Water Mass	3258624.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	9383	ft3
Vol Below Top of C	1400	ft3
Net Water to Sump	7983	ft3
	363804.6	lbs
Mass Boric Acid	4157.767	
Water Mass	359646.8	

SHST @ 82.6 gal/ft

Level Change	22.8	ft
Density	76.046	lb/ft3
Mass of Solution	19145.23	lb
Mass NaOH	3829.046	lb
Water Mass	15316.18	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	4157.767	0	359646.8	363804.6
RWST	47226.44	0	3258624.	3305850.
SHST	0	3829.046	15316.18	19145.23
Total	54127.07	3829.046	3822845.	3880801.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.024666

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.225487

Calculate the pH using the ORNL data

Sump pH ≅ 7.5

DC00040-066, REV0
Page 75

Calculation of Minimum Equilibrium Sump pH With No Drawdown of of the SHST After The Injection Phase

Case R2-15: Update of Case R2-14 With SHST Level Change of 22.8 ft., RWST Level to Empty Alarm, All Water Sources Mixed

Base Assumptions

RWST @	2500 ppm boron with initial level at high level alarm
SI ACC @	2500 ppm boron with initial level at high level alarm
RCS @	2000 ppm boron
SHST @	20 w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

RWST @ 9399.6 gal/ft

Level Change	48.685	ft
Mass of Solution	3811161.	
Mass Boric Acid	54445.16	lbs
Water Mass	3756716.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	9383	ft3
Vol Below Top of C	0	ft3
Net Water to Sump	9383	ft3
	427606.0	lbs
Mass Boric Acid	4886.925	
Water Mass	422719.0	

SHST @ 82.6 gal/ft

Level Change	22.8	ft
Density	76.046	lb/ft3
Mass of Solution	19145.23	lb
Mass NaOH	3829.046	lb
Water Mass	15316.18	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	4886.925	0	422719.0	427606.0
RWST	54445.16	0	3756716.	3811161.
SHST	0	3829.046	15316.18	19145.23
Total	62074.96	3829.046	4384009.	4449913.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.021511

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.225524

Calculate the pH using the ORNL data

Sump pH ≅ 7.4

DC00040-066, REV 0
Page 76

Calculation of Minimum Equilibrium Sump pH With No Drawdown of of the SHST After The Injection Phase

Case R2-16: Update of Case R2-15 With RCS pH Control Credited

Base Assumptions

RWST @	2500	ppm boron with initial level at high level alarm
SI ACC @	2500	ppm boron with initial level at high level alarm
RCS @	432.738	ppm boron
SHST @	20	w/o NaOH with level initially at 37 ft

SI Accumulators

# of Tanks	3	
Vol per Tank	1027.3	ft3
Density	62.2995	lb/ft3
Mass of Solution	192000.8	lbs
Mass Boric Acid	2742.868	lbs
Water Mass	189257.9	lbs

RWST @ 9399.6 gal/ft

Level Change	48.685	ft
Mass of Solution	3811161.	
Mass Boric Acid	54445.16	lbs
Water Mass	3756716.	lbs

Reactor Coolant System

Density	45.57242	lb\ft3
RCS Liq Vol	9383	ft3
Vol Below Top of C	0	ft3

Net Water to Sump	9383	ft3
	427606.0	lbs
Mass Boric Acid	1057.379	
Water Mass	426548.6	

SHST @ 82.6 gal/ft

Level Change	22.8	ft
Density	76.046	lb/ft3
Mass of Solution	19145.23	lb
Mass NaOH	3829.046	lb
Water Mass	15316.18	lb

Source	lbs H3BO3	lbs NaOH	lbs Water	lbs Solution
Accum	2742.868	0	189257.9	192000.8
RCS	1057.379	0	426548.6	427606.0
RWST	54445.16	0	3756716.	3811161.
SHST	0	3829.046	15316.18	19145.23
Total	58245.41	3829.046	4387839.	4449913.

