ATTACHMENT 4

ST. LUCIE UNIT 2

Boric Acid Concentration Reduction

Report CEN - 365 (L)



EJW/020.PLA

# BORIC ACID
# CONCENTRATION REDUCTION EFFORT
# CEN - 365 (L)

## TECHNICAL BASES
## AND
## OPERATIONAL ANALYSIS

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# 1.0 INTRODUCTION

## 1.1 PURPOSE AND SCOPE

This report defines the methodology and outlines the technical bases which allows a reduction in the boric acid makeup tank (BAMT) concentration to the point where heat tracing of the boric acid makeup system is no longer required in order to prevent boric acid precipitation. The basic methodology or procedure used to set the minimum BAMT concentration and level for Modes 1, 2, 3, and 4 is derived from the safe shutdown requirements of NUREG 0800 Branch Technical Position RSB 5-1, "Design Requirements for the Residual Heat Removal System", (BTP 5-1). The St. Lucie Unit 2 plant has been classified as a Class 2 plant. Two independent boration sources are provided to compensate for reactivity changes and all expected transients throughout core life. These sources are the boric acid makeup tanks (BAMT) and the refueling water tank (RWT). This report reexamines the design basis used to establish BAMT boron concentration and volume requirements. In addition, the minimum RWT volume requirements are recalculated. Specifically, sufficient dissolved boric acid is maintained in these tanks in order to provide the required shutdown margin of Technical Specification 3.1.1.1 for a cooldown from hot standby to cold shutdown conditions. In addition, the minimum BAMT concentration and level for Modes 5 and 6 are based upon the ability to maintain the required shutdown margin in Technical Specification 3.1.1.2 following xenon decay and cooldown from 200 degrees to 135 degrees.

The work detailed in this report was performed specifically for the St. Lucie Unit 2 plant. The calculation performed herein and the values obtained should be applicable to future cycles. (See Section 2.2.3 below). The physics parameters used in this analysis were conservatively selected to bound core physics parameters for the remainder of plant life. Future cycle core physics parameters will be compared to the data in Appendix 5 to ensure that this calculation is bounding. The curve in Figure 3.1-1 of Technical Specification 3.1.2.8 and the values in 3.1.2.7 may change slightly; however, there should not be a need to heat trace the majority of the boric acid system for the remainder of plant life.

## 1.2 REPORT ORGANIZATION

This report has been organized into three general sections: Introduction, Technical Bases, and Operational Analysis. The Technical Bases Section 2.0, outlines the methodology which allows a significant reduction in boric acid makeup tank concentration and presents the results of the detailed calculations performed in support of the Technical Specifications. Separate calculations were performed for Specification 3.1.2.7 (Borated Water Source - Shutdown), Specification 3.1.2.8 (Borated Water Source - Operating), and Specification B3/4.1.2 (Boration Systems Bases). For completeness, the volume requirements for the RWT have been recalculated to demonstrate that the boration requirements for reactivity control in Modes 1, 2, 3 and 4 are much less than the emergency core cooling requirements. Also included in Section 2.0 are the technical responses to typical questions asked by the NRC during review of similar submittals by other nuclear facilities. The Operational Analysis Section, Section 3.0, outlines the impact on normal operations of a reduced boric acid makeup tank concentration. The types of operations evaluated in Section 3.0 include feed-and-bleed, blended makeup, shutdown to refueling, and shutdown to cold shutdown. All tables and figures are contained at the end of each section for easy reference.

## 1.3 PAST vs. PRESENT METHODOLOGY OF SETTING BAMT CONCENTRATION

Prior to the development of the new methodology for setting BAMT concentration and level described in this report, the level and concentration specified in the plant Technical Specifications for Modes 1, 2, 3, and 4 were based upon the ability to perform a cooldown to cold shutdown in the absence of letdown. (Safe Shutdown requirements of NUREG-0800 BTP 5-1 event). The RCS was borated to the boric acid concentration required to provide a shutdown margin of 5000 pcm at 200 degrees prior to commencing plant cooldown. In the limiting situation where letdown was not available, this boration was accomplished by charging to the RCS while simultaneously filling the pressurizer. Since boron concentration typically had to be increased by 800 ppm or more prior to commencing cooldown, highly concentrated boric acid solutions were required due to the limited space that was available in the pressurizer.

Relatively recent advances have made it possible to develop new methodologies for setting BAMT concentration and levels. The methodology for setting concentration and level of Modes 1, 2, 3, and 4 described in this report differs from previous methodologies in that boration of the reactor coolant system is performed concurrently with plant cooldown, i.e., concentrated boric acid is added concurrently with cooldown as part of normal inventory makeup due to coolant contraction. By knowing the exact boron concentration required to maintain proper shutdown margin at each temperature during a plant cooldown, BAMT concentration can be decoupled from pressurizer volume. As a result, the concentration of boric acid required to be maintained in the boric acid makeup tanks in order to perform a cooldown without letdown to cold shutdown conditions can be lowered to a range of 2.5 to 3.5 wt%, where heat tracing of the boric acid system is no longer required, i.e., the ambient temperatures that normally exist in the plant's auxiliary building are sufficient to prevent boric acid precipitation.

Similarly, a new methodology was developed for setting the minimum concentration and level of the boration source required to be operational in Modes 5 and 6. Since letdown is available in Mode 5 and 6 cooldown scenarios, a feed and bleed can be conducted to increase RCS boron concentration. Additionally boration can be conducted concurrently with cooldown as part of normal system makeup. By insuring that the boron concentration is maintained greater than that required for proper shutdown margin at each temperature, the boric acid makeup tank concentration for Modes 5 and 6 can be lowered to 2.5 weight percent.

## 2.0 <u>TECHNICAL BASES FOR REDUCING BAMT CONCENTRATION</u>

### 2.1 BORIC ACID SOLUBILITY

Figure 2-1 is a plot showing the solubility of boric acid in water for temperatures ranging from 32 to 160 degrees. (Data for Figure 2-1 was obtained from Reference 4.1 and is reprinted in Table 2-1.) Note that the solubility of boric acid at 32 degrees is 2.52 weight percent and at 50 degrees is 3.49 weight percent. At or below a concentration of 3.5 weight percent boric acid, the ambient temperature that normally exists in the auxiliary building will be sufficient to prevent precipitation within the boric acid makeup system.

### 2.2 METHOD OF ANALYSIS AND ASSUMPTIONS

#### 2.2.1 <u>RCS Boron Concentration vs. Temperature</u>

##### 2.2.1.1 Operating Modes 1, 2, 3 and 4

As stated in Section 1.3 above, the methodology developed to allow a significant reduction in the boric acid concentration required to be maintained in the BAMTs in Modes 1, 2, 3, and 4 differs from the previous methodology in that boration of the reactor coolant system is performed concurrently with cooldown in order to insure proper shutdown margin, i.e., concentrated boron is added as part of normal system makeup during the cooldown process. To employ a methodology allowing boration concurrent with cooldown, the exact boron concentration required to be present in the reactor coolant system must be known at any temperature during the cooldown process. In addition, in order to insure applicability for an entire cycle, a cooldown scenario must be developed which is conservative in that it places the greatest burden on an operator's ability to control reactivity, i.e., this scenario must define the boration requirements for the most limiting time in core cycle. Such a limiting scenario is as follows:

1. Conservative core physics parameters were used to determine the required boron concentration and the required Boric Acid Makeup Tank volumes to be added during plant cooldown. End-of-cycle initial boron concentration is assumed to be zero. End-of-cycle moderator cooldown effects are used to maximize the reactivity change during the plant cooldown. End-of-cycle (EOC) inverse boron worth data was used in combination with EOC reactivity insertion rates normalized to the most Negative Technical Specification Moderator Temperature Coefficient (MTC) limit since it was known that this yields results that are more limiting than the combination of actual MTC and actual IBW values at all periods through the fuel cycle prior to end-of-cycle. These assumptions assure that the required boron concentration and the Boric Acid Makeup Tank minimum volume requirements conservatively bound all plant cooldowns during core life.

2. The most reactive rod is stuck in the full out position.

3. Prior to time zero, the plant is operating at 100% power with 100% equilibrium xenon. Zero RCS leakage.

4. At time zero, the plant is shutdown and held at hot zero power conditions for 25.5 hours. (The xenon peak after shutdown will have decayed back to the 100% power equilibrium xenon level. Further xenon decay will add positive reactivity to the core during the plant cooldown.) No credit was taken for the negative reactivity effects of the xenon concentration peak following the reactor shutdown.

5. At 25.5 hours, offsite power is lost and the plant goes into natural circulation. All non-safety grade plant equipment and components are lost. During the natural circulation the RCS average temperature rises 25°F due to decay heat in the core. The initial temperature at the start of the cooldown is 557°F.

6. Approximately 0.5 hours later, at 26 hours, the operators commence a cooldown to cold shutdown.

The scenario outlined above was used to generate the boration requirements for Modes 1, 2, 3, and 4 (Specification 3.1.2.8). It produces a situation where positive reactivity will be added to the reactor coolant system simultaneously from two sources at the time that a plant cooldown from hot shutdown is commenced. These two reactivity sources result from a temperature effect due to an overall negative isothermal temperature coefficient of reactivity, and a poison effect as the xenon-135 level in the core starts to decay below its equilibrium value at 100% power. This scenario, therefore, represents the greatest challenge to an operators ability to borate the reactor coolant system and maintain the required Technical Specification shutdown margin while cooling the plant from hot standby to cold shutdown conditions.

2.2.1.2 Operating Modes 5 and 6

The methodology developed for Modes 5 and 6 differs from the method used in previous ret[illegible]g cycles to determine boration requirements. In this new methodology boration of the reactor coolant system is performed concurrently with cooldown. Concentrated boric acid is added as part of normal system makeup during the cooldown process. To employ a methodology allowing boration concurrent with cooldown, the exact boron concentration required to be present in the reactor coolant system must be known at any temperature during the cooldown process. The following scenario was developed to identify the most limiting cooldown transient for Modes 5 and 6.

1. End-of-cycle conditions with the initial RCS boron concentration necessary to provide shutdown margins of 3000 pcm at 200 degrees and xenon free core. EOC moderator cooldown effects are used to maximize the reactivity change during the plant cooldown.

End-of-cycle (EOC) inverse boron worth data was used in combination with EOC reactivity insertion rates normalized to the Most Negative Technical Specification Moderator Temperature Coefficient (MTC) limit since it was known that this yields results that are more limiting than the combination of actual MTC and actual IBW values at all periods through the fuel cycle prior to end-of-cycle.

2. Most reactive rod is stuck in the full out position.

3. Zero RCS leakage.

4. RCS feed-and-bleed can be used to increase boron concentration.

5. RCS makeup is supplied either from the RWT alone or a combination of makeup from the BAMT and RWT.

6. The most limiting scenario for boration in Mode 5 requires that a 3000 pcm shutdown be maintained during the cooldown from 200°F to 135°F. The boration requirements for Mode 6 only address maintaining a previously established shutdown margin. If the required shutdown margin for Mode 6 is not maintained, Technical Specification 3.9.1 requires that the RCS be borated at 40 gallons per minute from source of water $\geq$ 1720 ppm boron. Technical Specification 3.1.2.7 provides three alternative sources to meet this requirement, either BAMT or the RWT.

The scenario outlined above was used to determine the boration requirements for Modes 5 and 6 (Specification 3.1.2.7). It produces a situation where positive reactivity will be added to the reactor coolant system due to the overall negative isothermal temperature coefficient of reactivity. Since the core is already assumed to be xenon free there is no contribution to core reactivity due to xenon decay.

### 2.2.2 Impact of Various Cooldown Rates

As discussed in the previous Section, a conservative cooldown scenario was selected for use in determining RCS boron concentration levels. These concentration results were then used to define the minimum Technical Specification boric acid makeup tank inventory requirements. In the scenario for Modes 1, 2, 3, and 4, positive reactivity was added simultaneously from two sources at the time that the plant cooldown from hot standby was commenced. The component resulting from an overall negative isothermal temperature coefficient of reactivity is independent of time, but it is directly dependent upon the amount that the system has been cooled. In contrast, the component that results from the decay of xenon-135 below its equilibrium value at 100% power is independent of temperature, but directly dependent upon time. As a result, a slow cooldown rate will require more boron to be added to the reactor coolant system than a fast cooldown rate for a given temperature decrease since more positive reactivity must be accounted for due to xenon decay. This effect is illustrated in Figure 2-2 and is applicable to the Modes 1, 2, 3, and 4 analysis. Note that the bases for Technical Specification 3.1.2.7 require a cooldown following xenon decay. As a result, boration requirements are independent of cooldown rate for the Modes 5 and 6 analysis.

For the purpose of setting the minimum Technical Specification boric acid makeup tank inventory requirements in Modes 1, 2, 3, and 4, reactor coolant system boron concentration data was used that was based upon an overall cooldown rate of 12.5 degree per hour. This slow cooldown rate was chosen in order to be consistent with the time frames specified in Section 5.2 of Reference 4.3 (natural circulation cooldown in CE NSSS) for reactor vessel upper head cooldown. Specifically, 23.07 hours was required in order to take the plant from hot standby conditions to cold shutdown as shown in Table 2-2. For additional conservatism, 5.73 hours was added to this number to arrive at a final total of 28.8 hours. An overall cooldown rate, therefore, of 12.5 degrees per hour was required to cool the plant from an average coolant temperature of 557 degrees to an average coolant temperature of 200 degrees in 28.8 hours. This cooldown scenario will conservatively bound cooldowns that occur sooner and/or at a higher cooldown rate. The above scenario bounds the reactivity affects of a BTP 5-1 cooldown. It is assumed in the BTP 5-1 scenario that the RHR will be capable of bringing the RCS to cold shutdown conditions within 36 hours. With respect to Xenon reactivity affects the scenario used in this report bounds the 36 hour cooldown time frame of BTP 5-1 (26 hours to let Xenon return to 100% equilibrium level and 28 hours for a slow cooldown).

### 2.2.3 Applicability to Future Reload Cycles

To ensure that the current analysis would be valid for future cycles, data from St. Lucie Unit 2 Cycle 3 was conservatively bounded. Cycle 3 Physics data was used because Unit 2 was in that operating cycle at the start of the Boric Acid Concentration Reduction Effort. The physics data used in this analysis should bound future fuel cycles of similar reload cores. The physics data used in the calculation does bound the physics data for St. Lucie 2 Cycle 4. Appendix 5 contains bounding physics assumptions that were used to produce the required boron concentration values. As long as these inputs are more conservative than the reload cycle physics parameters, the values produced in this analysis will bound the boron concentration values for the future reload cycles.

### 2.2.4 Boron Mixing in the RCS and in the Pressurizer

Throughout the plant cooldowns performed in Section 2.3 and Section 2.4 below, a constant pressurizer level was always assumed, i.e., plant operators charged to the RCS only as necessary to makeup for coolant contraction. The driving force is small, in this situation, for the mixing of fluid between the reactor coolant system and the pressurizer.

As a conservatism, however, complete and instantaneous mixing was assumed between all makeup fluid added to the reactor coolant system through the loop charging nozzles and the pressurizer. Further, various pressure reductions were performed during the plant cooldown process as indicated in Section 2.4. These pressure reductions are necessary since the shutdown cooling system is a low pressure system and is normally aligned at or below an RCS pressure of 275 psia. Typically, such depressurizations are performed using the auxiliary pressurizer spray system under conditions where the reactor coolant pumps are not running. As an added conservatism in the Modes 1, 2, 3, and 4 analysis, any boron added to the pressurizer via the spray system was assumed to stay in the pressurizer and not be available for mixing with the fluid in the remainder of the RCS.

## 2.3 BORATED WATER SOURCES - SHUTDOWN (MODES 5 AND 6)

### 2.3.1 Boration Requirements for Modes 5 and 6

As stated in the plant Technical Specifications, the boration capacity required below a reactor coolant system average temperature of 200 degrees is based upon providing a shutdown margin of 3000 pcm following xenon decay and a plant cooldown from 200 degrees to 135 degrees. From this basis the required RCS boron concentrations were determined using conservative core physics data. The results of these calculations are contained in Table 2-3. The results contained in Table 2-3 are plotted as the required shutdown curve in Figure 2-3. Note that a total boron concentration increase of 46.0 ppm for St. Lucie 2 was required for the cooldown.

### 2.3.2 Assumptions Used in the Modes 5 and 6 Analysis

A complete list of assumptions and initial conditions used in calculating the minimum boric acid makeup tank inventory requirements for Modes 5 and 6 is contained in Table 2-4. In the process of taking the plant from hot standby to cold shutdown, the shutdown cooling system (SDCS) will normally be aligned when the RCS temperature and pressure have been lowered to approximately 325 degrees and 275 psia for St. Lucie 2. As shown in the next Section, the total system volume, i.e., RCS volume plus PZR volume plus SDCS volume, is required to be known for the Modes 5 and 6 analysis. The exact volumes of the reactor coolant system and the pressurizer are known. The exact volume of the shutdown cooling system, however, is not known. (Best estimate calculations for this volume have yielded values from approximately 2500 $ft^3$ to approximately 3000 $ft^3$). For the purpose of the analysis in the following Section, the volume of the shutdown cooling system will be chosen conservatively large, equal to the RCS volume, so as to yield conservative results with respect to minimum boric acid makeup tank inventory requirements.

The exact system volume used in the Modes 5 and 6 calculation is as follows:

$$2 \times (\text{RCS volume}) + (\text{PZR volume at 0\% power}),$$

or

$$2(9398\ ft^3) + (450\ ft^3) = \underline{19,246\ ft^3}$$

### 2.3.3 Modes 5 and 6 Analysis Results

As stated in Section 2.3.1, the boration capacity required below a reactor coolant system average temperature of 200 degrees is based upon providing shutdown margins of 3000 pcm for St. Lucie 2 following xenon decay and a plant cooldown from 200 degrees to 135 degrees. The operating scenario that will be employed for the purpose of determining reactor coolant system boron concentration and ensuring that proper shutdown margin will be maintained is as follows:

Option 1: Provide RCS Makeup From BAMT

A. The systems are initially at 200 degrees and 275 psia. Initial concentration in the reactor coolant system, pressurizer, and in the shutdown cooling system is 570.3 ppm boron. (See Table 2-4 for a complete list of assumptions).

B. Perform a plant cooldown from an average temperature of 200 degrees to an average temperature of 135 degrees using makeup water from the BAMT (2.5 weight % boric acid solution at 70 degrees). Charge only as necessary to makeup for coolant contraction.

From Equation 2.0 of Appendix 3 and the conversion factor that is derived in Appendix 4, the initial boric acid mass in the system can be calculated as follows:

$$m_{ba} = \frac{\dfrac{570.3 \text{ ppm}}{1748.34 \text{ ppm/wt. \%}}\left[\dfrac{18,796 \text{ ft}^3}{0.01662 \text{ ft}^3/\text{lbm}} + \dfrac{450 \text{ ft}^3}{0.018775 \text{ ft}^3/\text{lbm}}\right]}{100 - (570.3 \text{ ppm})/(1748.34 \text{ ppm/wt. \%})}$$

or

$$m_{ba} = 3779.5 \text{ lbm boric acid}$$

Knowing the initial mass of boron in the system, the exact concentration and makeup requirements can be calculated for each 10 degrees of a cooldown from 200 degrees to 135 degrees. These values are contained in Table 2-6. Equations used to obtain the values shown in Table 2-6 are as follows:

Shrinkage Mass = $18{,}796\ (1/v_f - 1/v_i)$

Water Vol. = (Shrinkage Mass) / (8.329 lbm/gallon)[1]

Boric Acid Added = (Water Vol.) x (0.21356 lbm/gallon)[2]

Total Boric Acid = (Initial Boric Acid) + (Boric Acid Added)

Total System Mass = (Total initial Mass) + (Shrinkage Mass) + (Boric Acid Added)

$$\text{Final Conc.} = \frac{(\text{Total Boric Acid})(100)(1748.34)^{(3)}}{(\text{Total System Mass})}$$

Note that the initial total system mass of 1,158,674.2 lbm in Table 2-6 was obtained as follows:

(Initial Boric Acid) + (Initial System Water Mass) + (Pressurizer Water Mass)

$= 3779.5\ \text{lbm} + (18{,}976\ \text{ft}^3 / 0.01662\ \text{ft}^3/\text{lbm}) + (450\ \text{ft}^3 / 0.018775\ \text{ft}^3/\text{lbm})$

$= 1{,}158{,}674.2\ \text{lbm}$

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(1) Water density at 70 degrees.

(2) See Appendix 3 for values of dissolved boric acid in water.

(3) See Appendix 4 for the conversion factor between wt. % and ppm.

The boration results from the system cooldown from 200 to 135 degrees are plotted as the actual concentration curve in Figure 2-4. As can be seen from this figure,a shutdown margin of greater than the required 3000 pcm was maintained throughout the evaluation. A minimum concentration of 2.5 weight % boric acid was therefore specified in the plant Technical Specification 3.1.2.7. The minimum volume that should be specified in the Technical Specification is 3550 gallons. This volume was determined as follows:

| | |
|---|---|
| Makeup volume [4] | 3049.0 gallons |
| Arbitrary amount for conservatism | 500.0 gallons |
| Total | 3549.0 gallons |
| Round up to nearest 50 gallons | 3550 gallons |

(4) Total of values in Water Vol. column of Table 2-6.

OPTION 2: Feed and Bleed then Cooldown from RWT

The RWT will not provide enough boric acid to compensate for the reactivity inserted during the cooldown if charging is restricted to makeup for coolant contraction only. A system feed-and-bleed must be performed to raise the RCS concentration before the cooldown is commenced. The initial feed-and-bleed ensures that the actual RCS boron concentration is maintained above the required boron concentration for a 3000 pcm shutdown margin while the plant is cooled down from 200 degrees to 135 degrees.

For St. Lucie 2, in order to calculate the initial increase in boron concentration during the 3200 gallon system feed-and-bleed, Equation 9.0 of Appendix 1 will be used with values as follows:

$C_o$ = 570.3 ppm $\qquad$ $C_{in}$ = 1720 ppm

$$T = \frac{(18{,}976\ ft^3 / 0.01662\ ft^3/lbm)^{(5)} + (450\ ft^3 / 0.018775\ ft^3/lbm)^{(6)}}{40\ \frac{gallons}{min} \times 8.343^{(7)}\ \frac{lbm}{gallon}}$$

T = 3,493.1 min.

(5) Specific volume of compressed water at 200°F and 275 psia

(6) Specific volume of saturated water at 275 psia

(7) Density of water at 50°F

If one charging pump at 40 gpm (as assumed in calculating the value of T above) is used to conduct the system feed-and-bleed, 80 minutes are required (3200 gal/40 gpm = 80 min). Concentrations vs time for the feed-and-bleed from equation 9.0 of Appendix D is therefore:

| Time | Conc |
|---|---|
| 0 | 570.3 |
| 20 | 577.0 |
| 40 | 583.5 |
| 60 | 590.1 |
| 80 | 596.6 |

The feed-and-bleed portion of the cooldown process is indicated on Figure 2-4 as the vertical line. As shown, concentration was increased from 570.3 ppm to 596.6 ppm following the 3200 gallon feed-and-bleed.

From Equation 2.0 of Appendix 3 and the conversion factor derived in Appendix 4, the mass of boric acid in the system corresponding to concentrations of 596.6 ppm can be calculated as follows:

$$M_{ba} = \frac{CM_w}{100 - C}$$

$$= \frac{[(596.6\ ppm)/(1748.34ppm/wt.\%)]\ (18,976ft^3/0.01662ft^3/lbm+450ft^3/0.018775ft^3/lbm)}{100 - (596.6ppm)/(1748.34ppm/wt.\%)}$$

= 3954.2 lbm boric acid

Knowing the masses of boric acid in the system following the feed-and-bleed, the exact concentrations and makeup requirements can be calculated for each 10 degrees of cooldowns from 200°F to 135°F. These values are contained in Table 2-7. The cooldown assumes a constant pressurizer volume of 450 $ft^3$ and a constant pressure of 275 psia. In addition, complete mixing between the RCS and the PZR is assumed as discussed in Section 2.2.4 above. Equations used to obtain the values contained in Table 2-7 are as follows:

Shrinkage mass = 18,976 $(1/v_f - 1/v_i)$

Water Vol. = (Shrinkage mass) / (8.343 lbm/gallon)

Boric acid added = (water vol.) (0.08289 lbm/gallon)

Total boric acid = initial boric acid + boric acid added

Total System mass = Total initial mass + shrinkage mass + boric acid added

$$\text{Final concentration} = \frac{\text{(Total Boric Acid) (100) (1748.34)}}{\text{Total System Mass}}$$

The results of the initial system feed-and-bleed plus the plant cooldown are plotted as Curve II in Figure 2-4. Note that throughout the evaluation, a shutdown margin greater than 3000 pcm was maintained as required.

The initial total system mass in Table 2-7 was obtained as follows:

Initial boric acid mass + initial system water mass + initial PZR water mass = 3954.2 lbm + (18.976 $ft^3$) / (0.01662 $ft^3$/lbm) + (450 $ft^3$) / (0.018775 $ft^3$/lbm) = 1,158,730.2 lbm

RWT concentrations of 1720 ppm will therefore be specified in Technical Specification 3.1.2.7 since the proper shutdown margin could be maintained. The minimum volume will be specified as follows for the RWT cooldown:

| | |
|---|---|
| Feed-and-Bleed Volume | 3200.0 gallons |
| Makeup Volume | 3043.1 gallons |
| Total | 6243.1 |
| Round up to nearest 50 + 500 gallons | 6750 gallons |

With 60,000 gallons of the RWT unusable, the actual required volumes in the RWT at 1720 ppm is 66,750 gallons for St. Lucie 2.

## 2.4 BORATED WATER SOURCES - OPERATING (MODES 1, 2, 3, and 4)

### 2.4.1 Boration Requirements for Modes 1, 2, 3, and 4

For this analysis a shutdown margin of 5000 pcm is provided at all temperatures above a reactor coolant system average temperature of 200 degrees. For temperatures at or below 200 degrees, a shutdown margin of 3000 pcm is provided after xenon decay and cooldown to 200 degrees. From this basis, the required RCS boron concentrations were determined using conservative core physics parameters and the limiting cooldown scenario outlined in Section 2.2.1 above. The results are plotted as the shutdown curve in Figure 2-5.

### 2.4.2 Assumptions Used in the Modes 1, 2, 3, and 4 Analysis

A complete list of assumptions and initial conditions used in calculating the minimum boric acid makeup tank inventory requirements for Modes 1, 2, 3, and 4 are contained in Table 2-5. Note that complete and instantaneous mixing between the reactor coolant system and the pressurizer was assumed as stated in Section 2.2.4 for all fluid added to the reactor coolant system via the loop charging nozzles. The mechanism used to implement this assumption in the analysis was to include the pressurizer water mass as part of the total system mass for the purpose of calculating boron concentration. Specifically, boron concentration in terms of weight fraction is defined as follows:

$$\text{(boron conc.)} = \frac{\text{(mass of boron in system)}}{\text{(total system mass)}}$$

where, if complete mixing is assumed between the RCS and the pressurizer, the total system mass is the sum of the boron mass in the system, the reactor coolant system water mass, and the pressurizer water mass.

Therefore, the initial total system mass of 458,238.7 lbm in Table 2-8 through Table 2-32 for St. Lucie 2 was calculated as follows:

Initial boron mass + Initial RCS water mass + Initial PZR water mass, or

$$0 + \frac{9398\ ft^3}{0.021567\ ft^3/lbm^{(8)}} + \frac{600\ ft^3}{0.02669\ ft^3/lbm^{(9)}}$$

### 2.4.3 Modes 1, 2, 3, and 4 Analysis Results

As stated in Section 2.4.1, the boration capacity required below a reactor coolant system average temperature of 200 degrees is based upon providing a 3000 pcm shutdown margin after xenon decay and a plant cooldown to 200 degrees from expected operating conditions. In addition, for this analysis a shutdown margin of 5000 pcm is provided at all temperatures above a reactor coolant system average temperature of 200 degrees. In order to perform a plant cooldown from hot standby conditions to cold shutdown and maintain the above shutdown margin at each temperature above 200 degrees, the following operating scenario will be employed:

(8) Specific volume of compressed water at 557 degrees and 2200 psia.
(9) Specific volume of saturated water at 2200 psia.

A. Assuming the initial conditions outlined in Table 2-5, perform a plant cooldown starting from an initial RCS average temperature of 557 degrees to a final average system temperature of 200 degrees.

B. Charge to the RCS only as necessary to makeup for coolant contraction. Charge from the BAMT initially until BAMT is drained, then switch to the RWT for the remainder of the cooldown.

The exact reactor coolant system boron concentrations versus temperature for plant cooldowns and depressurizations from 557 degrees and 2200 psia to 200 degrees and 275 psia with a boric acid makeup tank concentration of 3.50 weight percent and a refueling water tank concentration of 1720 ppm boron is contained in Table 2-8. These results are plotted as the actual concentration curve in Figure 2-5. (The exact temperature at which charging pump suction was switched from the BAMTs to the refueling water tank was determined via an iterative process. In this process, the smallest boric acid makeup tank volume necessary to maintain the required shutdown margin was calculated for the given set of tank concentrations). Note that at each temperature during the cooldown process, RCS boron concentration is greater than that required for the shutdown margin of 5000 pcm. Also note in Figure 2-5 that the shutdown margin drops from 5000 pcm to 3000 pcm at an average coolant temperature of 200 degrees. Following xenon decay the final concentration required to be present in the system at the most limiting time in core cycle is 570.3 ppm boron. Using the scenario outlined on the previous page, the final system concentrations will always be at least 64.6 ppm greater than these amounts.

A detailed parametric analysis was performed for the modes 1, 2, 3, and 4 Technical Specification (Specification 3.1.2.8). In this study, BAMT concentration was varied from 3.5 weight percent boric acid to 2.5 weight percent boric acid. Although St. Lucie Unit 2 Technical Specifications allow only a maximum RWT concentration of 2100 ppm boron, this report provides analysis for the RWT concentration range from 1720 ppm boron to 2300 ppm boron. This was done to be consistent with the Boric Acid Concentration Reduction Reports provided to other units. The results are contained in Table 2-9 through Table 2-32. Equations used to obtain the values in these tables as well as Table 2-8 are as follows:

Shrinkage Mass = $9398\ (1/v_f - 1/v_i)$

BAMT Vol. = (Shrinkage Mass) / (8.3290 lbm/gallon)[10]

RWT Vol. = (Shrinkage Mass ) / (8.343 lbm/gallon)[11]

Boric Acid Added = (BAMT Vol.) x (mass of boric acid/gallon)[12]

or

= (RWT Vol.) x (mass of boric acid/gallon)[12]

Total Boric Acid = (Initial Boric Acid) + (Boric Acid Added)

Total System Mass = (RCS water mass) + (PZR water mass) [13] + (Total boric acid)

Final Conc. = $\frac{\text{(Total Boric Acid)(100)(1748.34)}^{(14)}}{\text{(Total System Mass)}}$

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(10) Density of water at assumed tank temperature 70°F.

(11) Density of water at assumed tank temperature 50°F.

(12) See Appendix 3 for values of dissolved boric acid in water.

(13) PZR water mass = (600 $ft^3$) / (specific volume at indicated $P_{sat}$).

(14) See Appendix 4 for the conversion factor between wt. % and ppm.

Note that the value of the total system mass at any temperature and pressure in Table 2-8 through Table 2-32 can be obtained as follows:

RCS water mass + PZR water mass + total boric acid mass = total system mass.

As an example, the value of the total system mass at 200 degrees and 275 psia in Table 2-8 was obtained as follows:

$$\frac{9{,}398\ ft^3}{0.01662\ ft^3/lbm^{(15)}} + \frac{600\ ft^3}{0.018775\ ft^3/lbm^{(16)}} + 2350.7\ lbm$$

$$= 599{,}771.4\ lbm.$$

In a similar manner as in the results of Table 2-8, the concentration results of Table 2-9 through Table 2-32 were compared to the required concentrations at each temperature for a plant cooldown from 557 degrees to 200 degrees which are contained in Table 2-33. In each case, the actual system boron concentrations were greater than that necessary for the required shutdown margin as indicated in Figure 2-5. To set the minimum Technical Specification boric acid makeup tank volume corresponding to the various BAMT and RWT concentrations, the

(15) Specific volume of compressed water at 200 degrees and 275 psia.

(16) Specific volume of saturated water as 275 psia.

makeup tank volumes from Table 2-8 through Table 2-32 were compiled into Table 2-34. The volumes contained in Table 2-34 are the minimum BAMT volumes needed to borate the RCS to the required shutdown margin. These volumes must be contained in the region of the BAMT above zero percent indicated level. These volumes are rounded up to the next 50 gallons and 500 gallons are added to provide conservatism. The resulting volumes after adjustment are contained in Table 2-35. These values are plotted in Figure 2-6. The cooldown scenario used assumes that V-2504 is opened remotely or manually and depressurization of the RCS is achieved by auxiliary spray from the RWT.

In a similar manner, the values at 1720 ppm in the RWT from Table 2-35 are plotted in Figure 3.1-1 of the St. Lucie 2 Technical Specifications. This figure replaces the existing Technical Specification Figure 3.1-1.

### 2.4.4 Simplification Used Following Shutdown Cooling Initiation

In the cooldown and depressurization process assumed in Table 2-8 through Table 2-32, the plant operators must physically align the shutdown cooling systems an RCS temperature and pressure of approximately 325 degrees and 275 psia. Following this alignment, the volume and mass of the system that the operator must contend with during any subsequent cooldown will obviously increase by the volume and mass associated with the shutdown cooling system. Further, the total boron mass in the system that the operator is now dealing with will also have increased by the amount of boron in the SDCS prior to alignment. In Table 2-8 through 2-32, as a simplification, no attempt was made to factor into the equations the higher total volume and total boron mass that would result when the shutdown cooling system is placed in service. The use of these simplifications in the Modes 1, 2, 3, and 4 calculations can be justified as follows:

1. At the time that the shutdown cooling system is aligned, makeup is being supplied from the refueling water tank. Therefore, additional makeup that would be required during the cooldown from 325 degrees to 200 degrees due to a larger system volume will not affect the total BAMT volume requirements. This assumption would affect the minimum volume requirement of the RWT in Modes 1, 2, 3, and 4. Since the RWT requirements for emergency core cooling are much greater than the requirements for this cooldown scenario, this simplification does not impact RWT sizing requirements.

2. In a cooldown process where an operator is charging only as necessary to makeup for coolant contraction, the change in boron concentration within the system is independent of the total system volume, i.e., the final system boron concentration is not a function of total system volume. (A proof of this statement is contained in Appendix 2).

3. As stated in Table 2-5 boron concentration in the SOCS is assumed to be equal to reactor coolant system concentration at the time of shutdown cooling initiation. This assumption is in fact a conservatism since the concentration in that system in most situations will be closer to refueling water tank concentration at the time of initiation.

2.4.5 Refueling Water Tank Boration Requirements-Modes 1,2,3 and 4

The refueling water tank provides an independent source of borated water that can be used to compensate for core reactivity changes and expected transients throughout core life. It should be noted that in Modes 1, 2, 3 and 4 the minimum RWT water volume is 417,100 gallons as required by emergency core cooling considerations. The purpose of this section is to demonstrate that the RWT minimum inventory requirements in modes 1, 2, 3 and 4 to compensate for these reactivity changes during a shutdown are much less than the emergency core cooling requirements.

This calculation derives the minimum quantity of RWT water necessary to bring the plant from hot standby to cold shutdown while maintaining the plant at a 5000 pcm shutdown margin. All RCS makeup is supplied from the RWT at a boron concentration of 1720 ppm. This cooldown is performed as described below.

A. Perform a RCS feed-and-bleed to raise RCS boron concentration from 0 ppm to 388.9 ppm boron. This is a 110 minute feed and bleed using 3 charging pumps.

B. Perform a plant cooldown from an initial RCS temperature and pressure of 557 degrees and 2200 psia to 325 degrees and 275 psig. Charge only as required to makeup for coolant contraction.

C. Align the shutdown cooling system (SDCS) to the RCS. Assume that the SDCS volume is 9398 $ft^3$. Assume that the concentration of the SDCS is equal to that of the RCS at the time of shutdown cooling initiation.

D. Continue cooldown from 325 degrees and 275 psia to a final RCS condition of 200 degrees and 275 psia. Charge only as necessary to makeup for coolant contraction.

Table 2-38 contains the results of the calculated volumes in steps A through D. The RWT boration requirement for Modes 1, 2, 3 and 4 has been rounded up to 35,000 gallons. Figure 2-11 shows the RCS boron concentration as the plant cooldown progresses. As expected the boration requirements imposed a RWT sizing are much smaller than the minimum volume requirements placed on the RWT by emergency core cooling requirements (417,100 gallons).

2.5 BORATION SYSTEMS - BASES

The BASES section of the technical specifications was developed to demonstrate the boration system capability to maintain adequate shutdown margin from all operating conditions. Section 3/4.1.2 of the plant Technical Specifications will be changed to state the following:

"The boration capability of either system is sufficient to provide a SHUTDOWN MARGIN from all operating conditions of 3.5% delta k/k after xenon decay and cooldown to 200°F. The maximum boration capability requirement occurs at EOL from full power equilibrium xenon conditions. This requirement can be met for a range of boric acid concentrations in the BAMT and RWT. This range is bounded by 5350.0 gallons of 3.5 weight % boric acid from the BAMT and 16,000 gallons of 1720 ppm borated water from the RWT to 8650.0 gallons of 2.5 weight % boric acid from the BAMT and 12,000 gallons of 1720 ppm borated water from the RWT. A minimum of 35,000 gallons of 1720 ppm boron is required from the RWT if it is to be used to borate the RCS alone."

The 16,000 gallon RWT volume for St. Lucie 2 in Section 3/4.1.2 of the plant Technical Specifications was obtained by assuming RCS makeup was provided from the BAMT and the RWT. Total RCS makeup due to the coolant contraction during cooldown is calculated as described in A, B and C below. This yielded a contraction volume of 20,516.1 gallons. From this volume the minimum BAMT volume for the RWT at 1720 ppm boron from Table 2-35, 5350.0 gallons was subtracted yielding 15,166.1 gallons, which was rounded up to 16,000 gallons. As a result of the addition of 3.5 weight % boric acid from the BAMT, a feed-and-bleed is not required to maintain the shutdown margin of 3.5% delta k/k. Table 2-36 shows how this RWT volume was calculated.

The 12,000 gallon RWT volume was obtained in a similar manner. The total makeup is the same. From this volume, the maximum BAMT volume for the RWT at 1720 ppm boron from Table 2-35, 8650.0 gallons was subtracted yielding 11,866.1 gallons, which was rounded up to 12,000 gallons. As a result of the addition of 2.5 weight % boric acid from the BAMT, a feed-and-bleed is not required to maintain the shutdown margin of 3.5% delta k/k. Table 2-37 shows how this RWT volume was calculated.

A plant cooldown using water from the RWT alone is discussed in Section 2.4.5 of this report. This cooldown scenario provides the minimum RWT water volume requirement for plant cooldown considerations of 35,000 gallons. This number is contained in Technical Specification Bases 3/4.1.2.

## 2.6 RESPONSE TO REVIEW QUESTIONS

This Section of the report details the responses to the typical questions asked during the review of the Technical Specifications.

Question 1: What are the uncertainties and conservatism associated with the two curves shown in Figure 2-5 of this report?

Response to Question 1:

The lower curve in Figure 2-5 of this report represents an upper bound on the minimum concentrations required to be present in the reactor coolant system for a required shutdown margin at the indicated temperatures. In the computer analyses that were performed to generate these curves, appropriate analytical and measurement uncertainties as well as appropriate conservatism were included to ensure that an upper bounding curve was obtained. The major uncertainties and conservatism that were factored into the required shutdown curve of Figure 2-5 was as follows:

1. Initial scram is assumed to take place from the hot full power PDIL (power dependent insertion limit) to all rods in, with the worst case rod stuck in the full out position.

2. A bias of -9% and uncertainty of 13% was applied to the scram worth for the Unit 2 data.

3. A combined bias and uncertainty of 10% was applied to the moderator data.

4. A bias of 15% and an uncertainty of 15% was applied to the Doppler data.

5. The assumption that the cooldown begins at 26 hours is conservative in relation to the buildup and decay of Xenon.

Since appropriate analytical and measurement uncertainties as well as appropriate conservatism associated with the analysis were factored into the lower curve in Figure 2-5, it is not necessary to factor any additional uncertainties or conservatism directly into the upper curve shown in that figure. Although no additional uncertainties were included in the upper curve, the cooldown scenario followed by the operator was specifically chosen to be conservative such that the actual concentration curve in Figure 2-5 in effect represents a lower bound on the boron concentration that can be achieved by an operator given a certain boric acid makeup tank (BAMT) level and boron content. Specifically, conservatism in the cooldown scenario was insured in two ways. First, the cooldown was conducted assuming a constant pressurizer level, i.e., plant operators charged to the reactor coolant system only as necessary to makeup for coolant contraction. As a result, boron concentration in the reactor coolant system can be increased above the upper curve in Figure 2-5 by over-charging during the cooldown process, i.e., charge in excess of the makeup required for coolant contraction by allowing pressurizer level to increase. Second, the BAMT volumes obtained in Table 2-8 through Table 2-32 of this report were rounded up to the nearest 50 gallons and 500 gallons were added in order to give the final results that appear in Figure 2-6. Boron concentration in the reactor coolant system, therefore, can be increased further since more inventory is available in the BAMTs than that used to generate the actual concentration curve in Figure 2-3.

Question 2: What are the implications of a reduction in boric acid makeup tank concentrations with respect to plant emergency procedures and Combustion Engineering's Emergency Procedure Guidelines?

Response to Question 2:

As stated in Section 3.2 of this report credit is not taken for boron addition to the reactor coolant system from the boric acid makeup tanks for the purpose of reactivity control in the accidents analyzed in Chapter 15 of the plant's Final Safety Analysis Report. The response of an operator, therefore, to such events as steam line break, overcooling, boron dilution, etc., will not be affected by a reduction in BAMT concentration. In particular, the action statements associated with Technical Specification 3.1.1.2 require that boration be commenced at greater than 40 gallons per minute using a solution of at least 1720 ppm boron in the event that shutdown margin is lost. Such statements are conservatively based upon the refueling water tank concentration and are therefore independent of the amount of boron in the BAMTs.

Similar to the Technical Specification action steps in the event of a loss of shutdown margin, the operator guidance in Combustion Engineering's Emergency Procedure Guidelines (EPGs), CEN-152, Rev. 2, are also independent of specific boron concentrations within the boric acid makeup tanks. Specifically, the acceptance criteria developed for the reactivity control section of the Functional Recovery Guidelines of CEN-152 are based upon a boron addition rate from the chemical and volume control system of 40 gallons per minute without reference to a particular boration concentration. The reduction in boron concentration within the boric acid makeup tanks therefore has no impact on, and does not change, the guidance contained in the EPGs.

Question 3: Under natural circulation conditions, show that boron mixing in the reactor coolant system is rapid enough to ensure that proper shutdown margin is maintained during a safe shutdown. What is the effect of various cooldown rates on the mixing process? If an operator charges only as necessary to makeup for coolant contraction, what is the impact of pressurizer level instrument errors on boron concentration?

Response to Question 3:

As discussed in Section 1.1 of this report the basic methodology or procedure used to set the minimum boric acid makeup tank (BAMT) level and concentration for Modes 1, 2, 3, and 4 is derived from the safe shutdown requirements of Branch Technical Position (RSB) 5-1. Specifically, sufficient dissolved boric acid is maintained in these tanks in order to provide the required shutdown margin of Technical Specification 3.1.1.1 for a cooldown from hot standby to cold shutdown conditions. Further, the methodology outlined in Section 2.0 of the report for Modes 1, 2, 3, and 4 was developed by incorporating appropriate conservatism to insure that the shutdown margin of 5.0% delta k/k would indeed be satisfied at each temperature during the cooldown process.

The conservatism includes a cooldown scenario that maximized the boration requirements due to xenon decay. In Section 2.0 the cooldown was not commenced until twenty-six hours after the reactor trip. This time interval allowed the post trip xenon to peak and decay back to the pre-trip steady state value. Selecting the low cooldown rate of 12.5

degrees per hour maximized the xenon contribution to the boration requirement by allowing more xenon decay during the cooldown than would have occurred if a more rapid cooldown had been conducted.

Boron mixing effects were evaluated for natural circulation cooldown conditions specified in the safe shutdown requirements of Reference 4.4. Just prior to event initiation, the plant is operating at 100% of rated thermal power. Previous operating history is such as to davelop the maximum core decay heat load. At time zero, event initiation occurs and offsite power is lost. The reactor coolant pumps deenergize causing a reactor trip, and the plant goes into natural circulation. All non-safety grade equipment is lost, including letdown, and one diesel generator fails to start. The plant is held at these conditions in hot standby for four hours, at which time a cooldown to cold shutdown is commenced. (Section 5.4 of CEN-201(S), Supplement No. 1, contains a computer simulation of the safe shutdown scenario of Reference 4.3 and shows these events).

The exact boration requirements that give a 5.0% shutdown margin for these scenarios are shown in Figure 2-7. (These curves were obtained using conservative core physics parameters. Note that the above shutdown curves in these figures are based upon a 100 degree per hour cooldown rate. A cooldown rate of 100 degrees per hour was selected for the following reasons: First, a fast cooldown rate is more limiting than a slow cooldown with respect to boron mixing since the slope of the required boration curve is greater. The effect of the assumed mixing time (less than thirty minutes) would be more adverse than a cooldown at a slower cooldown rate (see Figure 2-7). Second, a 100 degrees per hour cooldown rate is the maximum allowable. For an added conservatism the actual RCS boron concentration was derived by using BAMT concentrations of 2.5 weight percent. (BAMT concentrations of 2.5 weight % was selected since these are the lowest values that will be allowed by Technical Specification 3.1.2.8 and since it yields the slowest increases in reactor coolant system concentrations during the cooldown process). The actual concentration curves were obtained using the methodology outlined in Section 2.4 of this report and includes the following assumptions and conservatism:

1. No boron addition is credited prior to commencing plant cooldown. (Note that one charging pump will operate immediately following plant trip in response to pressurizer level shrink as indicated in Section 5.4 of CEN-201(S), Supplement No. 1. Credit for boron addition, however, during this period will not be taken).

2. Pressurizer volume at the start of plant cooldown equals 450 $ft^3$.

3. Charging will be secured at the start of the plant cooldown and will remain secured until pressurizer level has decreased by 10%. (In the methodology outlined in this report operators were assumed to charge as necessary to maintain a constant pressurizer level. Note that the error associated with pressurizer level is typically $\pm$ 2 percent, therefore allowing a 10 percent decrease in level before initiating charging is conservative).

4. Following the initial 10% decrease in pressurizer level, charging will be initiated and maintained as necessary to keep pressurizer levels constant for the remainder of the plant cooldown.

5. Complete and instantaneous mixing with all fluid added via the charging nozzles with the contents of the RCS and the pressurizer is assumed. (Note that this assumption in relation to a delay in boron mixing will be discussed below).

The concentration curve that was obtained using these assumptions is shown in Figure 2-7. In order to account for the effect of a delay in the boron mixing process under natural circulation conditions, the actual concentration curve in Figure 2-7 will be shifted to the right by 0.5 hours. (Note that 30 minutes is consistent with the boron mixing time that was determined in CEN-259 and, in addition, is conservative since CEN-259 also indicates that significant mixing of added boron does occur prior to 30 minutes). The shift is shown in Figure 2-8. The relationship between the shifted curve and the required concentration curve is shown in greater detail in Figure 2-9 and Figure 2-10. As can be seen in Figure 2-8 to Figure 2-10, the concentrations within the reactor coolant system for the 0.5 hour shift curves are above the required shutdown curve at each temperature during the cooldown.

Question 4: LP&L included boron measurement uncertainties in their report. FP&L did not include them. Why?

Response to Question 4:

A boron measurement uncertainty was included in the LP&L physics data when the natural circulation scenario assumed that the boronometer would be used to verify RCS boron concentration. A very conservative boronometer measurement uncertainty (50 ppm) was added to the RCS boron requirements. A review of the cooldown scenario shows that the addition of boronometer measurement uncertainty to the RCS boron requirements is unnecessary. The cooldown scenario in CEN-365(L) identifies the minimum volume of BAMT water that must be added to maintain the desired shutdown margin throughout the cooldown. Delivery of this quantity of BAMT water will ensure that the RCS is adequately borated. The boronometer readings will not be used during the cooldown as a criteria to reduce the amount of BAMT water delivered to the RCS during this cooldown. In conclusion, boronometer measurement uncertainties need not be included in the boration requirement curves for either plant.