Calculate Molarity per the G/C Method

NaOH Molarity = (Total lbs NaOH)(25)/(Total lbs Solution)
= 0.021511

H3BO3 Molarity = (Total lbs H3BO3)(16.167)/(Total lbs Solution)
= 0.211611

Calculate the pH using the ORNL data

Sump pH ≃ 7.5

DC00040-066, REV0

Page 77

7.2.8 Min Spray pH - Recirculation Phase

The SHST does not empty during the injection period. Within the Ref 4 calculation, the SHST is assumed to drain until empty. During the drain period, the spray pH is controlled primarily by the flow rate from the SHST. The drawdown analysis shows that the SHST drain flow slowly decreases thus resulting in a similiar decrease in spray pH. The minimum value occurs just prior to emptying the SHST. A min spray pH of 8.7 is calculated. This calculation was benchmarked in Section 7.1.7 and the effect of the new SGs were determined to be negligible. These are very conservative calculations because of the following two assumptions:

1. Sump boron level is assumed constant and equal to the maximum RWST level of 2500 ppm.

2. The amount of NaOH in the sump is assumed constant and equal to the amount which has drained from the SHST during the injection period. No credit for additional NaOH is taken even though the SHST is assumed to continue to drain until empty.

The only calculation assumption which could be made more limiting is to increase the total amount of sump solution to reflect the continued drawdown of the RWST by the Chg/SI pumps after recirculation is initiated. This is judged to have a small effect which would be more than offset by existing margins due to the above two assumption. Thus, it is concluded that the calculation of the min spray pH of 8.7 during the recirculation phase continues to be a bounding value.

7.2.9 Max Spray pH - Recirculation Phase

The SHST does not empty during the injection period. Within the Ref 4 calculation, the SHST is assumed to drain until empty during the recirculation period. During the drain period, the spray pH is controlled primarily by the flow rate from the SHST. The drawdown analysis shows that the SHST drain flow slowly decreases during recirculation thus resulting in a similar decrease in spray pH. The maximum value basically occurs at the onset of the recirculation phase. A max spray pH of 10.2 is calculated for the Ref 4 calculation Case 3 with max NaOH conditions and min boron conditions. Case R2-17 benchmarks the Ref 4 calculation; results are essentially identical.

During the course of this review, several more limiting assumptions were identified which could lead to a higher spray pH. They were:

1.The solution from the sump was assumed to be at the min RWST boron concentration (2300 ppm). Given that the accumulators could have a boron concentration of 2200 ppm and the RCS could approach 0 ppm at end of cycle, a lower equivalent sump boron concentration is possible. A more limiting assumption would be to use a mixed mean value.

2.Since the RCS will be assumed to be at 0 ppm to calculate the sump concentration, the larger volume associated with the new SGs should be used.

Case R2-18 will investigate the impact of the above changes. To calculate the sump's mixed mean boron concentration, the sump conditions at the end of the injection phase will be utilized.

From the Ref 4 calculation Case 3 with max NaOH @ the end of the injection phase, the sump conditions are:

Accum	187104.05 lbs @ 2200 ppm
RCS	320374.06 lbs @ 2000 ppm
RWST	3137543.79 lbs @ 2300 ppm
SHST	19481.06 lbs @ 22 w/o
Total	3664502.96 lbs in sump

Prior calculations show that the RCS volume of 9383 ft3 with the new SG is equivalent to 427606 lb. Assuming all of this volume is added to the sump, the new sump mass becomes

(3664503 + 427606 - 320374) = 3771735 lbs

The mixed mean boron concentration then becomes:

ENGINEERS

TECHNICAL WORK RECORD

Serial 227-68-1864

Engineer L R Cartin

Date 24 Sept 1994

PROJECT-TITLE SPRAY/SUMP pH WITH DELTA-75 SGs TAB 163 PAGE 80

$$\frac{187104(2200)+427606(0)+3137544(2300)+19481(0)}{3771735} = 2022 \text{ ppm}$$

The Case R2-18 results are enclosed. The resulting max spray pH is approximately 10.5 which is approximately 0.3 higher than that calculated in the Ref 4 calculation. This is a significant change but is of short duration since the spray pH will decrease during the recirculation phase. The recirculation phase is also very short (minutes). Following depletion of the SHST, the spray pH will correspond to the equilibrium sump value which is less than 9.0.