Question 5: Explain the uncertainties and conservatism for the Scram Worth, Moderator Temperature Coefficient (MTC) and the Doppler Coefficient used in the FP&L boric acid makeup tank report.

Response to Question 5:

A bias of -9% and an uncertainty of 13% was applied to the Scram Worth data. No conservative correction was needed to the MTC curve since it was already consistent with the Most Negative Technical Specification MTC limit. A combined bias and uncertainty of 10% was applied to the moderator data. The application of bias of 15% and an uncertainty of 15% to the Doppler data is consistent with the licensing methodology used at other plants.

Question 6: Why is there a substantial difference between the boric acid requirements specified for St. Lucie Unit 1 and Unit 2?

Response to Question 6:

The substantial difference is due to the fact that the fuel vendors for the two units are different. C-E is the fuel vendor for Unit 2 and C-E provides the Reload Safety Analysis. C-E had all the physics data required to determine the boration requirements, particularly the Inverse Boron Worth and the Cooldown Curve.

In the case of St. Lucie Unit 1, ANF is the fuel vendor and provides the Reload Safety Analysis. To perform the Unit 1 work FP&L, through ANF, provided the physics data inputs to C-E. In the analysis, it was noted that the ANF Inverse Boron Worth (IBW) values were significantly different than those that would be provided with C-E methodology. The ANF IBW values were conservative (i.e. the boron requirements were greater than similar data C-E would generate). C-E also analyzed the Moderator Temperature Coefficient (MTC) curve provided by ANF and found it necessary to normalize the curve provided to the Most Negative Technical Specification MTC limit. This normalization was done in a very conservative manner, and it probably shows a much greater reactivity insertion due to cooldown than if the fuel vendor had done the evaluation. The normalized MTC values were conservative.

Question 7: What shutdown margin was used to generate the boron concentration requirements for Modes 5 and 6?

Response to Question 7:

Although the Technical Specifications only required a shutdown margin of 3000 pcm in Modes 5 and 6, a shutdown margin of 3500 pcm was used in the calculations to generate the boron concentration requirements. The only effect is that the use of 3500 pcm changes both the initial and final concentration requirements by a constant amount. Since the difference between the initial and final requirements is due only to the moderator temperature coefficient, the use of 3500 pcm does not change the difference between the requirements. The requirements are conservative.

Table 2-1

Boric Acid Solubility in Water[1]

| Temperature (Degrees F) | Wt. % $H_3BO_3$ |
|---|---|
| 32.0 | 2.52 |
| 41.0 | 2.98 |
| 50.0 | 3.49 |
| 59.0 | 4.08 |
| 68.0 | 4.72 |
| 77.0 | 5.46 |
| 86.0 | 6.23 |
| 95.0 | 7.12 |
| 104.0 | 8.08 |
| 113.0 | 9.12 |
| 122.0 | 10.27 |
| 131.0 | 11.55 |
| 140.0 | 12.97 |
| 149.0 | 14.42 |
| 158.0 | 15.75 |
| 167.0 | 17.91 |
| 176.0 | 19.10 |

(1) Solubility from Technical Data Sheet IC-11, US Borax & Chemical Corporation, 3-83-J.W.

Table 2-2

Time Frames for Determining an Overall
RCS Cooldown Rate

| | |
|---|---|
| Initial Hot Standby hold period (*) | 4.0 hours |
| Plant cooldown from 557 to 325 degrees (#) | 2.32 hours |
| Hold period for cooling the reactor vessel upper head | 15.5 hours |
| Plant cooldown from 325 to 200 degrees (#) | 1.25 hours |
| Additional conservatism | 5.73 hours |
| Total | 28.8 hours |

(*) Per the requirements of Branch Technical Position (RSB) 5-1.

(#) Assume an average cooldown rate of 100 degrees per hour.

Table 2-3

Required Boron Concentration for a Cooldown from 200 Degrees to 135 Degrees

| Temperature (Degrees F) | Concentration (@) (ppm boron) |
|---|---|
| 200 | 570.3 |
| 190 | 577.4 |
| 180 | 584.5 |
| 170 | 591.6 |
| 160 | 598.6 |
| 150 | 605.7 |
| 140 | 612.8 |
| 135 | 616.3 |

(@) Based upon a 3000 pcm shutdown margin after xenon decay.

Table 2-4

Initial Conditions and Assumptions Used in the Modes 5 and 6 Calculation

a. Reactor coolant system volume = 9,398 $ft^3$.

b. Reactor coolant system pressure = 275 psia.

c. Pressurizer volume = 450 $ft^3$.

d. Pressurizer is saturated.

e. Zero reactor coolant system leakage.

f. Boration source concentration = 2.5 weight % boron.

g. Boration source temperature = 70 degrees.

h. Initial reactor coolant system concentration = 570.3 ppm

i. Initial pressurizer concentration = 570.3 ppm boron.

j. Complete and instantaneous mixing between the pressurizer and the reactor coolant system. (Refer to discussion on Section 2.2.4 above).

k. Constant pressurizer level maintained during the plant cooldown, i.e., charge only as necessary to makeup for coolant contraction.

l. Total system volume (RCS + SDCS + PZR) = 19,246 $ft^3$. (See discussion in Section 2.3.2).

Table 2-5
Initial Conditions and Assumptions Used
in the Modes 1, 2, 3, and 4 Calculation

a. Reactor coolant system volume = 9,398 $ft^3$.

b. Initial reactor coolant system pressure = 2200 psia.

c. Pressurizer volume = 600 $ft^3$ (40% level).

d. Pressurizer is saturated.

e. Reactor coolant system depressurization performed as shown in Table 2-8 through Table 2-32.

f. Zero reactor coolant system Technical Specification leakage.

g. Initial reactor coolant system concentration = 0 ppm.

h. Initial pressurizer concentration = 0 ppm boron.

i. Complete and instantaneous mixing between the pressurizer and the reactor coolant system. (Refer to discussion on Section 2.2.4 above).

j. Constant pressurizer level maintained during the plant cooldown, i.e., charge only as necessary to makeup [illegible] lant contraction.

k. Boron concentration in the SDCS [illegible] equa[illegible] the boron concentration in the reactor coolant system at th[illegible] shutdown cooling initiation.

l. Letdown is not available.

m. RWT temperature = 50 degrees.

n. BAMT temperature = 70 degrees.

Table 2-6

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 200 F TO 135 F; BAMT AT 2.5 wt% BORIC ACID

| AVG. SYS. TEMP (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 200 | 275 | 1.0000C | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 3,779.5 | 1,156,674.2 | 570.3 |
| 200 | 190 | 275 | 0.01662 | 0.01656 | 4,097.6 | 492.0 | 0.0 | .05.1 | 3,884.6 | 1,162,876.8 | 584.0 |
| 190 | 180 | 275 | 0.01656 | 0.01650 | 4,127.4 | 495.5 | 0.0 | 105.8 | 3,990.4 | 1,167,110.0 | 597.8 |
| 180 | 170 | 275 | 0.01650 | 0.01644 | 4,157.5 | 499.2 | 0.0 | 106.6 | 4,097.0 | 1,171,374.1 | 611.5 |
| 170 | 160 | 275 | 0.01644 | 0.01638 | 4,187.9 | 502.8 | 0.C | 107.4 | 4,204.4 | 1,175,669.4 | 625.2 |
| 160 | 150 | 275 | 0.01638 | 0.01633 | 3,513.5 | 421.8 | 0.0 | 90.1 | 4,294.5 | 1,179,273.0 | 636.7 |
| 150 | 140 | 275 | 0.01633 | 0.01628 | 3,535.0 | 424.4 | 0.0 | 90.6 | 4,385.1 | 1,162,898.6 | 648.1 |
| 140 | 135 | 275 | 0.01628 | 0.01626 | 1,775.7 | 213.2 | 0.0 | 45.5 | 4,430.7 | 1,184,719.8 | 653.9 |

TOTAL BAMT VOLUME 3048.9 gallons

Table 2-7

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 200 F TO 135 F; RWT AT 1720 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | [illegible] (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 200 | 275 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 3,954.2 | 1,158,848.9 | 596.6 |
| 200 | 190 | 275 | 0.01662 | 0.01656 | 4,097.6 | 0.0 | 491.0 | 40.7 | 3,994.9 | 1,162,987.1 | 600.6 |
| 190 | 180 | 275 | 0.01656 | 0.01650 | 4,127.4 | 0.0 | 494.6 | 41.0 | 4,035.9 | 1,167,155.5 | 604.6 |
| 180 | 170 | 275 | 0.01650 | 0.01644 | 4,157.5 | 0.0 | 498.2 | 41.3 | 4,077.2 | 1,171,354.3 | 608.6 |
| 170 | 160 | 275 | 0.01644 | 0.01638 | 4,187.9 | 0.0 | 501.8 | 41.6 | 4,118.8 | 1,175,583.8 | 612.6 |
| 160 | 150 | 275 | 0.01638 | 0.01633 | 3,513.5 | 0.0 | 421.0 | 34.9 | 4,153.7 | 1,179,132.2 | 615.9 |
| 150 | 140 | 275 | 0.01633 | 0.01628 | 3,535.0 | 0.0 | 423.6 | 35.1 | 4,188.8 | 1,182,702.3 | 619.2 |
| 140 | 135 | 275 | 0.01628 | 0.01626 | 1,775.7 | 0.0 | 212.8 | 17.6 | 4,206.5 | 1,184,495.6 | 620.9 |

TOTAL RWT VOLUME 3043.0 gallons

Table 2-8

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.5 wt% BORIC ACID; RWT AT 1720 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,235.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 969.9 | 969.9 | 485,950.2 | 349.0 |
| 510 | 482 | 2200 | 0.02032 | 0.01974 | 13,589.2 | 1,631.5 | 0.0 | 492.9 | 1,462.8 | 500,032.3 | 511.5 |
| 482 | 480 | 2200 | 0.01974 | 0.01970 | 966.7 | 0.0 | 115.9 | 9.6 | 1,472.4 | 501,008.6 | 513.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 46.2 | 1,518.5 | 505,700.6 | 525.0 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 44.6 | 1,563.1 | 510,230.7 | 535.6 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 42.9 | 1,606.0 | 514,587.3 | 545.6 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 41.0 | 1,647.0 | 518,758.9 | 555.1 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 47[illegible].8 | 39.1 | 1,686.1 | 522,734.1 | 563.9 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 39.7 | 1,725.8 | 526,773.0 | 572.8 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 40.4 | 1,766.2 | 530,877.3 | 581.7 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 35.5 | 1,801.7 | 534,488.4 | 589.4 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 38.8 | 1,840.6 | 538,434.7 | 597.6 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 33.8 | 1,874.3 | 541,865.7 | 604.8 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 34.2 | 1,908.5 | 545,342.3 | 611.9 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 34.7 | 1,943.2 | 548,865.5 | 619.0 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 32.2 | 1,975.4 | 552,136.8 | 625.5 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 32.6 | 2,007.9 | 555,448.7 | 632.0 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 33.0 | 2,040.9 | 558,802.1 | 638.6 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 15.1 | 2,056.1 | 560,340.3 | 641.5 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,056.1 | 569,817.3 | 630.9 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 30.5 | 2,086.6 | 572,920.1 | 636.8 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 116.0 | 2,202.6 | 584,716.6 | 658.6 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 64.8 | 2,267.5 | 591,308.5 | 670.4 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 59.7 | 2,327.2 | 597,376.2 | 681.1 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 23.6 | 2,350.7 | 599,771.4 | 685.2 |

TOTAL BAMT VOLUME 4842.2 gallons

Table 2-9

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.25 wt% BORIC ACID; RWT AT 1720 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 898.3 | 898.3 | 485,878.6 | 323.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 327.9 | 1,226.2 | 495,967.9 | 432.3 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 161.1 | 1,387.3 | 500,923.4 | 484.2 |
| 480 | 472 | 2200 | 0.01970 | 0.01955 | 3,709.5 | 445.4 | 0.0 | 124.6 | 1,511.9 | 504,757.5 | 523.7 |
| 472 | 460 | 2200 | 0.01955 | 0.01933 | 5,[illegible]22.0 | 0.0 | 649.9 | 53.9 | 1,565.8 | 510,233.4 | 536.5 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 42.9 | 1,608.6 | 514,590.0 | 546.5 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 41.0 | 1,649.7 | 518,761.6 | 556.0 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 39.1 | 1,688.8 | 522,736.7 | 564.8 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 39.7 | 1,728.5 | 526,775.7 | 573.7 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 40.4 | 1,768.9 | 530,879.9 | 582.5 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 35.5 | 1,804.4 | 534,491.0 | 590.2 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 38.8 | 1,843.2 | 538,437.3 | 598.5 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 33.8 | 1,877.0 | 541,868.3 | 605.6 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 34.2 | 1,911.2 | 545,344.9 | 612.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 34.7 | 1,945.8 | 548,868.1 | 619.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 32.2 | 1,978.0 | 552,139.4 | 626.3 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 32.6 | 2,010.6 | 555,451.4 | 632.9 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 33.0 | 2,043.6 | 558,804.7 | 639.4 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 15.1 | 2,058.7 | 560,342.9 | 642.3 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,058.7 | 569,820.0 | 631.7 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 30.5 | 2,089.2 | 572,922.8 | 637.6 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 116.0 | 2,205.3 | 584,719.2 | 659.4 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 64.8 | 2,270.1 | 591,311.1 | 671.2 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 59.7 | 2,329.8 | 597,378.9 | 681.9 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 23.6 | 2,353.4 | 599,774.1 | 686.0 |

TOTAL BAMT VOLUME 5403.6 gallons

Table 2-10

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.0 wt% BORIC ACID; RWT AT 1720 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./ibm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 827.1 | 827.1 | 485,807.4 | 297.6 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 301.9 | 1,129.0 | 495,870.6 | 398.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 148.3 | 1,277.3 | 500,613.4 | 445.9 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 143.7 | 1,420.9 | 505,603.0 | 491.4 |
| 470 | 459 | 2200 | 0.01951 | 0.01931 | 4,913.5 | 589.9 | 0.0 | 152.0 | 1,572.9 | 510,668.5 | 538.5 |
| 459 | 450 | 2200 | 0.01931 | 0.01916 | 3,885.8 | 0.0 | 465.8 | 38.6 | 1,611.5 | 514,592.9 | 547.5 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 41.0 | 1,652.6 | 518,764.5 | 556.9 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 39.1 | 1,691.7 | 522,739.6 | 565.8 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 39.7 | 1,731.4 | 526,778.6 | 574.6 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 40.4 | 1,771.8 | 530,882.8 | 583.5 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 35.5 | 1,807.3 | 534,493.9 | 591.2 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 38.8 | 1,846.1 | 538,440.2 | 599.4 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 33.8 | 1,879.9 | 541,871.2 | 606.5 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 34.2 | 1,914.1 | 545,347.8 | 613.6 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 34.7 | 1,946.7 | 548,871.0 | 620.7 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 32.2 | 1,980.9 | 552,142.3 | 627.2 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 32.6 | 2,013.5 | 555,454.3 | 633.8 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 33.0 | 2,046.5 | 558,807.6 | 640.3 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 15.1 | 2,061.6 | 560,345.8 | 643.2 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,061.6 | 569,822.9 | 632.5 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 30.5 | 2,092.1 | 572,925.7 | 638.4 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 116.0 | 2,208.2 | 584,722.1 | 660.3 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 64.8 | 2,273.0 | 591,314.0 | 672.1 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 59.7 | 2,332.7 | 597,381.8 | 682.7 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 23.6 | 2,356.3 | 599,777.0 | 686.9 |

TOTAL BAMT VOLUME 6106.0 gallons

Table 2-1i

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.75 wt% BORIC ACID; RWT AT 1720 ppm BORON

| AVG.SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 756.2 | 756.2 | 485,736.5 | 272.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 276.0 | 1,032.2 | 495,773.8 | 364.0 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 135.6 | 1,167.8 | 500,703.9 | 407.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 131.4 | 1,299.1 | 505,481.2 | 449.3 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 538.5 | 0.0 | 126.8 | 1,426.0 | 510,093.6 | 488.8 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 517.9 | 0.0 | 122.0 | 1,548.0 | 514,529.3 | 526.0 |
| 450 | 442 | 2200 | 0.01916 | 0.01903 | 3,298.9 | 396.1 | 0.0 | 93.3 | 1,641.2 | 517,921.5 | 554.0 |
| 442 | 430 | 2200 | 0.01903 | 0.01885 | 4,767.7 | 0.0 | 571.5 | 47.4 | 1,688.6 | 522,736.6 | 564.8 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 39.7 | 1,72[illegible].3 | 526,775.5 | 573.6 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 40.4 | 1,768.7 | 530,879.8 | 582.5 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 35.5 | 1,804.2 | 534,490.9 | 590.2 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 38.8 | 1,843.1 | 538,437.2 | 598.5 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 33.8 | 1,876.8 | 541,838.2 | 605.6 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 34.2 | 1,911.0 | 545,3[illegible].8 | 612.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 34.7 | 1,945.7 | 548,668.0 | 619.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 32.2 | 1,977.9 | 552,139.3 | 626.3 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 32.6 | 2,010.4 | 555,451.2 | 632.8 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 33.0 | 2,043.4 | 558,804.6 | 639.3 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 15.1 | 2,058.6 | 560,342.8 | 642.3 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,058.6 | 569,819.8 | 631.6 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 30.5 | 2,089.1 | 572,922.6 | 637.5 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 116.0 | 2,205.1 | 584,719.1 | 659.3 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 64.8 | 2,270.0 | 591,311.0 | 671.2 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 59.7 | 2,329.7 | 597,378.7 | 681.8 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 23.6 | 2,353.2 | 599,773.9 | 686.0 |

TOTAL BAMT VOLUME 6968.6 gallons

Table 2-12

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.50 wt% BORIC ACID; RWT AT 1720 ppm BORON

| AVG. SYS. TEMP. (F) Ti | AVG. SYS. TEMP. (F) Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | SPECIFIC VOLUME (cu.ft./lbm) Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 685.7 | 685.7 | 485,666.0 | 246.8 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 25[illegible].3 | 936.0 | 495,677.6 | 330.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 122.9 | 1,058.9 | 500,595.1 | 369.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 119.1 | 1,178.0 | 505,360.0 | 407.5 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 538.5 | 0.0 | 115.0 | 1,293.0 | 509,960.6 | 443.3 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.6 | 517.9 | 0.0 | 110.6 | 1,403.6 | 514,385.0 | 477.1 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 495.9 | 0.0 | 105.9 | 1,509.5 | 518,621.5 | 508.9 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 472.6 | 0.0 | 100.9 | 1,610.5 | 522,658.4 | 538.7 |
| 430 | 418 | 2200 | 0.01885 | 0.01867 | 4,806.8 | 577.1 | 0.0 | 123.2 | 1,733.7 | 527,588.4 | 574.5 |
| 418 | 410 | 2200 | 0.01867 | 0.01855 | 3,256.3 | 0.0 | 390.3 | 32.4 | 1,766.1 | 530,877.1 | 581.6 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 35.5 | 1,801.6 | 534,488.2 | 589.3 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 38.8 | 1,840.4 | 538,434.5 | 597.6 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 33.8 | 1,874.2 | 541,865.5 | 604.7 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 34.2 | 1,908.4 | 545,342.1 | 611.8 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 34.7 | 1,943.0 | 548,865.3 | 618.9 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 32.2 | 1,975.2 | 552,136.6 | 625.4 |
| 350 | 340 | 2200 | 0.01781 | [illegible] | 3,279.4 | 0.0 | 393.1 | 32.6 | 2,007.8 | 555,448.6 | 632.0 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 33.0 | 2,040.8 | 558,801.9 | 638.5 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 15.1 | 2,055.9 | 560,340.1 | 641.5 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,055.9 | 569,817.2 | 630.8 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 30.5 | 2,086.4 | 572,920.0 | 636.7 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 116.0 | 2,202.5 | 584,716.4 | 658.6 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 64.8 | 2,267.3 | 591,308.3 | 670.4 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 59.7 | 2,327.0 | 597,376.1 | 681.0 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 23.6 | 2,350.6 | 599,771.3 | 685.2 |

TOTAL BAMT VOLUME 8118.1 gallons

Table 2-13

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.5 wt% BORIC ACID; RWT AT 1850 ppm BORON

| AVG.SYS. TEMP. (F) Ti | If | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 969.9 | 969.9 | 485,950.2 | 349.0 |
| 510 | 487 | 2200 | 0.02032 | 0.01984 | 11,189.5 | 1,343.4 | 0.0 | 405.8 | 1,375.8 | 497,545.6 | 483.4 |
| 487 | 480 | 2200 | 0.01984 | 0.01970 | 3,366.3 | 0.0 | 403. | 36.0 | 1,411.8 | 500,947.9 | 492.7 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 49.7 | 1,461.4 | 505,643.5 | 505.3 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 48.0 | 1,509.4 | 510,177.0 | 517.3 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 46.1 | 1,555.6 | 514,536.9 | 528.6 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 44.2 | 1,599.7 | 518,711.6 | 539.2 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 42.1 | 1,641.8 | 522,689.8 | 549.2 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 42.8 | 1,684.6 | 526,731.8 | 559.2 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 43.5 | 1,728.1 | 530,839.1 | 569.1 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 38.2 | 1,766.3 | 534,452.9 | 577.8 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 41.8 | 1,808.1 | 538,402.2 | 587.1 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 36.3 | 1,844.4 | 541,835.8 | 595.1 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 36.8 | 1,881.2 | 545,315.0 | 603.1 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 37.3 | 1,918.6 | 548,840.9 | 611.2 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 34.6 | 1,953.2 | 552,114.6 | 618.5 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 35.1 | 1,988.3 | 555,429.1 | 625.9 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 35.5 | 2,023.8 | 558,785.0 | 633.2 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 16.3 | 2,040.1 | 560,324.3 | 636.6 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,040.1 | 569,801.3 | 626.0 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 32.9 | 2,072.9 | 572,906.5 | 632.6 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 124.9 | 2,197.9 | 584,711.8 | 657.2 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 69.8 | 2,267.7 | 591,308.6 | 670.5 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 64.3 | 2,331.9 | 597,381.0 | 682.5 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 25.4 | 2,357.3 | 599,778.0 | 687.1 |

TOTAL BAMT VOLUME 4554.1 gallons

Table 2-14

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.25 wt% BORIC ACID; RWT AT 1850 ppm BORON

| AVG.SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 89[illegible] | 898.3 | 485,878.6 | 323.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 327.9 | 1,226.2 | 495,967.9 | 432.3 |
| 490 | 478 | 2200 | 0.01990 | 0.01966 | 5,716.5 | 686.3 | 0.0 | 192.0 | 1,418.2 | 501,876.4 | 494.1 |
| 478 | 470 | 2200 | 0.01966 | 0.01951 | 3,723.9 | 0.0 | 446.3 | 39.8 | 1,458.1 | 505,640.1 | 504.2 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 48.0 | 1,506.1 | 510,173.7 | 516.1 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 46.1 | 1,552.2 | 514,533.6 | 527.4 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,150.5 | 0.0 | 495.1 | 44.2 | 1,596.4 | 518,708.3 | 538.1 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 42.1 | 1,638.5 | 522,686.4 | 548.1 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 42.8 | 1,681.2 | 526,728.4 | 558.0 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 43.5 | 1,724.7 | 530,835.8 | 568.0 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,5[illegible].6 | 0.0 | 428.6 | 38.2 | 1,762.9 | 534,449.6 | 576.7 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 41.8 | 1,804.7 | 538,398.8 | 586.0 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 36.3 | 1,841.1 | 541,832.4 | 594.1 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 36.8 | 1,877.9 | 545,311.6 | 602.1 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 37.3 | 1,915.2 | 548,837.5 | 610.1 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 34.6 | 1,949.8 | 552,111.2 | 617.4 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 395.1 | 35.1 | 1,984.9 | 555,425.7 | 624.8 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 35.5 | 2,020.4 | 558,781.6 | 632.2 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 16.3 | 2,036.7 | 560,320.9 | 635.5 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,036.7 | 569,798.0 | 624.9 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 32.9 | 2,069.6 | 572,993.1 | 631.6 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 124.9 | 2,194.5 | 584,708.4 | 656.2 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 69.8 | 2,264.3 | 591,305.3 | 669.5 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 64.3 | 2,328.6 | 597,377.6 | 681.5 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 25.4 | 2,353.9 | 599,774.6 | 686.2 |

TOTAL BAMT VOLUME 5069.0 gallons

Table 2-15

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.00 wt% BORIC ACID; RWT AT 1850 ppm BORON

| AVG.SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 827.1 | 827.1 | 485,807.4 | 297.6 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 301.9 | 1,129.0 | 495,870.6 | 398.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 148.3 | 1,277.3 | 500,813.4 | 445.9 |
| 480 | 466 | 2200 | 0.01970 | 0.01944 | 6,430.1 | 772.0 | 0.0 | 198.9 | 1,476.1 | 507,442.4 | 508.6 |
| 466 | 460 | 2200 | 0.01944 | 0.01933 | 2,701.3 | 0.0 | 323.8 | 28.9 | 1,505.0 | 510,172.6 | 515.8 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 46.1 | 1,551.2 | 514,532.5 | 527.1 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 44.2 | 1,595.3 | 518,707.2 | 537.7 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 42.1 | 1,637.4 | 522,685.4 | 547.7 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 42.8 | 1,680.2 | 526,727.4 | 557.7 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 43.5 | 1,723.7 | 530,834.7 | 567.7 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 38.2 | 1,761.9 | 534,448.5 | 576.4 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 41.8 | 1,803.7 | 538,397.8 | 585.7 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 36.3 | 1,840.0 | 541,831.4 | 593.7 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 36.8 | 1,876.8 | 545,310.6 | 601.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,462.5 | 0.0 | 418.1 | 37.3 | 1,914.2 | 548,836.5 | 609.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 34.6 | 1,948.8 | 552,110.2 | 617.1 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 35.1 | 1,983.9 | 555,424.7 | 624.5 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 35.5 | 2,019.4 | 558,780.6 | 631.8 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 16.3 | 2,035.7 | 560,319.9 | 635.2 |
| 325 | 310 | 275 | 0.0175[illegible] | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,035.7 | 569,796.9 | 624.6 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 32.9 | 2,068.5 | 572,902.1 | 631.3 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,[illegible]0.0 | 124.9 | 2,193.5 | 584,707.4 | 655.9 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | [illegible] | 69.8 | 2,263.3 | 591,304.2 | 669.2 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 64.3 | 2,327.5 | 597,376.6 | 681.2 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 25.4 | 2,352.9 | 599,773.6 | 685.9 |

TOTAL BAMT VOLUME 5730.3 gallons

Table 2-16

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.75 wt% BORIC ACID; RWT AT 1850 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 756.2 | 756.2 | 485,736.5 | 272.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 276.0 | 1,032.2 | 495,773.8 | 364.0 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 135.6 | 1,167.8 | 500,703.9 | 407.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 131.4 | 1,299.1 | 505,481.2 | 449.3 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 538.5 | 0.0 | 126.8 | 1,426.0 | 510,093.6 | 488.8 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 517.9 | 0.0 | 122.0 | 1,548.0 | 514,529.3 | 526.0 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 44.2 | 1,592.1 | 518,704.1 | 536.6 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 42.1 | 1,634.2 | 522,682.2 | 546.6 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 42.8 | 1,677.0 | 526,724.2 | 556.6 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 43.5 | 1,720.5 | 530,831.5 | 566.7 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 38.2 | 1,758.7 | 534,445.3 | 575.3 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 41.8 | 1,800.5 | 538,394.6 | 584.7 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 36.3 | 1,836.8 | 541,828.2 | 592.7 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 36.8 | 1,873.7 | 545,307.4 | 600.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 37.3 | 1,911.0 | 548,833.3 | 608.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 34.6 | 1,945.6 | 552,107.0 | 616.1 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 35.1 | 1,980.7 | 555,421.5 | 623.5 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 35.5 | 2,016.2 | 558,777.4 | 630.8 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 16.3 | 2,032.5 | 560,316.7 | 634.2 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,032.5 | 569,793.8 | 623.6 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 32.9 | 2,065.3 | 572,898.9 | 630.3 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 124.9 | 2,190.3 | 584,704.2 | 654.9 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 69.8 | 2,260.1 | 591,301.0 | 668.3 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 64.3 | 2,324.3 | 597,373.4 | 680.3 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 25.4 | 2,349.7 | 599,770.4 | 684.9 |

TOTAL BAMT VOLUME 6572.5 gallons

Table 2-17

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.50 wt% BORIC ACID; RWT AT 1850 ppm BORON

| AVG.SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 685.7 | 685.7 | 485,666.0 | 246.8 |
| 510 | 490 | 2200 | 0.02032 | 0.01999 | 9,761.3 | 1,172.0 | 0.0 | 250.3 | 936.0 | 495,677.6 | 330.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 122.9 | 1,058.9 | 500,595.1 | 369.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,615.9 | 557.8 | 0.0 | 119.1 | 1,178.0 | 505,360.0 | 497.5 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 538.5 | 0.0 | 115.0 | 1,293.0 | 509,960.6 | 443.3 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 517.9 | 0.0 | 110.6 | 1,403.6 | 514,385.0 | 477.1 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 495.9 | 0.0 | 105.9 | 1,509.5 | 518,621.5 | 508.9 |
| 440 | 426 | 2200 | 0.01900 | 0.01879 | 5,528.[illegible] | 663.7 | 0.0 | 141.7 | 1,651.3 | 524,291.3 | 550.6 |
| 425 | 420 | 2200 | 0.01879 | 0.01870 | 2,407.2 | 0.0 | 288.5 | 25.7 | 1,677.0 | 526,724.2 | 556.7 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 43.5 | 1,720.5 | 530,831.6 | 566.7 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 38.2 | 1,758.7 | 534,445.4 | 575.3 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 41.8 | 1,800.5 | 538,394.6 | 584.7 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 36.3 | 1,836.9 | 541,828.2 | 592.7 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 36.8 | 1,873.7 | 545,307.4 | 600.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 37.3 | 1,911.0 | 548,833.3 | 608.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 34.6 | 1,945.6 | 552,107.0 | 616.1 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 35.1 | 1,980.7 | 555,421.5 | 623.5 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 35.5 | 2,016.2 | 558,777.4 | 630.8 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 16.3 | 2,032.5 | 560,316.7 | 634.2 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,032.5 | 569,793.8 | 623.6 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 32.9 | 2,065.4 | 572,898.9 | 630.3 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 124.9 | 2,190.3 | 584,704.2 | 654.9 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 69.8 | 2,260.1 | 591,301.1 | 668.3 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 64.3 | 2,324.4 | 597,373.4 | 680.3 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 25.4 | 2,349.7 | 599,770.4 | 684.9 |

TOTAL BAMT VOLUME 7732.2 gallons

Table 2-18

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.5 wt% BORIC ACID; RWT AT 2000 ppm BORON

| AVG.SYS. TEMP. (F) Ti | AVG.SYS. TEMP. (F) Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | SPECIFIC VOLUME (cu.ft./lbm) Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 969.9 | 969.9 | 485,950.2 | 342.0 |
| 510 | 494 | 2200 | 0.02032 | 0.01998 | 7,776.2 | 933.6 | 0.0 | 282.0 | 1,252.0 | 494,008.5 | 443.1 |
| 494 | 480 | 2200 | 0.01998 | 0.01970 | 6,779.6 | 0.0 | 812.6 | 78.4 | 1,330.4 | 500,866.6 | 464.4 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 53.8 | 1,384.2 | 505,566.2 | 478.7 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 51.9 | 1,436.1 | 510,103.7 | 492.2 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 49.9 | 1,486.0 | 514,467.4 | 505.0 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 47.8 | 1,533.8 | 518,645.7 | 517.0 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 45.5 | 1,579.3 | 522,627.3 | 528.3 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 46.3 | 1,625.6 | 526,672.8 | 539.6 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 47.0 | 1,672.6 | 530,783.7 | 550.9 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 41.4 | 1,714.0 | 534,400.6 | 560.7 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 45.2 | 1,759.2 | 538,353.3 | 571.3 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 39.3 | 1,798.5 | 541,789.9 | 580.4 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 39.8 | 1,838.4 | 545,272.1 | 589.4 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 40.4 | 1,878.7 | 548,801.0 | 598.5 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 37.5 | 1,916.2 | 552,077.6 | 606.8 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 37.9 | 1,954.2 | 555,394.9 | 615.2 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 38.4 | 1,992.6 | 558,753.7 | 623.5 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 17.6 | 2,010.2 | 560,294.4 | 627.3 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,010.2 | 569,771.5 | 616.8 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 35.6 | 2,045.7 | 572,879.3 | 624.3 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 135.2 | 2,180.9 | 584,694.8 | 652.1 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 75.5 | 2,256.4 | 591,297.4 | 667.2 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 69.5 | 2,326.0 | 597,375.0 | 680.7 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 27.4 | 2,353.4 | 599,774.1 | 686.0 |

TOTAL BAMT VOLUME 4144.3 gallons

Table 2-19

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.25 wt% BORIC ACID; RWT AT 2000 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu ft./lbm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 898.3 | 898.3 | 485,878.6 | 323.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 327.9 | 1,226.2 | 495,967.9 | 432.3 |
| 490 | 485 | 2200 | 0.01990 | 0.01980 | 2,385.2 | 286.4 | 0.0 | 80.1 | 1,306.3 | 498,433.1 | 458.2 |
| 485 | 470 | 2200 | 0.01980 | 0.01951 | 7,055.2 | 0.0 | 845.6 | 81.6 | 1,388.0 | 505,570.0 | 480.0 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 51.9 | 1,439.9 | 510,107.5 | 493.5 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 49.9 | 1,489.8 | 514,471.2 | 506.3 |
| 450 | 440 | 2200 | 0.01915 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 47.8 | 1,537.6 | 518,649.5 | 518.3 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 45.5 | 1,583.1 | 522,631.1 | 529.6 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 46.3 | 1,629.4 | 526,676.6 | 549.9 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 47.0 | 1,676.4 | 530,787.5 | 552.2 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 41.4 | 1,717.8 | 534,404.4 | 562.0 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 45.2 | 1,763.0 | 538,357.1 | 572.6 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 39.3 | 1,802.3 | 541,793.7 | 581.6 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 39.8 | 1,842.2 | 545,275.9 | 590.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 40.4 | 1,882.5 | 548,804.8 | 599.7 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 37.5 | 1,920.0 | 552,081.4 | 608.0 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 37.9 | 1,958.0 | 555,398.8 | 616.3 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 38.4 | 1,996.4 | 558,757.6 | 624.7 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 17.6 | 2,014.0 | 560,298.2 | 628.4 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,014.0 | 569,775.3 | 618.0 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 35.6 | 2,049.6 | 572,883.1 | 625.5 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 135.2 | 2,184.7 | 584,698.6 | 653.3 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 75.5 | 2,260.3 | 591,301.2 | 668.3 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 69.5 | 2,329.8 | 597,378.8 | 681.9 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 27.4 | 2,357.2 | 599,777.9 | [illegible] |

TOTAL BAMT VOLUME 4669.0 gallons

Table 2-20

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.00 wt% BORIC ACID; RWT AT 2000 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 827.1 | 827.1 | 485,807.4 | 297.6 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 301.9 | 1,129.0 | 495,870.6 | 398.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 148.3 | 1,277.3 | 500,813.4 | 445.9 |
| 480 | 473 | 2200 | 0.01970 | 0.01957 | 3,242.6 | 389.3 | 0.0 | 100.3 | 1,377.5 | 504,156.3 | 477.7 |
| 473 | 460 | 2200 | 0.01957 | 0.01933 | 5,888.8 | 0.0 | 705.8 | 68.1 | 1,445.7 | 510,113.3 | 495.5 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 49.9 | 1,495.6 | 514,477.0 | 508.2 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 47.8 | 1,543.4 | 518,655.3 | 520.3 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 45.5 | 1,588.9 | 522,636.9 | 531.5 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 46.3 | 1,635.2 | 526,682.4 | 542.6 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 47.0 | 1,682.2 | 530,793.3 | 554.1 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 41.4 | 1,723.6 | 534,410.2 | 563.9 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 45.2 | 1,768.8 | 538,362.9 | 574.4 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 39.3 | 1,808.1 | 541,799.5 | 583.5 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 39.8 | 1,848.0 | 545,281.7 | 592.5 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 40.4 | 1,888.3 | 548,810.6 | 601.6 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 37.5 | 1,925.8 | 552,087.2 | 609.9 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 37.9 | 1,963.8 | 555,404.6 | 618.2 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 38.4 | 2,002.2 | 558,763.4 | 626.5 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 17.6 | 2,019.8 | 560,304.0 | 630.3 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,019.8 | 569,781.1 | 619.8 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 35.6 | 2,055.4 | 572,888.9 | 627.3 |
| 300 | 264 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 135.2 | 2,190.5 | 584,704.4 | 655.0 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 75.5 | 2,266.1 | 591,307.0 | 670.0 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 69.5 | 2,335.6 | 597,384.6 | 683.5 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 27.4 | 2,363.0 | 599,783.7 | 688.8 |

TOTAL BAMT VOLUME 5347.6 gallons

Table 2-21

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.75 wt% BORIC ACID; RWT AT 2000 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | P/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 7[illegible].2 | 756.2 | 485,736.5 | 272.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 276.0 | 1,032.2 | 495,773.8 | 364.0 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 135.6 | 1,167.8 | 500,703.9 | 407.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 131.4 | 1,299.1 | 505,481.2 | 449.3 |
| 470 | 459 | 2200 | 0.01951 | 0.01931 | 4,913.5 | 589.9 | 0.0 | 138.9 | 1,438.1 | 510,533.6 | 492.5 |
| 459 | 450 | 2200 | 0.01931 | 0.01916 | 3,885.8 | 0.0 | 465.8 | 45.0 | 1,483.1 | 514,464.4 | 504.0 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 47.8 | 1,530.8 | 518,642.8 | 516.0 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 45.5 | 1,576.4 | 522,624.4 | 527.4 |
| 4[illegible] | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 46.3 | 1,622.7 | 526,669.8 | 538.7 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 47.0 | 1,669.7 | 530,780.8 | 550.0 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 41.4 | 1,711.1 | 534,39[illegible].7 | 559.8 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 45.2 | 1,756.3 | 538,350.4 | 570.4 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 39.3 | 1,795.6 | 541,786.9 | 579.4 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 39.8 | 1,835.4 | 545,269.2 | 588.5 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 40.4 | 1,875.8 | 548,798.1 | 597.6 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 37.5 | 1,913.3 | 552,074.7 | 605.9 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 37.9 | 1,951.2 | 555,392.0 | 614.2 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 38.4 | 1,989.6 | 558,750.8 | 622.6 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 17.6 | 2,007.3 | 560,291.5 | 626.3 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,007.3 | 569,768.5 | 615.9 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 35.6 | 2,042.8 | 572,876.4 | 623.4 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 135.2 | 2,178.0 | 584,691.9 | 651.3 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 75.5 | 2,253.5 | 591,294.5 | 666.3 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 69.5 | 2,323.0 | 597,372.1 | 679.9 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 27.4 | 2,350.5 | 599,771.2 | 685.2 |

TOTAL BAMT VOLUME 6106.0 gallons

Table 2-22

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ST. LUCIE UNIT 2 — PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.50 wt% BORIC ACID; RWT AT 2000 ppm BORON | | | | | | | | | | | |
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 685.7 | 685.7 | 485,666.0 | 246.8 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.6 | 0.0 | 250.3 | 936.0 | 495,677.6 | 330.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 122.9 | 1,058.9 | 500,595.1 | 369.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 119.1 | 1,178.0 | 505,360.0 | 407.5 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 538.5 | 0.0 | 115.0 | 1,293.0 | 509,960.6 | 443.3 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 517.9 | 0.0 | 110.6 | 1,403.6 | 514,385.0 | 477.1 |
| 450 | 436 | 2200 | 0.01916 | 0.01894 | 5,697.5 | 684.1 | 0.0 | 146.1 | 1,549.7 | 520,228.6 | 520.8 |
| 436 | 430 | 2200 | 0.01894 | 0.01885 | 2,369.1 | 0.0 | 284.0 | 27.4 | 1,577.1 | 522,625.1 | 527.6 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 46.3 | 1,623.4 | 526,670.6 | 538.9 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 47.0 | 1,670.4 | 530,781.5 | 550.2 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 41.4 | 1,711.8 | 534,398.4 | 560.0 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 45.2 | 1,757.0 | 538,351.1 | 570.6 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 39.3 | 1,796.3 | 541,787.7 | 579.7 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 39.8 | 1,836.2 | 545,269.9 | 588.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 40.4 | 1,876.5 | 548,798.8 | 597.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 37.5 | 1,914.0 | 552,075.4 | 606.1 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 37.9 | 1,952.0 | 555,392.7 | 614.5 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 38.4 | 1,990.4 | 558,751.6 | 622.8 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 17.6 | 2,008.0 | 560,292.2 | 626.6 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 2,008.0 | 569,769.3 | 616.2 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 35.6 | [illegible] | 572,877.1 | 623.7 |
| 300 | [illegible] | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | [illegible] | [illegible] | 2,178.7 | 584,692.6 | 651.5 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | [illegible] | 782.3 | [illegible] | 2,254.2 | 591,295.2 | 666.5 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | [illegible] | 2,323.8 | 597,372.8 | 680.1 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | [illegible] | 0.0 | 284.3 | [illegible] | 2,351.2 | 599,771.9 | 685.4 |

TOTAL BAMT VOLUME 7256.6 gallons

Table 2-23

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 260 F; BAMT AT 3.5 wt% BORIC ACID; RWT AT 2150 ppm BORON

| AVG. SYS. TEMP. (F) Ti | AVG. SYS. TEMP. (F) Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) vi | SPECIFIC VOLUME (cu.ft./lbm) vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 969.9 | 969.9 | 485,950.2 | 349.0 |
| 510 | 501 | 2200 | 0.02032 | 0.02013 | 4,342.2 | 521.3 | 0.0 | 157.5 | 1,127.4 | 490,449.9 | 401.9 |
| 501 | 480 | 2200 | 0.02013 | 0.01970 | 10,213.7 | 0.0 | 1,224.2 | 127.3 | 1,254.7 | 500,790.8 | 438.0 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 57.9 | 1,312.6 | 505,494.6 | 454.0 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 55.9 | 1,368.5 | 510,036.1 | 469.1 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 53.8 | 1,422.2 | 514,403.6 | 483.4 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 51.5 | 1,473.7 | 518,585.6 | 496.8 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 49.1 | 1,522.8 | 522,570.7 | 509.5 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 49.8 | 1,572.6 | 526,619.8 | 522.1 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 50.6 | 1,623.2 | 530,734.3 | 534.7 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 44.6 | 1,667.8 | 534,354.4 | 545.7 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 48.7 | 1,716.5 | 538,310.6 | 557.5 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 42.3 | 1,758.8 | 541,750.2 | 567.6 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 42.9 | 1,801.7 | 545,235.5 | 577.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 43.5 | 1,845.2 | 548,767.5 | 587.9 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 40.4 | 1,885.6 | 552,047.0 | 597.2 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 40.9 | 1,926.4 | 555,367.2 | 606.5 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 41.4 | 1,967.8 | 558,729.0 | 615.8 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 19.0 | 1,986.8 | 560,271.0 | 620.0 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,986.8 | 569,748.1 | 609.7 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 38.3 | 2,025.1 | 572,858.6 | 618.0 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 145.6 | 2,170.6 | 584,684.6 | 649.1 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 81.3 | 2,252.0 | 591,293.0 | 665.9 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 74.9 | 2,326.9 | 597,375.9 | 681.0 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 29.6 | 2,356.4 | 599,777.1 | 686.9 |

TOTAL BAMT VOLUME 3732.0 gallons

Table 2-24

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.25 wt% BORIC ACID; RWT AT 2150 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 898.3 | 898.3 | 485,878.6 | 323.2 |
| 510 | 493 | 2200 | 0.02032 | 0.01996 | 8,270.9 | 993.0 | 0.0 | 277.8 | 1,176.2 | 494,427.4 | 415.9 |
| 493 | 480 | 2200 | 0.01996 | 0.01970 | 6,284.9 | 0.0 | 753.3 | 78.3 | 1,254.5 | 500,790.6 | 438.0 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 57.9 | 1,312.4 | 505,494.4 | 453.9 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 55.9 | 1,368.3 | 510,035.9 | 469.0 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 53.8 | 1,422.0 | 514,403.4 | 483.3 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 51.5 | 1,473.5 | 518,585.4 | 496.8 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 49.1 | 1,522.6 | 522,570.5 | 509.4 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 49.8 | 1,577.4 | 526,619.6 | 522.0 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 50.6 | 1,623.0 | 530,734.1 | 534.7 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 44.6 | 1,667.6 | 534,354.2 | 545.6 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 48.7 | 1,716.3 | 538,310.4 | 557.4 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 42.3 | 1,758.6 | 541,750.0 | 567.5 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 42.9 | 1,801.5 | 545,235.3 | 577.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 43.5 | 1,845.0 | 548,767.3 | 587.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 40.4 | 1,885.4 | 552,046.8 | 597.1 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 40.9 | 1,926.2 | 555,367.0 | 606.4 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 41.4 | 1,967.6 | 558,728.8 | 615.7 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 19.0 | 1,986.6 | 560,270.8 | 619.9 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,986.6 | 569,747.9 | 609.6 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 38.3 | 2,024.9 | 572,858.4 | 618.0 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 145.6 | 2,170.4 | 584,684.4 | 649.0 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 81.3 | 2,251.8 | 591,292.7 | 665.8 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 74.9 | 2,326.6 | 597,375.7 | 680.9 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 29.6 | 2,356.2 | 599,776.9 | 686.8 |

TOTAL BAMT VOLUME 4203.7 gallons

Table 2-25

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.00 wt% BORIC ACID; RWT AT 2150 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 827.1 | 827.1 | 485,007.4 | 297.6 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 301.9 | 1,129.0 | 495,870.6 | 398.1 |
| 490 | 483 | 2200 | 0.01990 | 0.01976 | 3,346.0 | 401.7 | 0.0 | 103.5 | 1,232.5 | 499,320.1 | 431.5 |
| 483 | 470 | 2200 | 0.01976 | 0.01951 | 6,094.4 | 0.0 | 730.5 | 75.9 | 1,308.4 | 505,490.4 | 452.5 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 55.9 | 1,364.3 | 510,031.9 | 467.7 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 53.8 | 1,418.1 | 514,399.4 | 482.0 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 51.5 | 1,469.5 | 518,581.4 | 495.4 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 49.1 | 1,518.6 | 522,566.6 | 508.1 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 49.8 | 1,568.4 | 526,615.6 | 520.7 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 50.6 | 1,619.1 | 530,730.1 | 533.4 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 44.6 | 1,663.6 | 534,350.2 | 544.3 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 48.7 | 1,712.3 | 538,306.4 | 556.1 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 42.3 | 1,754.7 | 541,746.0 | 566.3 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 42.9 | 1,797.6 | 545,231.3 | 576.4 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 43.5 | 1,841.0 | 548,763.3 | 586.5 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 40.4 | 1,881.4 | 552,042.8 | 595.8 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 40.9 | 1,922.3 | 555,363.0 | 605.1 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 41.4 | 1,963.6 | 558,724.8 | 614.5 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 19.0 | 1,982.6 | 560,266.8 | 618.7 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,982.6 | 569,743.9 | 608.4 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 38.3 | 2,020.9 | 572,854.4 | 616.8 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 145.6 | 2,166.5 | 584,680.4 | 647.8 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 81.3 | 2,247.8 | 591,288.8 | 664.6 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 74.9 | 2,322.7 | 597,371.7 | 679.8 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 29.6 | 2,352.2 | 597,772.9 | 685.7 |