Calculation of - Maximum Spray pH- During
Recirculation Prior to Emptying The SHST

Case R2-17: Benchmark of Rev 1 Calculation

Initial Conditions		Case Dependent Inputs	
RWST @	2300 ppm boron	SHST Flow =	47.7 gpm
SI ACC @	2200 ppm boron	NaOH in Sump =	4285.83 lbm
RCS @	2000 ppm boron	Total Sump Soln =	3664502. lbm
SHST @	22 w/o NaOH	Sump ppm =	2300 ppm

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations

NaOH Injected = 2.277 x NaOH Flow

= 108.6129 lbm/min

NaOH Sprayed = $\frac{\text{NaOH in Sump}}{\text{Total Sump Soln}}$ x 8.329 x (2500 - NaOH Flow)

= 23.88835 lbm/min

Total NaOH Into Hrd = NaOH Injected + NaOH Sprayed

= 132.5012 lbm/min

NaOH Molarity = 0.001198 x (Total NaOH Into Hrd)

= 0.158736 g-mole/l

H3BO3 Sprayed = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)

= 268.4439 lbm/min

H3BO3 Molarity = 7.754E-04 x H3BO3 Sprayed

= 0.208151

Calculate the pH using the ORNL Data

Spray pH ≅ 10.2

DC00040-066, REV 0

Page 81

Calculation of - Maximum Spray pH- During
Recirculation Prior to Emptying The SHST

Case R2-18: Case R2-17 Updated to Reflect New SGs & RCS @ 0 ppm

Initial Conditions		Case Dependent Inputs	
RWST @	2300 ppm boron	SHST Flow =	47.7 gpm
SI ACC @	2200 ppm boron	NaOH in Sump =	4285.83 lbm
RCS @	0 ppm boron	Total Sump Soln =	3771735 lbm
SHST @	22 w/o NaOH	Sump ppm =	2022 ppm

Constant Inputs

Spray Train Flow = 2500 gpm total of spray solution

Calculations

NaOH Injected = 2.277 x NaOH Flow

= 108.6129 lbm/min

NaOH Sprayed = $\frac{\text{NaOH in Sump}}{\text{Total Sump Soln}}$ x 8.329 x (2500 - NaOH Flow)

= 23.20920 lbm/min

Total NaOH Into Hrd = NaOH Injected + NaOH Sprayed

= 131.8221 lbm/min

NaOH Molarity = 0.001198 x (Total NaOH Into Hrd)

= 0.157922 g-mole/l

H3BO3 Sprayed = 4.7594E-05 x (2500 - NaOH Flow)(sump ppm)

= 235.9972 lbm/min

H3BO3 Molarity = 7.754E-04 x H3BO3 Sprayed

= 0.182992

Calculate the pH using the ORNL Data

Spray pH ≅ 10.5

7.2.10 **Summary of Part 2 Calculations**

Rev 2 Calc Case #	pH Limit	Conditions		Comment
		H3BO3	NaOH	
R2-9	Max Sump pH @ End of Injection	Min	Max	Benchmark of Ref 4 Calc Case 4 with a RWST Level Change of 42.32 ft
R2-10		Min	Max	Benchmark of Ref 4 Calc Case 4 with a RWST Level Change of 40.08 ft
R2-11		Min	Max	Case R2-10 with new SGs, 0 ppm boron in RCS, all RCS mass added to sump, and Residual RV volume below nozzles at RWST boron concentration
R2-12	Max Equil Sump pH w/SHST Empty	Min	Max	Benchmark of Ref 4 Calculation
R2-13		Min	Max	Case R2-12 with new SGs, 0 ppm boron in RCS, and all RCS mass added to sump
R2-14	Min Equil Sump pH w/o SHST Draining During Recirculation	Max	Min	Same as Case R2-4 from Part 1 calculation. Reflects impact of new SGs and assumes SHST does not drain after the injection phase.
R2-15		Max	Min	Case R2-14 with RWST drained to empty (6%) alarm and all RCS mass added to sump.
R2-16		Max	Min	Case R2-15 with RCS pH Control Credited
R2-17	Max Spray pH Recirc Prior to SHST Draining	Min	Max	Benchmark of the Ref 4 Calc Case 3
R2-18		Min	Max	Case R2-17 with new SGs, RCS @ 0 ppm boron, and sump boron level at mixed mean value