TOTAL BAMT VOLUME 4784.4 gallons

Table 2-26

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.75 wt% BORIC ACID; RWT AT 2150 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 756.2 | 756.2 | 485,736.5 | 272.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 276.0 | 1,032.2 | 495,773.8 | 364.0 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 135.6 | 1,167.8 | 500,703.9 | 407.8 |
| 480 | 469 | 2200 | 0.01970 | 0.01949 | 5,090.7 | 611.2 | 0.0 | 143.9 | 1,311.7 | 505,938.6 | 453.3 |
| 469 | 460 | 2200 | 0.01949 | 0.01933 | 4,040.8 | 0.0 | 484.3 | 50.4 | 1,362.1 | 510,029.7 | 466.9 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 53.8 | 1,415.8 | 514,3?7.2 | 481.2 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 51.5 | 1,467.3 | 518,579.2 | 494.7 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 49.1 | 1,516.4 | 522,564.3 | 507.3 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 49.8 | 1,566.2 | 526,613.4 | 520.0 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 50.6 | 1,616.8 | 530,727.9 | 532.6 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 44.6 | 1,661.4 | 334,348.0 | 543.6 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 48.7 | 1,710.1 | 538,304.2 | 555.4 |
| 390 | 380 | 2200 | 0.01828 | 0.01316 | 3,397.2 | 0.0 | 407.2 | 42.3 | 1,752.4 | 541,743.8 | 565.6 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 42.9 | 1,795.3 | 545,229.1 | 575.7 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 43.5 | 1,838.8 | 548,761.1 | 585.8 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 40.4 | 1,879.2 | 552,040.6 | 595. |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 40.9 | 1,920.0 | 555,360.8 | 604.5 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 41.4 | 1,961.4 | 558,722.6 | 613.8 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 19.0 | 1,980.4 | 560,264.6 | 618.0 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,980.4 | 569,741.7 | 607.7 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 38.3 | 2,018.7 | 572,852.2 | 616.1 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 145.6 | 2,164.2 | 584,678.2 | 647.2 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 81.3 | 2,245.6 | 591,286.6 | 664.0 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 74.9 | 2,320.5 | 597,369.5 | 679.1 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 29.6 | 2,350.0 | 599,770.7 | 685.0 |

TOTAL BAMT VOLUME 5569.5 gallons

Table 2-27

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.5 wt% BORIC ACID; RWT AT 2150 ppm BORON

| AVG.SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 685.7 | 685.7 | 485,666.0 | 246.8 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 250.3 | 936.0 | 495,677.6 | 330.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 122.9 | 1,058.9 | 500,595.1 | 369.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 119.1 | 1,178.0 | 505,360.0 | 407.5 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 538.5 | 0.0 | 115.0 | 1,293.0 | 509,960.6 | 443.3 |
| 460 | 447 | 2200 | 0.01933 | 0.01911 | 5,545.7 | 665.8 | 0.0 | 142.2 | 1,435.2 | 515,648.5 | 486.6 |
| 447 | 440 | 2200 | 0.01911 | 0.01900 | 2,898.6 | 0.0 | 347.4 | 36.1 | 1,471.3 | 518,583.3 | 496.0 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 49.1 | 1,520.4 | 522,568.4 | 508.7 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 49.8 | 1,570.2 | 526,617.4 | 521.3 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 50.6 | 1,620.9 | 530,731.9 | 533.9 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 44.6 | 1,665.4 | 534,352.1 | 544.9 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 48.7 | 1,714.1 | 538,308.2 | 556.7 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 42.3 | 1,756.5 | 541,747.8 | 566.8 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 42.9 | 1,799.4 | 545,233.1 | 577.0 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 43.5 | 1,842.8 | 548,765.1 | 587.1 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 40.4 | 1,883.2 | 552,044.6 | 596.4 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 40.9 | 1,924.1 | 555,364.9 | 605.7 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 41.4 | 1,965.4 | 558,726.6 | 615.0 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 19.0 | 1,984.4 | 560,268.6 | 619.2 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,984.4 | 569,745.7 | 608.9 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 38.3 | 2,022.7 | 572,856.3 | 617.3 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 145.6 | 2,168.3 | 584,682.2 | 648.4 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 81.3 | 2,249.6 | 591,290.6 | 665.2 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 74.9 | 2,324.5 | 597,373.5 | 680.3 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 29.6 | 2,354.0 | 599,774.7 | 686.2 |

TOTAL BAMT VOLUME 6720.4 gallons

Table 2-28

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.5 wt% BORIC ACID; RWT AT 2300 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS (lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 509 | 2200 | 0.02157 | 0.02028 | 27,699.6 | 3,325.7 | 0.0 | 1,004.7 | 1,004.7 | 486,942.9 | 360.7 |
| 509 | 490 | 2200 | 0.02028 | 0.01990 | 8,803.4 | 0.0 | 1,055.2 | 117.3 | 1,122.0 | 495,863.6 | 395.6 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 0.0 | 574.7 | 63.9 | 1,185.9 | 500,722.1 | 414.1 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 61.9 | 1,247.8 | 505,429.9 | 431.6 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 59.8 | 1,307.6 | 509,975.2 | 448.3 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 57.5 | 1,365.1 | 514,346.5 | 464.0 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 55.1 | 1,420.2 | 518,532.1 | 478.8 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 52.5 | 1,472.7 | 522,520.6 | 492.7 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 53.3 | 1,526.0 | 526,573.1 | 506.7 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 54.2 | 1,580.1 | 530,691.2 | 520.6 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 47.7 | 1,627.8 | 534,314.4 | 532.6 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 52.1 | 1,679.9 | 538,274.0 | 545.6 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 45.3 | 1,725.2 | 541,716.5 | 556.8 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 45.9 | 1,771.1 | 545,204.8 | 567.9 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 46.5 | 1,817.6 | 548,739.9 | 579.1 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 43.2 | 1,860.7 | 552,022.1 | 589.3 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 43.7 | 1,904.4 | 555,345.2 | 599.6 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 44.3 | 1,948.7 | 558,709.9 | 609.8 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 20.3 | 1,969.0 | 560,253.2 | 614.5 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,969.0 | 569,730.3 | 604.2 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 41.0 | 2,010.0 | 572,843.5 | 613.4 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 155.7 | 2,165.7 | 584,679.6 | 647.6 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 87.0 | 2,252.7 | 59[illegible],293.6 | 666.1 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 80.1 | 2,332.7 | 597,38[illegible].8 | 682.7 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 31.6 | 2,364.4 | 599,785.0 | 689.2 |

TOTAL BAMT VOLUME 3325.7 gallons

Table 2-29

ST.LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.25 wt% BORIC ACID; RWT AT 2300 ppm BORON

| AVG.STS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 898.3 | 898.3 | 485,878.6 | 323.2 |
| 510 | 501 | 2200 | 0.02032 | 0.02013 | 4,342.2 | 521.3 | 0.0 | 145.9 | 1,044.2 | 490,366.7 | 372.3 |
| 501 | 480 | 2200 | 0.02013 | 0.01970 | 10,213.7 | 0.0 | 1,224.2 | 136.1 | 1,180.3 | 500,716.5 | 412.1 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 61.9 | 1,242.3 | 505,424.3 | 429.7 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 59.8 | 1,302.0 | 509,969.6 | 446.4 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 57.5 | 1,359.5 | 514,340.9 | 462.1 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 55.1 | 1,414.6 | 518,526.5 | 477.0 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 52.5 | 1,467.1 | 522,515.0 | 490.9 |
| 430 | 420 | 2206 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 53.3 | 1,520.4 | 526,567.6 | 504.8 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 54.2 | 1,574.5 | 530,685.6 | 518.7 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 47.7 | 1,622.2 | 534,308.8 | 530.0 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 668.4 | 52.1 | 1,674.3 | 538,268.4 | 543.8 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 45.3 | 1,719.6 | 541,710.9 | 555.0 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 45.9 | 1,765.5 | 545,199.2 | 566.1 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 46.5 | 1,812.0 | 548,734.3 | 577.3 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.9 | 388.2 | 43.2 | 1,855.1 | 552,016.6 | 587.6 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 43.7 | 1,898.9 | 555,339.6 | 597.8 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 44.3 | 1,943.1 | 558,704.3 | 608.1 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 20.3 | 1,963.4 | 560,247.6 | 612.7 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,963.4 | 569,724.7 | 602.5 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 41.0 | 2,004.4 | 572,637.9 | 611.7 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 155.7 | 2,160.1 | 584,674.0 | 645.9 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 87.0 | 2,247.1 | 591,288.0 | 664.4 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 80.1 | 2,327.2 | 597,376.2 | 681.1 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 31.6 | 2,358.8 | 599,779.5 | 687.6 |

TOTAL BAMT VOLUME 3732.0 gallons

Table 2-30

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 3.00 wt% BORIC ACID; RWT AT 2300 ppm BORON

| AVG.SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 827.1 | 827.1 | 485,807.4 | 297.6 |
| 510 | 492 | 2200 | 0.02032 | 0.01994 | 8,766.7 | 1,052.5 | 0.0 | 271.1 | 1,098.2 | 494,845.2 | 388.0 |
| 492 | 480 | 2200 | 0.01994 | 0.01970 | 5,789.2 | 0.0 | 693.9 | 77.2 | 1,175.4 | 500,711.5 | 410.4 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 0.0 | 556.9 | 61.9 | 1,237.3 | 505,419.3 | 428.0 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 59.8 | 1,297.1 | 509,964.7 | 444.7 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 57.5 | 1,354.6 | 514,336.0 | 460.5 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 55.1 | 1,409.7 | 518,521.6 | 475.3 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 52.5 | 1,462.1 | 522,510.1 | 489.2 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 53.3 | 1,515.4 | 526,562.6 | 503.2 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 54.2 | 1,569.6 | 530,680.7 | 517.1 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 47.7 | 1,617.3 | 534,303.9 | 529.2 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 52.1 | 1,669.3 | 538,263.5 | 542.2 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 45.3 | 1,714.6 | 541,706.0 | 553.4 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 45.9 | 1,760.5 | 545,194.3 | 564.6 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 46.5 | 1,807.0 | 548,729.3 | 575.7 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 43.2 | 1,850.2 | 552,011.6 | 586.0 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 43.7 | 1,893.9 | 555,334.7 | 596.3 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 44.3 | 1,938.2 | 558,699.3 | 606.5 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 20.3 | 1,958.5 | 560,242.7 | 611.2 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,958.5 | 569,719.7 | 601.0 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 41.0 | 1,999.4 | 572,833.0 | 610.2 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 155.7 | 2,155.1 | 584,669.0 | 644.4 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 87.0 | 2,242.1 | 591,283.1 | 663.0 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 80.1 | 2,322.2 | 597,371.3 | 679.6 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 31.6 | 2,353.8 | 599,774.5 | 686.1 |

TOTAL BAMT VOLUME 4263.2 gallons

Table 2-31

ST LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.75 wt% BORIC ACID; RWT AT 2300 ppm BORON

| AVG.SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,258.7 | 0.0 |
| 557 | 510 | 2200 | 0.02157 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 756.2 | 756.2 | 485,736.5 | 272.2 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 276.0 | 1,032.2 | 495,773.8 | 364.0 |
| 490 | 479 | 2200 | 0.01990 | 0.01968 | 5,255.1 | 630.9 | 0.0 | 148.6 | 1,180.8 | 501,177.5 | 411.9 |
| 479 | 470 | 2200 | 0.01968 | 0.01951 | 4,185.3 | 0.0 | 501.7 | 55.8 | 1,236.6 | 505,418.6 | 427.8 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 0.0 | 537.6 | 59.8 | 1,296.4 | 509,964.0 | 444.4 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 57.5 | 1,353.9 | 514,335.3 | 460.2 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 55.1 | 1,408.9 | 518,520.8 | 475.1 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 52.5 | 1,461.4 | 522,509.4 | 489.0 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 53.3 | 1,514.7 | 526,561.9 | 502.9 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 54.2 | 1,568.9 | 530,679.9 | 516.9 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 47.7 | 1,616.5 | 534,303.2 | 529.0 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 52.1 | 1,668.6 | 538,262.7 | 542.0 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 45.3 | 1,713.9 | 541,705.3 | 553.2 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 45.9 | 1,759.8 | 545,193.6 | 564.3 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 46.5 | 1,806.3 | 548,728.6 | 575.5 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 43.2 | 1,849.5 | 552,010.9 | 585.8 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 43.7 | 1,893.2 | 555,334.0 | 596.0 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 44.3 | 1,937.5 | 558,698.6 | 606.3 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 20.3 | 1,957.8 | 560,242.0 | 611.0 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,957.8 | 569,719.0 | 600.8 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 41.0 | 1,998.7 | 572,832.2 | 610.0 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 155.7 | 2,154.4 | 584,668.3 | 644.2 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 87.0 | 2,241.4 | 591,282.4 | 662.8 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 80.1 | 2,321.5 | 597,370.6 | 679.4 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 31.6 | 2,353.1 | 599,773.8 | 685.9 |

TOTAL BAMT VOLUME 5013.6 gallons

Table 2-32

ST. LUCIE UNIT 2

PLANT COOLDOWN FROM 557 F TO 200 F; BAMT AT 2.50 wt% BORIC ACID; RWT AT 2300 ppm BORON

| AVG. SYS. TEMP. (F) Ti | Tf | PZR PRESS (psia) | SPECIFIC VOLUME (cu.ft./lbm) Vi | Vf | SHRINKAGE MASS(lbm) | BAMT VOL @ 70 F (gal) | RWT VOL @ 50 F (gal) | B/A ADDED (lbm) | TOTAL B/A (lbm) | TOTAL SYS. MASS (lbm) | FINAL CONC. (ppm boron) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 557 | 2200 | 1.00000 | 1.00000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 458,238.7 | 0.0 |
| 557 | 510 | 2200 | 0.02137 | 0.02032 | 26,741.7 | 3,210.7 | 0.0 | 685.7 | 685.7 | 485,666.0 | 246.8 |
| 510 | 490 | 2200 | 0.02032 | 0.01990 | 9,761.3 | 1,172.0 | 0.0 | 250.3 | 936.0 | 495,677.6 | 330.1 |
| 490 | 480 | 2200 | 0.01990 | 0.01970 | 4,794.5 | 575.6 | 0.0 | 122.9 | 1,058.9 | 500,595.1 | 369.8 |
| 480 | 470 | 2200 | 0.01970 | 0.01951 | 4,645.9 | 557.8 | 0.0 | 119.1 | 1,178.0 | 505,360.0 | 407.5 |
| 470 | 460 | 2200 | 0.01951 | 0.01933 | 4,485.6 | 538.5 | 0.0 | 115.0 | 1,293.0 | 509,960.6 | 443.3 |
| 460 | 450 | 2200 | 0.01933 | 0.01916 | 4,313.8 | 0.0 | 517.1 | 57.5 | 1,350.5 | 514,331.9 | 459.1 |
| 450 | 440 | 2200 | 0.01916 | 0.01900 | 4,130.5 | 0.0 | 495.1 | 55.1 | 1,405.6 | 518,517.5 | 473.9 |
| 440 | 430 | 2200 | 0.01900 | 0.01885 | 3,936.1 | 0.0 | 471.8 | 52.5 | 1,458.1 | 522,506.0 | 487.9 |
| 430 | 420 | 2200 | 0.01885 | 0.01870 | 3,999.2 | 0.0 | 479.3 | 53.3 | 1,511.4 | 526,558.5 | 501.8 |
| 420 | 410 | 2200 | 0.01870 | 0.01855 | 4,063.9 | 0.0 | 487.1 | 54.2 | 1,565.5 | 530,676.6 | 515.8 |
| 410 | 400 | 2200 | 0.01855 | 0.01842 | 3,575.6 | 0.0 | 428.6 | 47.7 | 1,613.2 | 534,299.8 | 527.9 |
| 400 | 390 | 2200 | 0.01842 | 0.01828 | 3,907.5 | 0.0 | 468.4 | 52.1 | 1,665.3 | 538,259.4 | 540.9 |
| 390 | 380 | 2200 | 0.01828 | 0.01816 | 3,397.2 | 0.0 | 407.2 | 45.3 | 1,710.6 | 541,701.9 | 552.1 |
| 380 | 370 | 2200 | 0.01816 | 0.01804 | 3,442.4 | 0.0 | 412.6 | 45.9 | 1,756.4 | 545,190.2 | 563.3 |
| 370 | 360 | 2200 | 0.01804 | 0.01792 | 3,488.5 | 0.0 | 418.1 | 46.5 | 1,802.9 | 548,725.2 | 574.5 |
| 360 | 350 | 2200 | 0.01792 | 0.01781 | 3,239.1 | 0.0 | 388.2 | 43.2 | 1,846.1 | 552,007.5 | 584.7 |
| 350 | 340 | 2200 | 0.01781 | 0.01770 | 3,279.4 | 0.0 | 393.1 | 43.7 | 1,889.8 | 555,330.6 | 595.0 |
| 340 | 330 | 2200 | 0.01770 | 0.01759 | 3,320.4 | 0.0 | 398.0 | 44.3 | 1,934.1 | 558,695.3 | 605.2 |
| 330 | 325 | 2200 | 0.01759 | 0.01754 | 1,523.0 | 0.0 | 182.6 | 20.3 | 1,954.4 | 560,238.6 | 609.9 |
| 325 | 310 | 275 | 0.01754 | 0.01754 | 0.0 | 0.0 | 0.0 | 0.0 | 1,954.4 | 569,715.7 | 599.8 |
| 310 | 300 | 275 | 0.01754 | 0.01744 | 3,072.3 | 0.0 | 368.2 | 41.0 | 1,995.4 | 572,828.9 | 609.0 |
| 300 | 260 | 275 | 0.01744 | 0.01707 | 11,680.4 | 0.0 | 1,400.0 | 155.7 | 2,151.1 | 584,665.0 | 643.2 |
| 260 | 235 | 275 | 0.01707 | 0.01687 | 6,527.0 | 0.0 | 782.3 | 87.6 | 2,238.1 | 591,279.0 | 661.8 |
| 235 | 210 | 275 | 0.01687 | 0.01669 | 6,008.1 | 0.0 | 720.1 | 80.1 | 2,318.1 | 597,367.2 | 678.5 |
| 210 | 200 | 275 | 0.01669 | 0.01662 | 2,371.6 | 0.0 | 284.3 | 31.6 | 2,349.8 | 599,770.4 | 655.0 |

TOTAL BAMT VOLUME 6354.6 gallons

Table 2-33
Required Boron Concentration for a Cooldown from 557 Degrees to 200 Degrees

| Temperature (Degrees F) | Concentration (ppm boron) |
|---|---|
| 557 | -71.2 |
| 510 | 133.0 |
| 490 | 203.0 |
| 480 | 235.5 |
| 470 | 262.3 |
| 460 | 289.8 |
| 450 | 314.1 |
| 440 | 338.0 |
| 430 | 360.6 |
| 420 | 382.0 |
| 410 | 403.4 |
| 400 | 423.9 |
| 390 | 443.0 |
| 380 | 461.2 |
| 370 | 474.5 |
| 360 | 488.7 |
| 350 | 500.9 |
| 340 | 512.6 |
| 330 | 523.5 |
| 325 | 528.7 |
| 310 | 543.6 |
| 300 | 568.8 |
| 260 | 589.9 |
| 235 | 608.7 |
| 210 | 627.6 |
| 200 | 634.9 |
| 199.9* | 539.9 |
| 199.9** | 570.3 |

*Note: After Shutdown margin change from 5.0% delta k/k to 3.5% delta k/k.

**Note: The boracion requirement for a 3.5% shutdown margin and core is xenon free.

Table 2-34

Minimum Boric Acid Makeup Tank Boration Volume vs.
Stored Boric Acid Concentration for
Modes 1, 2, 3, and 4

Minimum Volume (gallons)

| BAMT Conc | RWT at 1720ppm | RWT at 1850 ppm | RWT at 2000 ppm | RWT at 2150 ppm | RWT at 2300 ppm |
|---|---|---|---|---|---|
| 3.5 | 4,842.2 | 4,554.1 | 4,144.3 | 3,732.0 | 3,325.7 |
| 3.25 | 5,403.6 | 5,069.0 | 4,669.0 | 4,203.7 | 3,732.0 |
| 3.0 | 6,106.0 | 5,730.3 | 5,347.6 | 4,784.4 | 4,263.2 |
| 2.75 | 6,968.6 | 6,572.5 | 6,106.0 | 5,569.5 | 5,013.6 |
| 2.5 | 8,118.1 | 7,732.2 | 7,256.6 | 6,720.4 | 6054.6 |

Table 2-35

Minimum Stored Boric Acid Makeup Tank Volume vs. Stored Boric Acid Concentration for Modes 1, 2, 3, and 4

| | Minimum Volume (gallons) | | | | |
|---|---|---|---|---|---|
| BAMT Conc | RWT at 1720 ppm | RWT at 1850 ppm | RWT at 2000 ppm | RWT at 2150 ppm | RWT at 2300 ppm |
| 3.5 | 5,350 | 5,100 | 4,650 | 4,250 | 3,850 |
| 3.25 | 5,950 | 5,600 | 5,200 | 4,750 | 4,250 |
| 3.0 | 6,650 | 6,250 | 5,850 | 5,300 | 4,800 |
| 2.75 | 7,500 | 7,100 | 6,650 | 6,100 | 5,550 |
| 2.50 | 8,650 | 8,250 | 7,800 | 7,250 | 6,600 |

Table 2-36

Calculation of the 16,000 Gallon Volume
In Specification 3/4.1.2

| | |
|---|---|
| 12,281.0 gallons | Cooldown to 325 degrees and 275 psia (Part A) |
| +8,235.1 | Cooldown to 200 degrees on shutdown cooling (Parts B & C) |
| -5,350.0 | Smallest BAMT inventory value for 1720 ppm Boron in the RWT from Table 2-35 |
| 15,166.1 gallons | Total |
| 16,000.0 gallons | Total rounded up to the nearest 1000 gallons |

Table 2-37

Calculation of the 12,000 Gallon Volume
In Specification 3/4.1.2

| | |
|---|---|
| 12,281.0 gallons | Cooldown to 325 degrees and 275 psia (Part A) |
| +8235.1 | Cooldown to 200 degrees on shutdown cooling (Parts B & C) |
| -8,650 | Greatest BAMT inventory value for 1720 ppm Boron in the RWT from Table 2-35 |
| 11,866.1 gallons | Total |
| 12,000 gallons | Total rounded up to the nearest 1000 gallons |

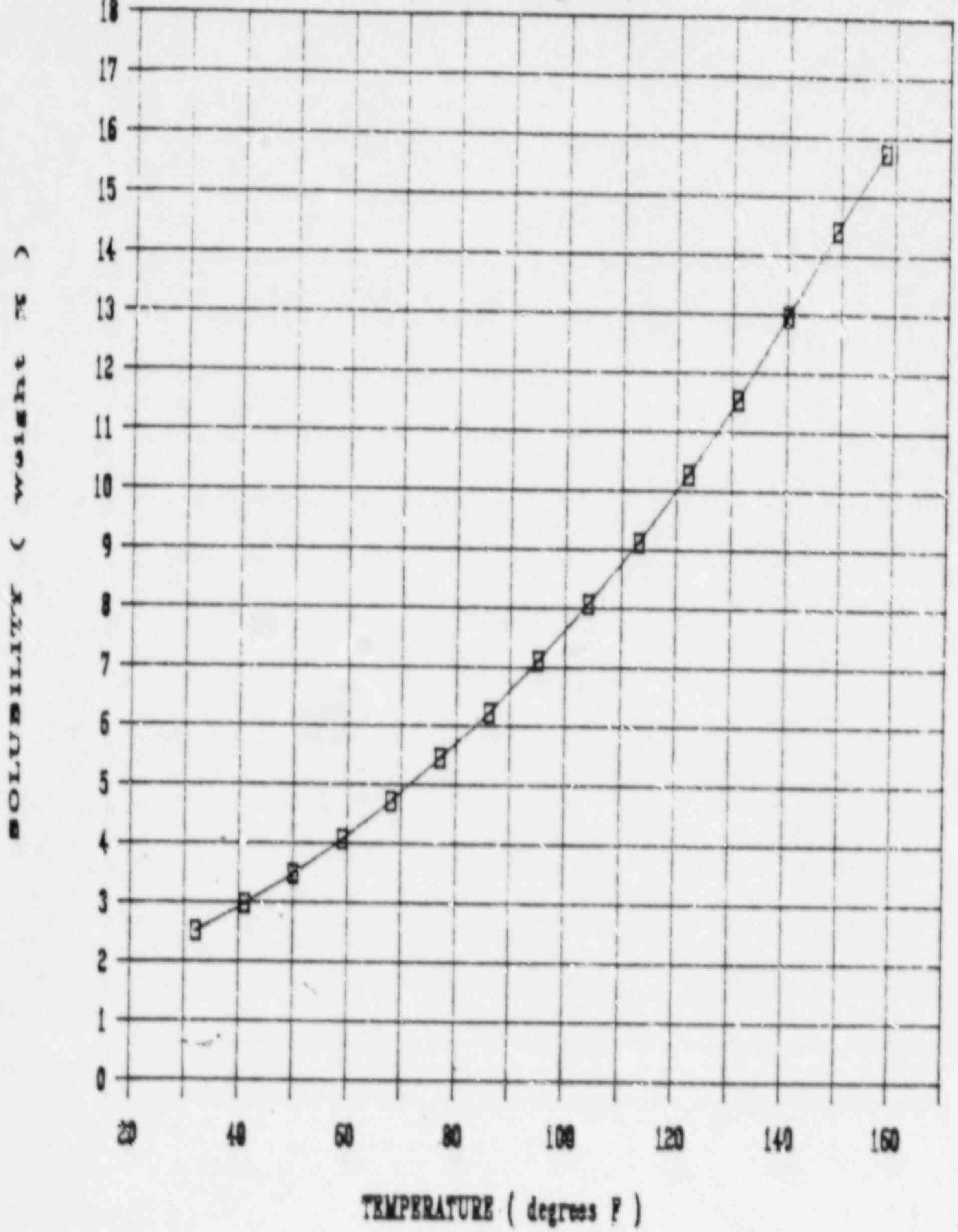
Table 2-38

Calculation of the 35,000 Gallon Volume
In Specification 3/4.1.2
for St. Lucie 1

| | |
|---|---|
| 14,080 gallons | System feed-and-bleed prior to cooldown |
| +12,281.0 | Cooldown to 325 degrees and 275 psia (Part A) |
| + 8,235.1 | Cooldown to 200 degrees on shutdown cooling (Parts B & C) |
| 34,615.1 gallons | Total |
| 35,000 gallons | Final volume rounded up to the nearest 1000 gallons. |

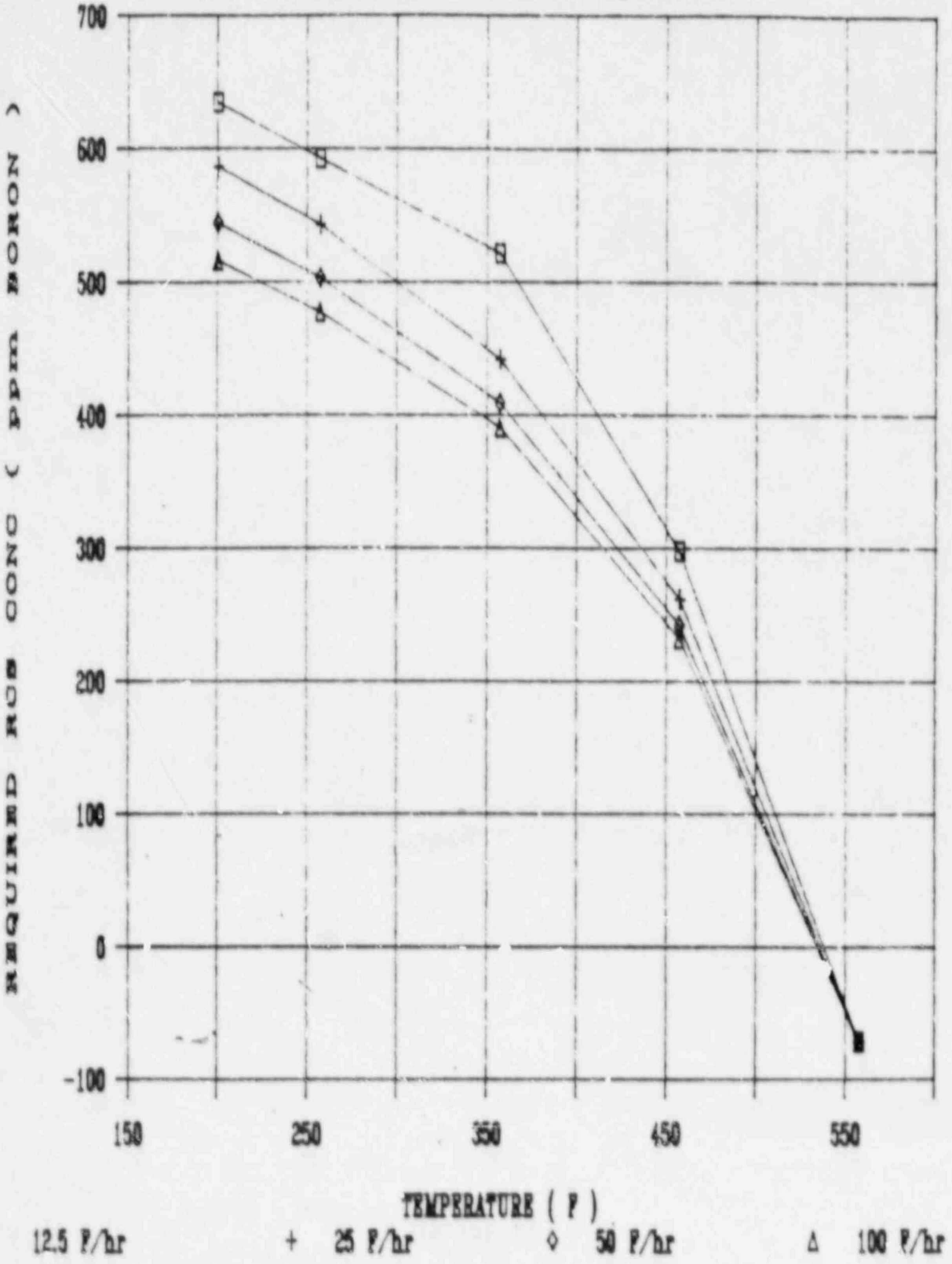
# FIGURE 2-1 BORIC ACID SOLUBILITY

IN WATER ( weight % )



# FIGURE 2-2 ST. LUCIE 2 EFFECT OF

COOLDOWN RATE ON BORATION REQUIREMENT



# FIGURE 2-3 ST.LUCIE 2 RCS BORON CONC

vs TEMPERATURE FOR MAKEUP FROM BAMT

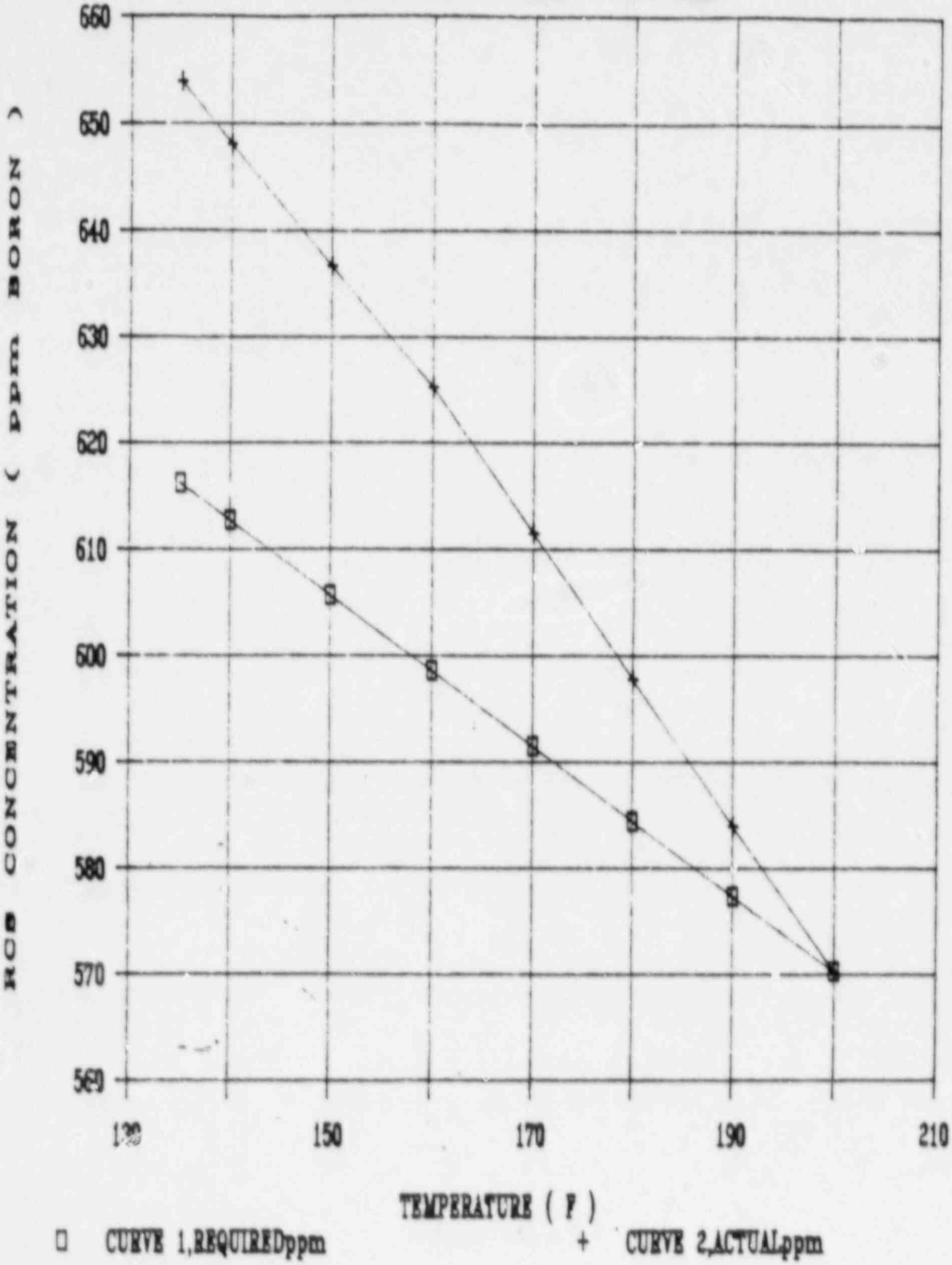
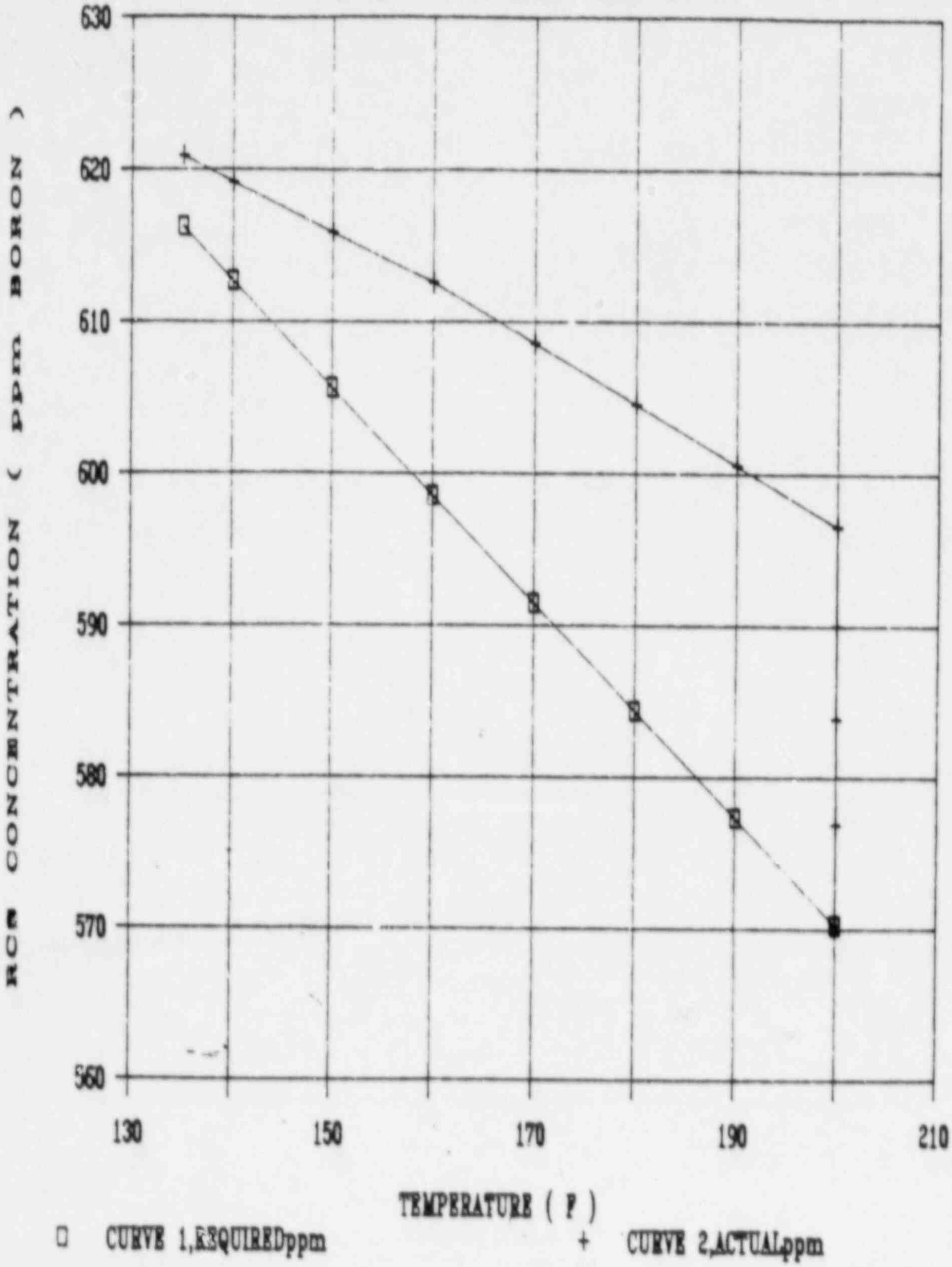