8.0 SUMMARY OF RESULTS

The results of the Part 1 & 2 calculations are shown below and are compared to the current limit values:

pH Limit	Description	Calculated Limit			Comment
		Current Value	New Value	Case #	
Min	Spray Inj Phase	8.8	8.8	N/A	Ref 4 Value Remains Bounding
	Sump @ End of Injection	7.5	7.5	R2-2	SGs Have Negligible Impact
	Spray Recirc Phase	8.7	8.7	R2-8	Ref 4 Value Remains Bounding
	Equilibrium Sump (W/SHST Empty)	8.1	8	R2-4	
	Equilibrium Sump (No NaOH Added After Injection)	N/A	7.61	R2-16	Low pH due to no addition of NaOH during recirc, RWST draindown to empty alarm, and all RCS mass added to sump.
Max	Spray Inj Phase	10.1	10.1	N/A	Ref 4 Value Remains Bounding
	Sump @ End of Injection	8.2	8.5	R2-11	pH increases due to error correction, 0 ppm boron for RCS, larger RCS vol due to new SG, and with all RCS mass added to sump
	Spray Recirc Phase	10.2	10.5	R2-18	pH increases due 0 ppm boron for RCS, larger RCS vol due to new SG, and with all RCS mass added to sump
	Equilibrium Sump (W/SHST Empty)	8.3	8.5	R2-13	pH increases due 0 ppm boron for RCS, larger RCS vol due to new SG, adding all RCS mass to sump, and use of a mixed mean sump boron concentration.
	Equilibrium Sump (No NaOH Added After Injection)	N/A	8.5	N/A	Bounded by Max Sump pH Value @ End of Injection

1. Credits normal RCS pH control.

Using the above results the resulting range of spray pH values would thus become:

ENGINEERS

TECHNICAL WORK RECORD

Serial 227-68-1864

Engineer L R Cartin *JRC*

Date 24 Sept 1994

PROJECT-TITLE SPRAY/SUMP pH WITH DELTA-75 SGs TAB 163 PAGE 85

Operating Period	Spray pH Range	
	Current Value	New Value
0-2 hours (min)	8.7 - 10.2	7.5 - 10.5
~~2-24 hours~~ 2 hr - 40 days* (max)	8.1 - 8.3	7.5 - 8.5

* POST ACCIDENT SPRAY OPERATING TIME WAS INCREASED FROM 24 hr to 40 DAYS PER REF. 10 AND DESIGN INPUT 8.

12

9.0 CONCLUSION

This calculations show the following:

1. The additional RCS volume due to the Replacement SGs has a negligible impact on sump pH.

2. The min/max pH limits (7.5 to 11.0) as defined in the bases of the Technical Specification are preserved following SG Replacement even with the more limiting assumptions imposed by this calculation. Compliance to the minimum limit of 7.5, however, required crediting normal pH control within the RCS.

3. Limiting spray pH values for EQ are not impacted by the Replacement SGs but do change slightly due to the more limiting assumptions imposed by this calculations. For EQ purposes, it is more conservative to assume high pH values. Therefore, as done in the Ref 4 calculation, the spray pH values assuming the SHST continues to drain during the recirculation phase would change as shown below:

Operating Period	Spray pH Range	
	Ref 4 Value	Rev 2 Value
0-2 hours (min)	8.7 - 10.2	8.7 - 10.5
~~2-24 hours~~ 2 hr - 40 days (max)	8.1 - 8.3	8.0 - 8.5

21

10.0 VERIFICATION

ENGINEERS
TECHNICAL WORK RECORD
"Verification of DC00040-066 REV 0"

TAB 94-30 SERIAL 251394263 ENGINEER WT WOOD DATE 9/24/94 PAGE 1 OF 1

I. Purpose

This TWR documents the results of an exhaustive review of VCSNS Design Calculation DC00040-066 REV 0, "SPRAY AND SUMP pH with Δ75 SGs".

II. Scope of Review

The following were checked for validity:

1. Calculation structure per ES-412
2. Methodology
3. Inputs
4. Assumptions
5. Computer spreadsheet structure and calculations
6. Use of ORNL curves for pH determination
7. Reasonableness of results
8. Conclusions

III. Results of Review

All eight items as outlined above were thoroughly checked and found to be in order and valid. All aspects of the calculation were deemed to be technically correct. The derived equations were transferred properly to the LOTUS spreadsheets that were used; no mistakes were found in the spreadsheets. For all the cases that were examined in the calculation, all inputs that were needed by the spreadsheets were derived properly and input properly; the mathematics, assumptions, and inputs for all cases matched the physical problems at hand. The use of the ORNL pH curves is difficult and tedious, yet all pH results were checked by hand and found to match the results in the calculation. The conclusions made were logical and reflected the findings of the calculations. A number of typographical errors were found; these were resolved with the author of the calculation in the course of this review. Suggestions for clarification of some portions of the calculation were presented to the author in the course of this review; these are not mandatory changes to be made, therefore these were left to the author's discretion.