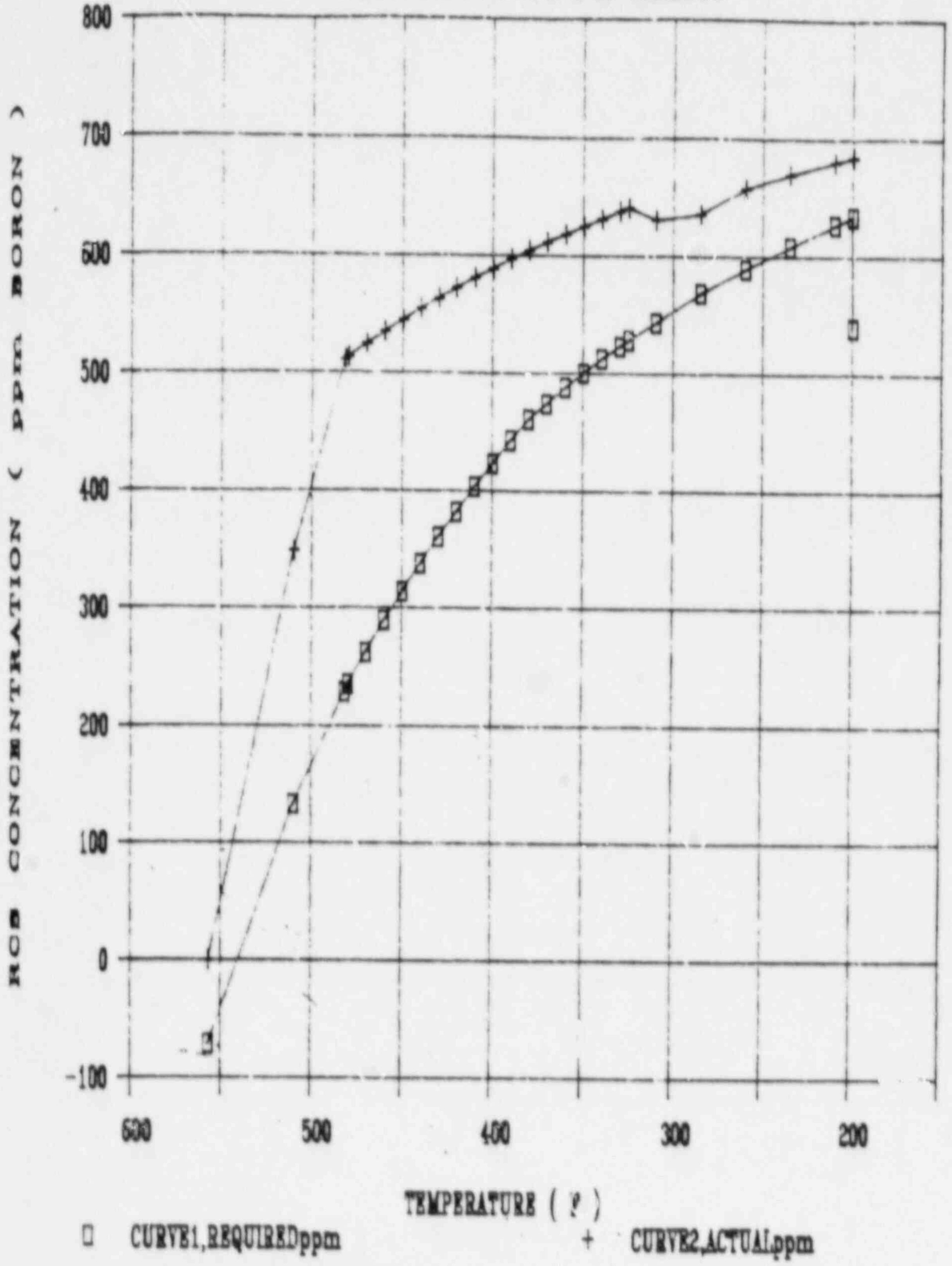
FIGURE 2-4 ST.LUCIE 2 RCS BORON CONC

vs TEMPERATURE FOR MAKEUP FROM THE RWT



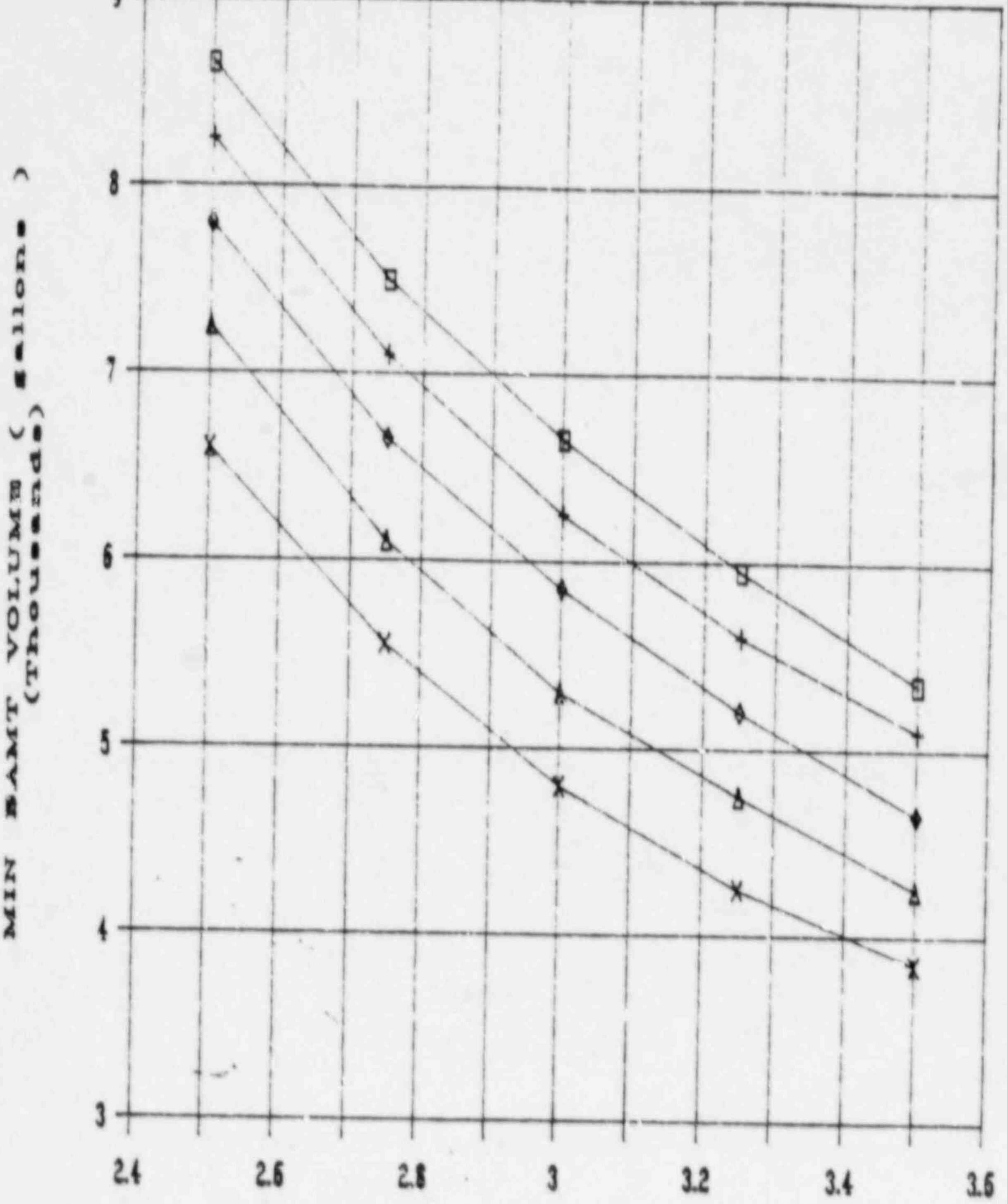
# FIGURE 2-5 ST.LUCIE 2 RCS BORON CONC

vs TEMPERATURE for 12.5 F/hr COOLDOWN



# FIGURE 2-6 ST. LUCIE 2 MIN BAMT VOLUME

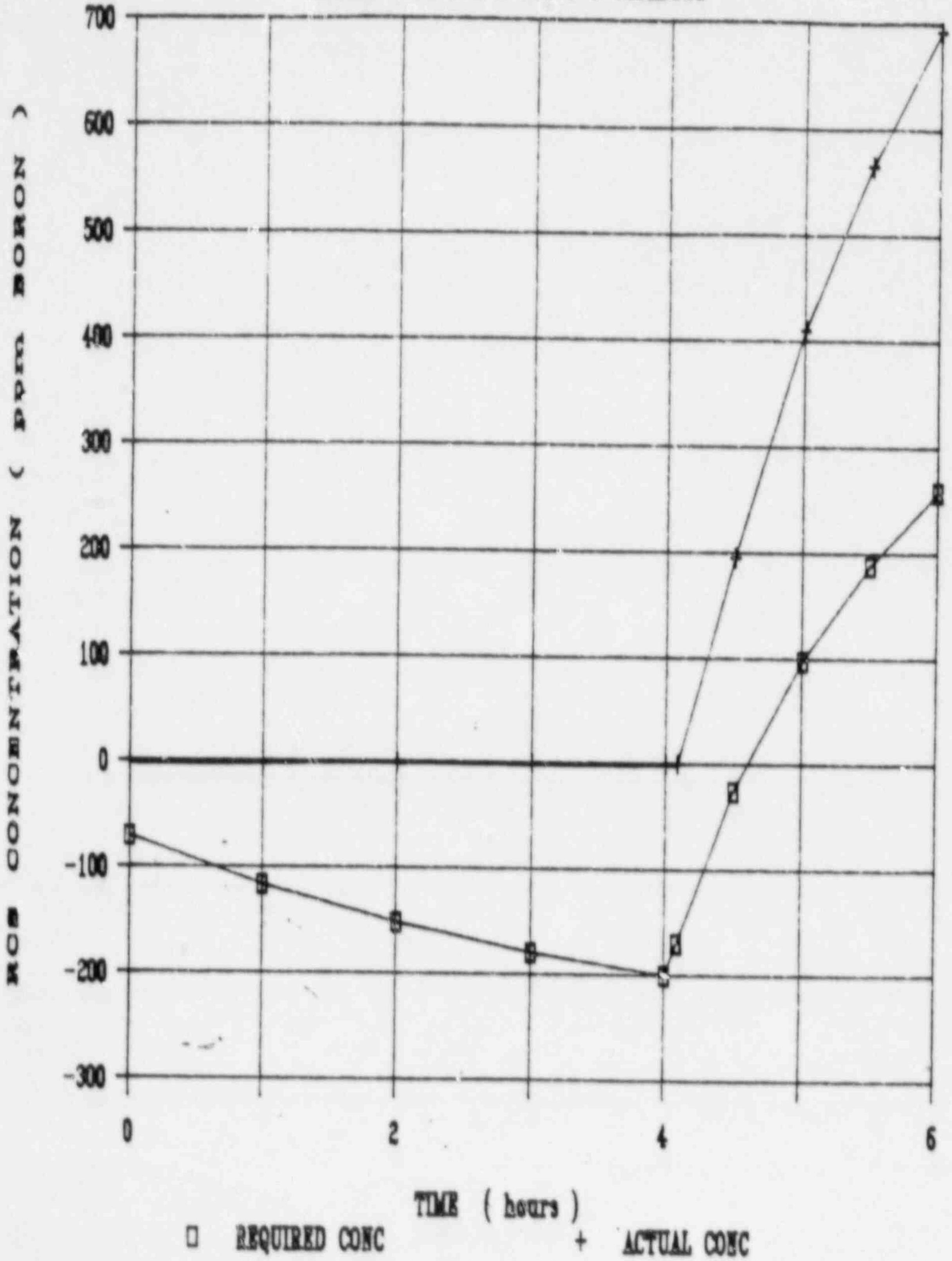
VS STORED BAMT CONCENTRATION




□ 1720 PPM IN RWT    + 1850 PPM IN RWT    ◊ 2000 PPM IN RWT    Δ 2150 PPM IN RWT    X 2300 PPM IN RWT

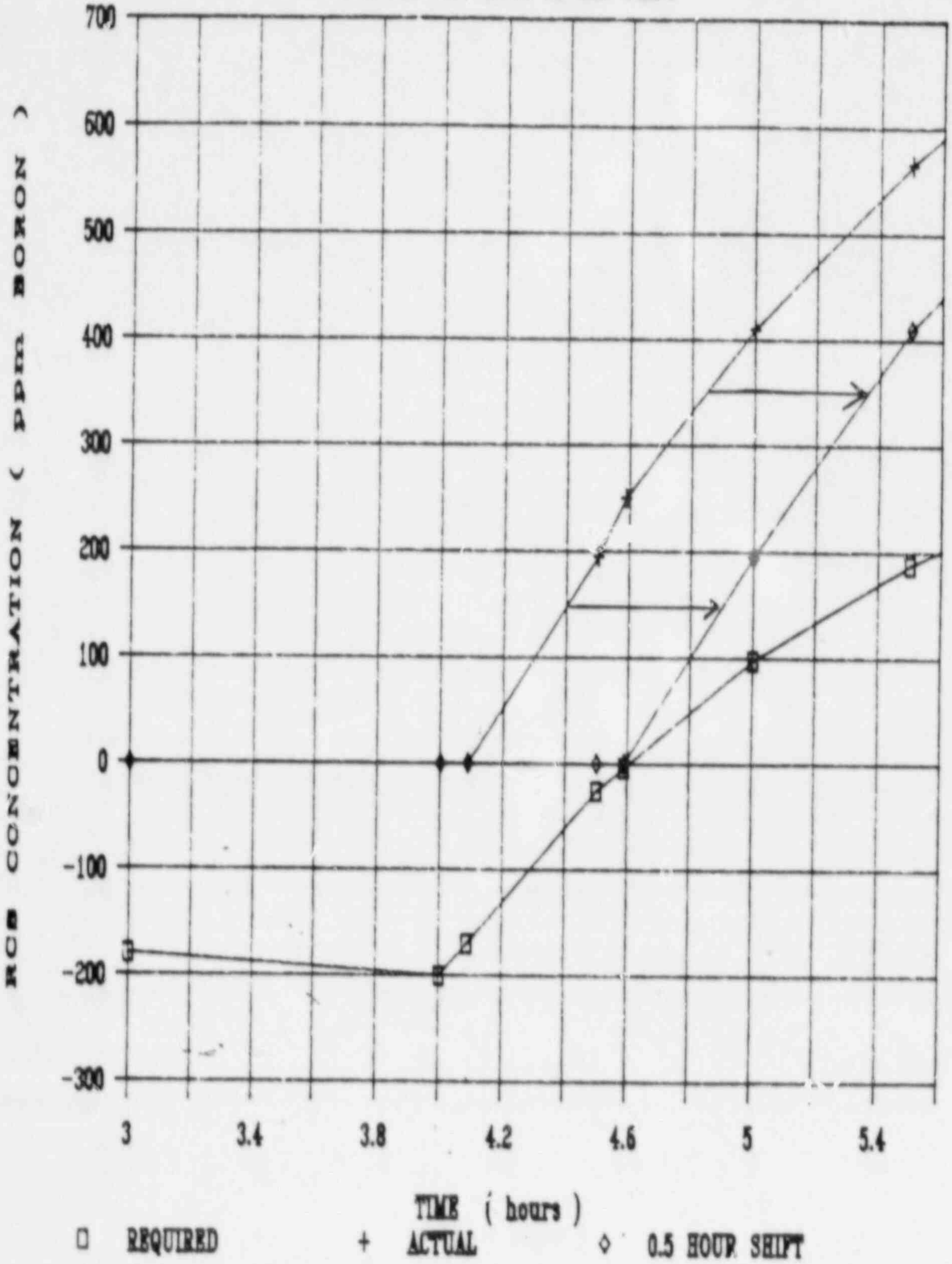
# FIGURE 2-7 ST. LUCIE 2 REQUIRED vs

ACTUAL CONC FOR A BTP 5-1 COOLDOWN



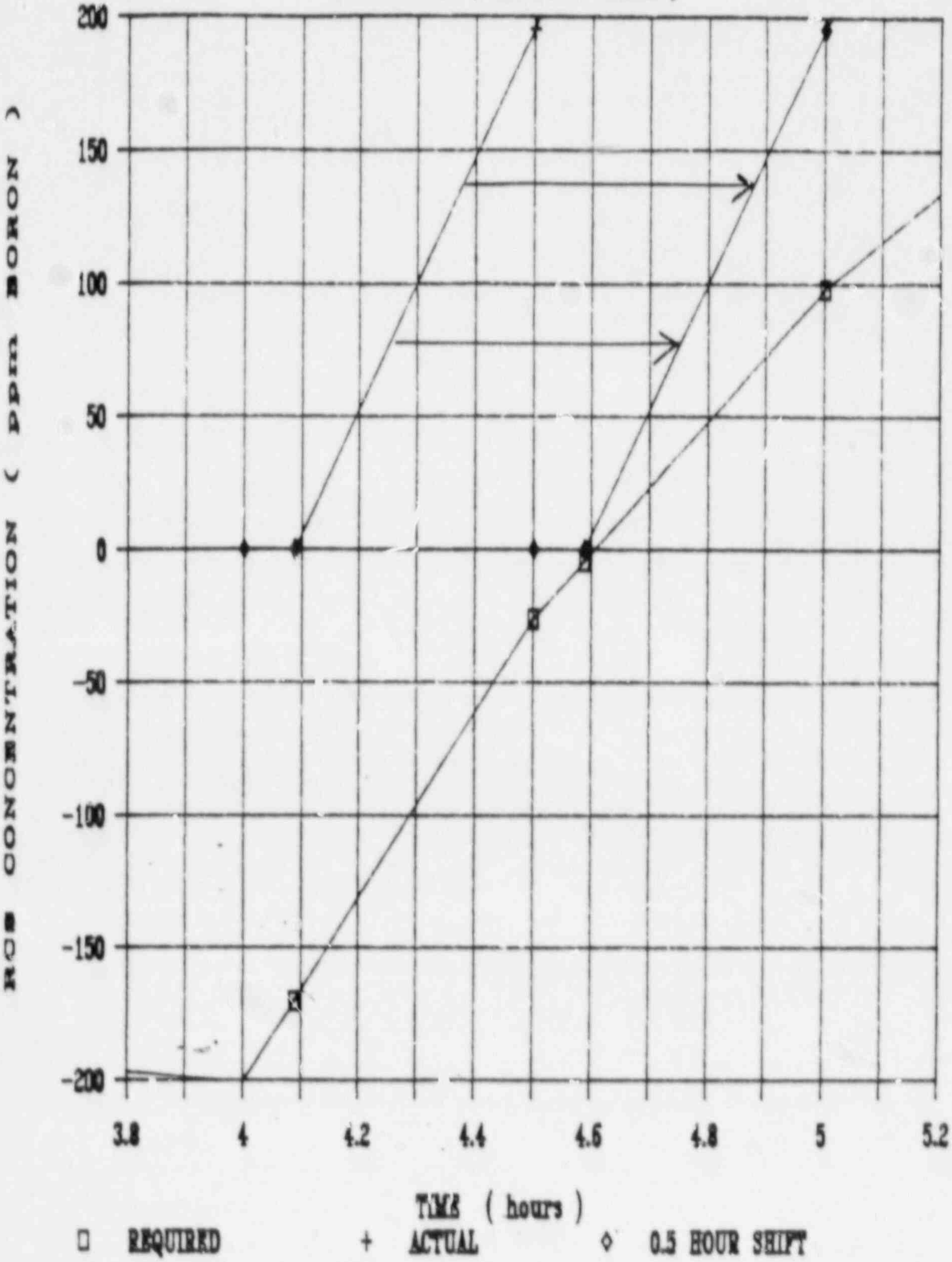
# FIGURE 2-8 ST. LUCIE 2 REQUIRED vs

ACTUAL CONC WITH 30 MIN SHIFT



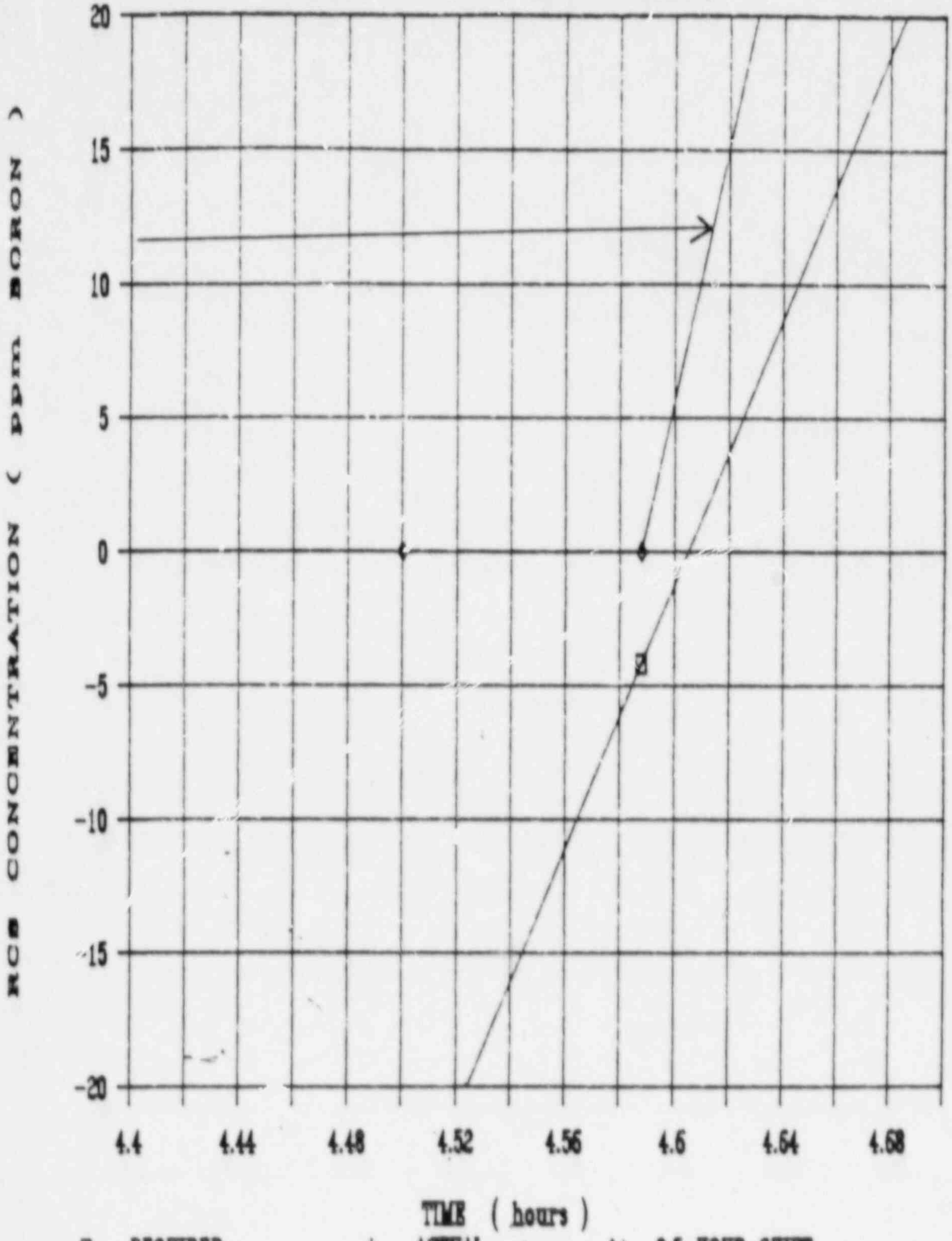
# FIGURE 2-9 ST. LUCIE 2 REQUIRED vs

ACTUAL CONC ( EXPANDED GRAPH )



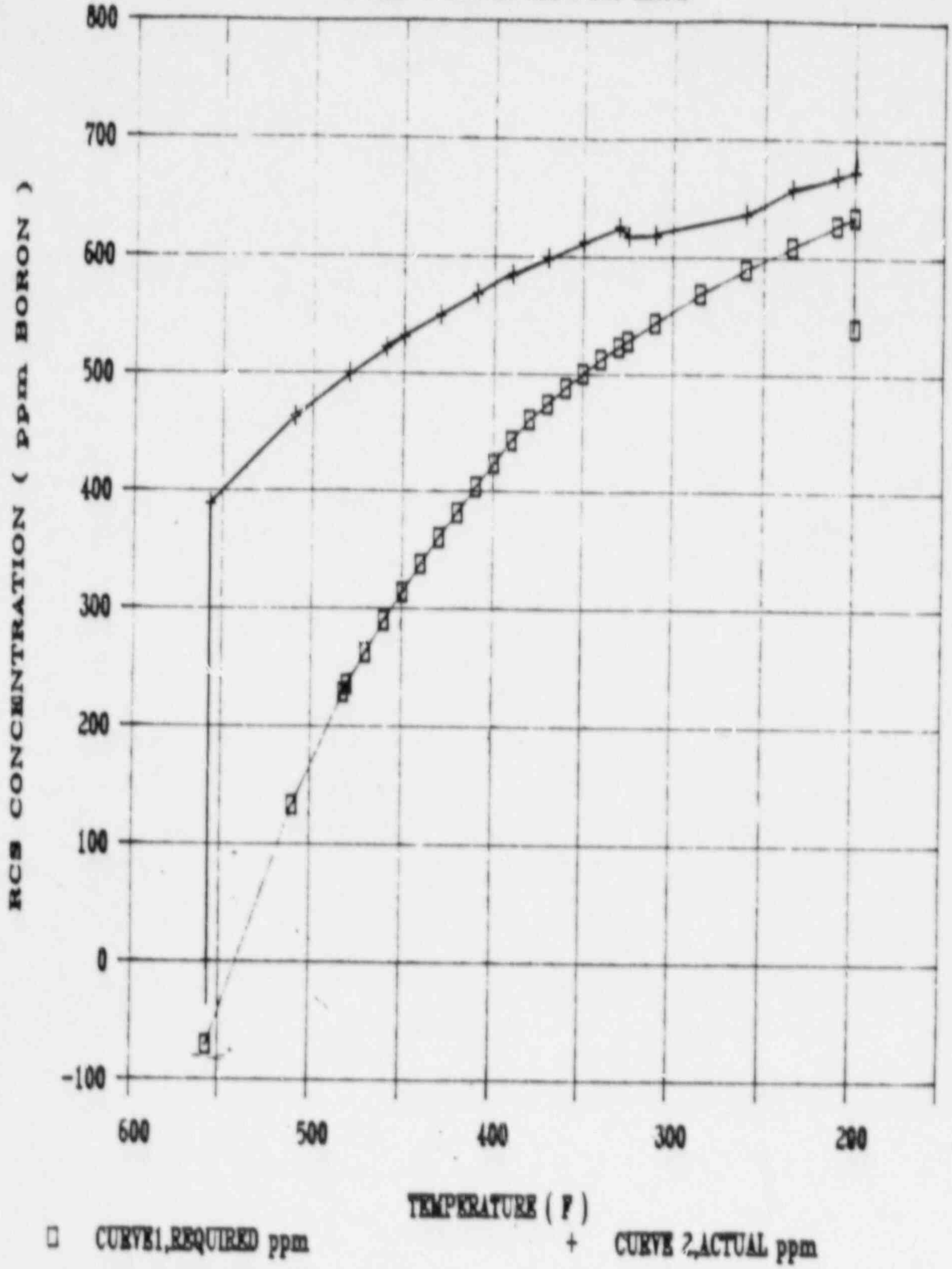
# FIGURE 2-10 ST. LUCIE 2 REQUIRED vs

ACTUAL CONC (SUPER EXPANDED GRAPH )



# FIGURE 2-11 ST.LUCIE 2 RCS BORON CONC

vs TEMP COOLDOWN USING RWT ALONE



## 3.0 OPERATIONAL ANALYSIS

### 3.1 INTRODUCTION TO THE OPERATIONAL ANALYSIS

The remaining Sections of this report present the results of an evaluation performed in order to demonstrate the general impact on plant operations of a reduction in boric acid makeup tank concentration. The specific areas that will be discussed include operator response to emergency situations, typical plant feed-and-bleed operations, typical plant blended makeup operations, plant shutdown to refueling, and plant shutdown to cold shutdown. Because it is obviously an impossible task to evaluate each of these five areas and consider all possible combinations of plant conditions, initial plant parameters and analysis assumptions that were used in the evaluation were selected, where possible, in a conservative manner in order to give worst case type answers. As a consequence, the results, i.e., the volumes and final concentrations that were obtained, should in general be bounding for any event or any set of initial plant conditions.

### 3.2 RESPONSE TO EMERGENCY SITUATIONS

In general, credit is not taken for boron addition to the reactor coolant system from the boric acid makeup tanks for the purpose of reactivity control in the accidents analyzed in Chapter 15 of the plant's Final Safety Analysis Report. The response of an operator, therefore, to such events as steam line break, overcooling, boron dilution, etc., will not be affected by a reduction in boric acid makeup tank concentration. In particular, the action statements associated with Technical Specification 3.1.1.1 and Technical Specification 3.1.1.2 require that boration be commenced at greater than 40 gallons per minute using a solution of at least 1720 ppm boron in the event that shutdown margin is lost. Such statements are conservatively based upon the refueling water tank concentration and are therefore independent of the amount of boron in the BAMTs. In addition, the acceptance criteria developed for the Reactivity Control Section of the Functional Recovery Guidelines of Reference 4.2 are based upon a boron addition rate of 40 gallons per minute and are also independent of the exact boration source concentration.

## 3.3 FEED-AND-BLEED OPERATIONS

During a feed-and-bleed operation to increase system boron content, the charging pumps are used to inject concentrated boric acid into the RCS with the excess inventory normally being diverted to the liquid waste system via letdown. The rate of increase in boron concentration is proportional to the difference between the system concentration at any given time and the concentration of the charging fluid. From this basic relationship, an equation describing feed-and-bleed can be derived. (Appendix 1 contains the derivation of the reactor coolant system feed-and-bleed equation). In general, if the concentration within the boric acid makeup tanks is reduced to the point where heat tracing is no longer required, the maximum rate of change of RCS boron concentration that an operator can expect to see during feed-and-bleed will be less than currently achievable.

The purpose of the evaluation performed in this section of the report was to show the exact feed-and-bleed rates that can be expected using boric acid makeup tanks having a reduced concentration. The analysis was done assuming hot zero power conditions with other key parameters and conditions shown in Table 3-1. Both a one charging pump and a two charging pump feed-and-bleed were evaluated from two initial system concentrations: zero ppm and 800 ppm. The results are presented in

Table 3-2 to Table 3-5. Equation 9.0 of Appendix 1 was used to generate the results in these tables. The value of the system mass used to obtain the time constant in Equation 9.0 was calculated as follows for St. Lucie 2:

$$(m_w)_{RCS} = (m_w)_{loops} + (m_w)_{PZR}$$

or

$$(m_w) = \frac{9,398 \text{ ft}^3}{0.020854 \text{ ft.}^3/\text{lbm}^{(1)}} + \frac{450 \text{ ft}^3}{0.02669 \text{ ft}^3/\text{lbm}^{(2)}}$$

From this system mass (477,626.2 lbm), the value of the feed-and-bleed time constant for one charging pump is

$$T_{40} = \frac{467,517.2 \text{ lbm}}{40 \text{ gpm} \times 8.329 \text{ lbm/gallon}^{(3)}}$$

or

$$T_{40} = 1,403.3 \text{ min.}$$

and the value of the feed-and-bleed time constant for two charging pumps is

$$T_{84} = \frac{467,517.2 \text{ lbm}}{84 \text{ gpm} \times 8.329 \text{ lbm/gallon}^{(3)}}$$

or

$$T_{84} = 668.2 \text{ min.}$$

---

(1) Specific volume of compressed water at 532 degrees and 2200 psia.

(2) Specific volume of saturated water at 2200 psia.

(3) Water density at 70 degrees.

Several of the concentration results shown in Table 3-2 through Table 3-5 are plotted in Figures 3-1 and 3-2 for comparison. Note that significant feed-and-bleed rates will be achievable following the reduction in boric acid makeup tank concentration levels.

## 3.4 BLENDED MAKEUP OPERATIONS

During typical plant blending operations, concentrated boric acid via FCV-2210Y is mixed with demineralized water via FCV-2210X at the blending tee and then added to the volume control tank. Since the ability to blend and add makeup to the reactor coolant system and to other systems is important to plant operations, three different parametric studies were performed in order to demonstrate the effect of a reduction in boric acid makeup tank concentration. The studies performed were as follows:

1. Flow through FCV-2210Y is varied between 0.5 gpm and 15.0 gpm while the flow through FCV-2210X is varied to give a total flow out of the blending tee of 44 gallons per minute.

2. Flow through FCV-2210Y is varied between 0.5 gpm and 15.0 gpm while the flow through FCV-2210X is varied to give a total flow out of the blending tee of 88 gallons per minute.

3. Flow through FCV-2210Y is varied between 0.5 gpm and 15.0 gpm while the flow through FCV-2210X is varied to give a total flow out of the blending tee of 132 gallons per minute.

In each of the three studies, the temperature of the boric acid makeup tank and the temperature of the demineralized water supply was assumed to be 70 degrees. The results are shown in Table 3-6 through Table 3-8. The final concentration out of the blending tee in each of these tables was obtained using the following equation:

$$C_{out} = \frac{(F_y \cdot C_y)}{(F_y \cdot C_y) + (F_{out} \cdot D_w)} (100)\ (1748.34).$$

In this equation, $C_{out}$ is the concentration coming out of the blending tee in ppm boron, $F_y$ is the flowrate coming out of CH-0210Y in gallons per minute, $C_y$ is the concentration of the boric acid makeup tanks in lbm per gallon, $F_{out}$ is the total flow coming out of the blending tee in gallons per minute, $D_w$ is the density of water at 70 degrees in lbm per gallon, and 1748.34 is the conversion factor between concentration expressed in terms of weight percent boric acid and concentration expressed in terms of ppm boron. (See Appendix 4 for a derivation of this conversion factor). The data contained in Tables 3-6, 3-7, and 3-8 is plotted in Figure 3-3 through Figure 3-5. Note that following the reduction in BAMT concentration, a full range of flowrates and boron concentrations are available for blended makeup operations.

## 3.5 SHUTDOWN TO REFUELING - MODES 6

The plant shutdown to the refueling is typically the most limiting evolution that an operator must perform with respect to system boration, i.e., this evolution normally requires the maximum amount of boron to be added to the reactor coolant system. A shutdown to refueling normally occurs at the end of core cycle when the critical boron concentration is low and requires an increase to the refueling boron concentration. In the most limiting case, boron concentration must be raised from zero ppm to the present refueling concentration of 1720 ppm.

This section presents the evaluation results of a plant shutdown to refueling. The evaluation was performed specifically to demonstrate the effect on makeup inventory requirements of a reduction in boric acid storage tank concentration. A list of key parameters and conditions assumed in the analysis is contained in Table 3-9. The evaluation was performed for end-of-cycle conditions in order to maximize the amount of boron that must be added to the reactor coolant system. As a result, the boron concentration within the RCS was required to be increased from zero ppm to the present refueling concentration of 1720 ppm. The shutdown for refueling was assumed to take place as follows:

1. The reactor is shutdown via rod insertion to hot zero power conditions.

2. Following shutdown, at time zero, operators commence system feed-and-bleeds for both plants using three charging pumps and the boric acid makeup tanks. (BAMT concentration is assumed to be 3.5 weight percent boric acid).

3. The feed-and-bleed is conducted for 40 minutes, after which time it is secured.

4. A plant cooldown and depressurization is commenced from an average coolant temperature and system pressure of 532 degrees and 2250 psia to an average coolant temperature and system pressure of 325 degrees and 275 psia. An overall cooldown rate of approximately 100 degrees per hour is assumed. Makeup inventory is supplied from the boric acid makeup tanks.

5. The shutdown cooling system is placed in operation at 325 degrees and 275 psia. (Prior to initiation, the concentration within the SDCS is assumed to be equal to the concentration in the reactor coolant system).

6. The plant cooldowns are continued following shutdown cooling initiation from 325 degrees to 135 degrees at 275 psia. A rate of 100 degrees per hour is assumed over the whole temperature range.

Evaluation results showing the system concentrations as a function of time and total boric acid makeup tank inventory requirements are contained in Table 3-10. Loop average temperature and system boron concentration data from this table is plotted in Figure 3-6. Concentrations during the initial feed-and-bleed operation was calculated using the methodology discussed in Section 3.3 above. Concentrations during the subsequent plant cooldown were calculated in the same manner as the concentrations for the plant cooldowns in Section 2.4. Note that the boron content of the RCS was raised from zero ppm at the start of the evaluation to greater than 1720 ppm by the time the plants had been cooled and depressurized to 135 degrees and 275 psia. A total volume of 23,085.0 gallons of a 3.5 weight percent boric acid solution was required. Of this volume, 5120 gallons were used during the initial forty minute plant feed-and-bleed operation, and 17,965.0 gallons were charged into the system to compensate for shrinkage during the cooldown process.

As can be seen from the results in Table 3-10, the volume of a 3.5 weight percent boric acid solution that is required in order to perform the shutdown to refueling is approximately 2.3 times the capacity of one boric acid makeup tank. Note that this result is conservative or bounding, and therefore, represents the maximum volume that would be required to be available assuming a refueling concentration of 1720 ppm boron and a boric acid makeup tank concentration of 3.5 weight percent boric acid. Since there are only two boric acid makeup tanks in each plant, with the combined capacities of approximately 19,950 gallons, additional provisions or operator actions are required in order to place the plant in Mode 6. These provisions could include some combination of the following:

1. The initial plant feed-and-bleed and some portion of the plant cooldown could be performed using the refueling water tank. This would decrease the amount of inventory needed from the boric acid makeup tanks.

2. Prior to conducting the evolution, both boric acid makeup tanks are full and available for use.

3. During the initial part of the evolution, charge from one boric acid makeup tank until depleted, then transfer to the second BAMT. Concurrent with continued cooldown, replenish inventory in the first tank.

These provisions, or operator actions, would need to be considered only once during core cycle, just prior to conducting a shutdown for refueling. Note that they are relatively simple actions that should be well within the current plant operating procedures. In addition, they can be planned for in advance so as to have no impact on maintenance activities or the plant refueling schedule.

## 3.6 SHUTDOWN TO COLD SHUTDOWN - MODE 5

As discussed in the previous Section, the shutdown to refueling is the most limiting evolution that an operator must perform with respect to system boration. This evolution is normally performed once during a fuel cycle just prior to refueling. Situations (such as unscheduled plant maintenance, etc.) can occur during a fuel cycle, however, and require that an operator perform a plant shutdown to cold shutdown conditions. Although not limiting with respect to boration requirements, it is important for an operator to be able to perform such a shutdown quickly and efficiently.

This section presents the evaluation results of a plant shutdown to cold shutdown. The analysis was performed specifically to demonstrate the effect on makeup inventory requirements of a reduction in boric acid storage tank concentration. A list of key parameters and conditions assumed in the analysis is contained in Table 3-11. In addition to the parameters in Table 3-11, the evaluation was performed for end-of-cycle conditions assuming a cold shutdown concentration of 800 ppm boron. As a result, boron concentration had to be increased from zero ppm to 800 ppm boron. The operator scenario employed in the shutdown to cold shutdown is as follows:

1. The reactor is shutdown to hot zero power conditions via rod insertion.

2. A plant cooldown and depressurization is immediately commenced from an average coolant temperature and system pressure of 532 degrees and 2200 psia to an average coolant temperature and system pressure of 325 degrees and 275 psia. An overall cooldown rate of approximately 100 degrees per hour is assumed. Makeup inventory is supplied from the boric acid makeup tanks.

3. The shutdown cooling system is placed in operation at 325 degrees and 275 psia.

4. The plant cooldown is continued following shutdown cooling initiation from 325 degrees to 135 degrees at 275 psia. Makeup inventory is supplied from the boric acid makeup tanks.

Evaluation results showing the system concentrations as a function of time and total boric acid makeup tank inventory requirements are contained in Table 3-12 and Table 3-13. Note that two cases were analyzed for comparison. In Case I the concentration within the shutdown cooling system was assumed to be equal to the concentration of the reactor coolant system at the time of shutdown cooling initiation. In Case II the concentration within the shutdown cooling system was assumed to be equal to the concentration of the refueling water tank at the time of shutdown cooling initiation. System boron concentration data from these two tables are plotted in Figure 3-7 and Figure 3-8. Concentrations during the plant cooldown were calculated using the methodology discussed in Section 2.4. During those portions of the plant cooldown in which blended makeup was used, data was calculated using the methodology contained in Section 3.4.

A total volume of 10,243.7 gallons of a 3.5 weight percent boric acid solution were required in order to perform the shutdown to cold shutdown for the case in which the concentration of the fluid within the shutdown cooling system was assumed to be equal to that of the reactor coolant system at the time of shutdown cooling initiation. In the case where the concentration within the shutdown cooling system was assumed to equal that of the refueling water tank at the time of shutdown cooling initiation, a total volume of 7248.1 gallons was required. Note that approximately 2995.6 gallons less of the boric acid makeup tank inventories were required to be used in the Case II cooldown. Since the plant operating procedures require that the shutdown cooling system be operated via recirculation with the refueling water tank prior to initiation, the concentration within that system will normally be very near that of the RWT any time that the shutdown cooling system is placed in operation.

## 3.7 LONG TERM COOLING AND CONTAINMENT SUMP pH

The impact of the Boric Acid Reduction Effort on post LOCA long term cooling and containment sump pH control was reviewed. Each analysis is discussed qualitatively below.

Performance of the Emergency Core Cooling System (ECCS) during extended periods of time following a loss-of-coolant accident (LOCA) was analyzed in Section 6.3.3.4 of the St. Lucie 2 FSAR. Long term residual heat removal is accomplished by continuous boil-off of fluid in the reactor vessel. As borated water is delivered to the core region via safety injection and virtually pure water escapes is steam, high levels of boric acid may accumulate in the reactor vessel. As an input to this analysis, boric acid makeup tank (BAMT) boron concentration was assumed to be 12 weight percent. This calculation conservatively bounds the maximum boric acid makeup tank boron concentration of 3.5 weight %.

A detailed calculation will be performed by Florida Power and Light Company to determine the effects of boric acid concentration reduction on the post LOCA sump $P^H$ and containment spray $P^H$. This evaluation will be conducted to determine if the hydrazine addition rate or total quantity injected by the containment spray system needs to be changed to maintain the sump and containment spray within the $P^H$ ranges specified in the St. Lucie Unit 2 FSAR. Two boundary cases are provided for this review and are listed below:

| | |
|---|---|
| Minimum BAMT Boric Acid contribution | 4,850 gallons of 3.5 weight % boric acid solution |
| Maximum BAMT Boric Acid contribution | 19,950 gallons of 2.5 weight % boric acid solution |

Table 3-1

Key Plant Parameters and Conditions Assumed in Generating the Feed-and-Bleed Curves

a. Reactor coolant system volume = 9,398 $ft^3$.

b. Reactor coolant system pressure = 2200 psia.

c. Reactor coolant system average temperature = 532 degrees.

d. Pressurizer volume = 450 $ft^3$.

e. Pressurizer is saturated.

f. Zero reactor coolant system Technical Specification leakage.

g. Boric acid makeup tank temperature = 70 degrees.

h. Complete and instantaneous mixing between the pressurizer and the reactor coolant system.

i. Constant pressurizer level maintained during the feed-and-bleed process.

j. Letdown flowrate from one charging pump = 40 gpm.

k. Letdown flowrate from two charging pumps = 84 gpm.

Table 3-2

Feed-and-Bleed Using One Charging Pump from an
Initial RCS Concentration of 0 ppm Boron
St. Lucie #2

RCS Boron Concentration (ppm boron)

| Time (min) | BAMT at 0.98 wt % | BAMT at 2.50 wt % | BAMT at 2.75 wt % | BAMT at 3.00 wt % | BAMT at 3.25 wt % | BAMT at 3.50 wt % |
|---|---|---|---|---|---|---|
| 10 | 12.2 | 31.0 | 34.1 | 37.2 | 40.3 | 43.4 |
| 20 | 24.3 | 61.9 | 68.0 | 74.2 | 80.4 | 86.6 |
| 30 | 36.4 | 92.5 | 101.7 | 110.9 | 120.2 | 129.4 |
| 40 | 48.3 | 122.8 | 135.1 | 147.4 | 159.7 | 172.0 |
| 50 | 60.2 | 153.0 | 168.3 | 183.6 | 198.9 | 214.2 |
| 60 | 72.0 | 182.9 | 201.2 | 219.5 | 237.8 | 256.1 |
| 70 | 83.7 | 212.7 | 234.0 | 255.2 | 276.5 | 297.7 |
| 80 | 95.3 | 242.2 | 266.4 | 290.6 | 314.9 | 339.1 |
| 90 | 106.8 | 271.5 | 298.7 | 325.8 | 353.0 | 380.1 |
| 100 | 118.3 | 300.6 | 330.7 | 360.9 | 390.8 | 420.9 |
| 110 | 129.7 | 329.5 | 362.5 | 395.4 | 428.4 | 461.3 |
| 120 | 141.0 | 358.2 | 394.1 | 429.9 | 465.7 | 501.5 |

Table 3-3

Feed-and-Bleed Using Two Charging Pumps from an
Initial RCS Concentration of 0 ppm Boron
St. Lucie #2

RCS Boron Concentration (ppm boron)

| Time (min) | BAMT at 0.98 wt % | BAMT at 2.50 wt % | BAMT at 2.75 wt % | BAMT at 3.00 wt % | BAMT at 3.25 wt % | BAMT at 3.50 wt % |
|---|---|---|---|---|---|---|
| 10 | 25.5 | 64.9 | 71.4 | 77.9 | 84.4 | 90.9 |
| 20 | 50.7 | 128.9 | 141.8 | 154.7 | 167.5 | 180.4 |
| 30 | 75.5 | 191.9 | 211.1 | 230.3 | 249.5 | 268.6 |
| 40 | 99.9 | 254.0 | 279.4 | 304.8 | 330.2 | 355.5 |
| 50 | 124.0 | 315.1 | 346.6 | 378.1 | 409.7 | 441.2 |
| 60 | 147.7 | 375.4 | 412.9 | 450.4 | 488.0 | 525.5 |
| 70 | 171.1 | 434.7 | 478.2 | 521.7 | 565.1 | 608.6 |
| 80 | 194.1 | 493.2 | 542.5 | 591.8 | 641.1 | 690.4 |
| 90 | 216.7 | 550.8 | 605.9 | 660.9 | 716.0 | 771.1 |
| 100 | 239.1 | 607.6 | 668.3 | 729.0 | 789.8 | 850.5 |
| 110 | 261.1 | 663.5 | 729.8 | 796.1 | 862.4 | 928.8 |
| 120 | 282.7 | 718.5 | 790.4 | 862.2 | 934.0 | 1005.9 |

Table 3-4

Feed-and-Bleed Using One Charging Pumps from an
Initial RCS Concentration of 800 ppm Boron
St. Lucie #2

RCS Boron Concentration (ppm boron)

| Time (min) | BAMT at 0.98 wt % | BAMT at 2.50 wt % | BAMT at 2.75 wt % | BAMT at 3.00 wt % | BAMT at 3.25 wt % | BAMT at 3.50 wt % |
|---|---|---|---|---|---|---|
| 10 | 806.5 | 825.3 | 828.4 | 831.5 | 834.6 | 837.7 |
| 20 | 813.0 | 850.6 | 856.7 | 862.9 | 869.1 | 875.3 |
| 30 | 819.5 | 875.6 | 884.8 | 894.0 | 903.3 | 912.5 |
| 40 | 825.8 | 900.3 | 912.6 | 924.9 | 937.2 | 949.5 |
| 50 | 832.2 | 925.0 | 940.3 | 955.6 | 970.9 | 986.2 |
| 60 | 838.5 | 949.4 | 967.7 | 986.0 | 1004.3 | 1022.6 |
| 70 | 844.8 | 973.8 | 995.1 | 1016.3 | 1037.6 | 1058.8 |
| 80 | 851.0 | 997.9 | 1022.1 | 1046.3 | 1070.6 | 1094.8 |
| 90 | 857.1 | 1021.8 | 1049.0 | 1076.1 | 1103.3 | 1130.4 |
| 100 | 863.3 | 1045.6 | 1075.7 | 1105.8 | 1135.8 | 1165.9 |
| 110 | 869.4 | 1069.3 | 1102.2 | 1135.1 | 1168.1 | 1201.0 |
| 120 | 875.4 | 1092.6 | 1128.5 | 1164.3 | 1200.1 | 1235.9 |

Table 3-5

Feed-and-Bleed Using Two Charging Pumps from an
Initial RCS Concentration of 800 ppm Boron
St. Lucie #2

RCS Boron Concentration (ppm boron)

| Time (min) | BAMT at 0.98 wt % | BAMT at 2.50 wt % | BAMT at 2.75 wt % | BAMT at 3.00 wt % | BAMT at 3.25 wt % | BAMT at 3.50 wt % |
|---|---|---|---|---|---|---|
| 10 | 813.6 | 853.0 | 859.5 | 866.0 | 872.5 | 879.0 |
| 20 | 827.1 | 905.3 | 918.2 | 931.1 | 943.9 | 956.8 |
| 30 | 840.4 | 956.9 | 976.0 | 995.2 | 1014.4 | 1033.5 |
| 40 | 853.4 | 1007.5 | 1032.9 | 1052.3 | 1083.7 | 1109.0 |
| 50 | 866.3 | 1057.4 | 1088.9 | 1120.4 | 1152.0 | 1183.5 |
| 60 | 879.0 | 1006.7 | 1144.2 | 1181.7 | 1219.3 | 1256.8 |
| 70 | 891.5 | 1155.1 | 1198.6 | 1242.1 | 1285.5 | 1329.0 |
| 80 | 903.8 | 1202.9 | 1252.2 | 1301.5 | 1350.8 | 1400.1 |
| 90 | 915.9 | 1250.0 | 1305.1 | 1360.1 | 1415.2 | 1470.3 |
| 100 | 927.9 | 1296.4 | 1357.1 | 1417.8 | 1478.6 | 1539.3 |
| 110 | 939.7 | 1342.1 | 1408.4 | 1474.7 | 1541.0 | 1607.4 |
| 120 | 951.2 | 1387.0 | 1458.9 | 1530.7 | 1602.5 | 1674.4 |

Table 3-6

Typical Blended Makeup Operations at
44 gpm out of Blending Tee

Concentration Out of Tee (ppm boron)

| Flow (gpm) | | BAMT at | BAMT at | BAMT at | BAMT at | BAMT at |
|---|---|---|---|---|---|---|
| FCV-2210Y | FCV-2210X | 2.50 wt % | 2.75 wt % | 3.00 wt % | 3.25 wt % | 3.50 wt % |
| 0.5 | 43.5 | 50.9 | 56.2 | 61.4 | 66.7 | 72.0 |
| 1.0 | 43.0 | 101.8 | 112.3 | 122.8 | 133.4 | 144.0 |
| 1.5 | 42.5 | 152.7 | 168.4 | 184.1 | 200.0 | 215.9 |
| 2.0 | 42.0 | 203.5 | 224.4 | 245.4 | 266.6 | 287.8 |
| 3.0 | 41.0 | 305.1 | 336.4 | 367.9 | 399.5 | 431.3 |
| 4.0 | 40.0 | 406.6 | 448.3 | 490.2 | 532.3 | 574.6 |
| 5.0 | 39.0 | 507.9 | 560.0 | 612.3 | 664.9 | 717.6 |
| 6.0 | 38.0 | 609.2 | 671.6 | 734.3 | 797.2 | 860.4 |
| 7.0 | 37.0 | 710.3 | 783.0 | 856.0 | 929.4 | 1003.0 |
| 8.0 | 36.0 | 811.3 | 894.3 | 977.6 | 1061.3 | 1145.4 |
| 9.0 | 35.0 | 912.2 | 1005.4 | 1099.1 | 1193.1 | 1287.5 |
| 10.0 | 34.0 | 1012.9 | 1116.4 | 1220.3 | 1324.7 | 1429.4 |
| 15.0 | 29.0 | 1515.0 | 1669.3 | 1824.2 | 1979.5 | 2135.4 |

Table 3-7

Typical Blended Makeup Operations at
88 gpm out of Blending Tee

Concentration Out of Tee (ppm boron)

| Flow (gpm) FCV-2210Y | FCV-2210X | BAMT at 2.50 wt % | BAMT at 2.75 wt % | BAMT at 3.00 wt % | BAMT at 3.25 wt % | BAMT at 3.50 wt % |
|---|---|---|---|---|---|---|
| 0.5 | 87.5 | 25.5 | 28.1 | 30.7 | 33.4 | 36.0 |
| 1.0 | 87.0 | 50.9 | 56.2 | 61.4 | 66.7 | 72.0 |
| 1.5 | 86.5 | 76.4 | 84.2 | 92.1 | 100.1 | 108.0 |
| 2.0 | 86.0 | 101.8 | 112.3 | 122.8 | 133.4 | 144.0 |
| 3.0 | 85.0 | 152.7 | 168.4 | 184.1 | 200.0 | 215.9 |
| 4.0 | 84.0 | 203.5 | 224.4 | 245.4 | 266.6 | 287.8 |
| 5.0 | 83.0 | 254.3 | 280.4 | 306.7 | 333.1 | 359.6 |
| 6.0 | 82.0 | 305.1 | 336.4 | 367.9 | 399.5 | 431.3 |
| 7.0 | 81.0 | 355.9 | 392.4 | 429.1 | 465.9 | 503.0 |
| 8.0 | 80.0 | 406.6 | 448.3 | 490.2 | 532.3 | 574.6 |
| 9.0 | 79.0 | 457.3 | 504.2 | 551.3 | 598.6 | 646.1 |
| 10.0 | 78.0 | 507.9 | 560.0 | 612.3 | 664.9 | 717.6 |
| 15.0 | 73.0 | 760.8 | 838.7 | 916.9 | 995.4 | 1074.2 |

Table 3-8

Typical Blended Makeup Operations at
132 gpm out of Blending Tee

Concentration Out of Tee (ppm boron)

| Flow (gpm) FCV-2210Y | FCV-2210X | BAMT at 2.50 wt % | BAMT at 2.75 wt % | BAMT at 3.00 wt % | BAMT at 3.25 wt % | BAMT at 3.50 wt % |
|---|---|---|---|---|---|---|
| 0.5 | 131.5 | 17.0 | 18.7 | 20.5 | 22.2 | 24.0 |
| 1.0 | 131.0 | 34.0 | 37.4 | 41.0 | 44.5 | 48.0 |
| 2.0 | 130.0 | 67.9 | 74.9 | 81.9 | 88.9 | 96.0 |
| 3.0 | 129.0 | 101.8 | 112.3 | 122.8 | 133.4 | 144.0 |
| 4.0 | 128.0 | 135.7 | 149.7 | 163.7 | 177.8 | 191.9 |
| 5.0 | 127.0 | 169.6 | 187.1 | 204.6 | 222.2 | 239.9 |
| 6.0 | 126.0 | 203.5 | 224.4 | 245.4 | 266.6 | 287.8 |
| 7.0 | 125.0 | 237.4 | 261.8 | 286.3 | 310.9 | 335.6 |
| 8.0 | 124.0 | 271.3 | 299.1 | 327.1 | 355.2 | 383.5 |
| 9.0 | 123.0 | 305.1 | 336.4 | 367.9 | 399.5 | 431.3 |
| 10.0 | 122.0 | 339.0 | 373.7 | 408.6 | 443.8 | 479.1 |
| 15.0 | 117.0 | 507.9 | 560.0 | 612.3 | 664.9 | 717.6 |

Table 3-9

Key Plant Parameters and Conditions Assumed in the Shutdown to Refueling Evaluation

a. Reactor coolant system volume = 9,398 $ft^3$.

b. Initial RCS average loop temperature = 532 degrees.

c. Pressurizer volume = 450 $ft^3$.

d. Pressurizer is saturated.

e. Zero reactor coolant system leakage.

f. Boric acid makeup tank temperature = 70 degrees.

g. Complete and instantaneous mixing between the pressurizer and the reactor coolant system.

h. Constant pressurizer level maintained during the feed-and-bleed process.

i. Initial RCS concentration = 0 ppm boron.

j. BAMT concentration = 3.50 weight percent boric acid.

k. RWT concentration = 1720 ppm boron.

l. Shutdown cooling system volume = 3000 $ft^3$.

m. Boron concentration in the shutdown cooling system is equal to the boron concentration in the RCS at the time of shutdown cooling initiation.

n. Refueling concentration, Mode 6 = 1720 ppm.

Table 3-10

Evaluation Results for Plant Shutdown to Refueling

| Temp (degrees) | Pressure (psia) | Concentration (ppm boron) | Total BAMT Volume (gal) |
|---|---|---|---|
| 532 | 2200 | 0 | 0 |
| 532 | 2200 | 138.0 | 1,280 |
| 532 | 2200 | 272.8 | 2,560 |
| 532 | 2200 | 404.6 | 3,840 |
| 532* | 2200 | 533.4 | 5,120 |
| 500 | 2200 | 734.6 | 7,149.7 |
| 450 | 2200 | 985.4 | 9,903.8 |
| 400 | 2200 | 1183.0 | 12,269.6 |
| 350 | 2200 | 1345.9 | 14,367.7 |
| 325# | 275 | 1359.1 | 15,632.8 |
| 325 | 275 | 1359.1 | 15,632.8 |
| 300 | 275 | 1427.3 | 16,862.8 |
| 250 | 275 | 1547.7 | 19,123.5 |
| 200 | 275 | 1646.7 | 21,073.9 |
| 150 | 275 | 1724.3 | 22,664.4 |
| 135 | 275 | 1744.4 | 23,085.0 |

* Initial 40 minute feed-and-bleed complete.
\# Cooldown stopped for one hour for shutdown cooling system alignment.

Table 3-11

Key Plant Parameters and Conditions Assumed in the Shutdown to Cold Shutdown Evaluation

a. Reactor coolant system volume = 9,398 $ft^3$.

b. Initial RCS average loop temperature = 532 degrees.

c. Pressurizer volume = 450 $ft^3$.

d. Pressurizer is saturated.

e. Zero reactor coolant system leakage.

f. Boric acid makeup tank temperature = 70 degrees.

g. Demineralized water supply temperature = 70 degrees.

h. Complete and instantaneous mixing between the pressurizer and the reactor coolant system.

i. Constant pressurizer level maintained during the plant cooldown.

j. Initial RCS concentration = 0 ppm boron.

k. BAMT concentration = 3.50 weight percent boric acid.

l. RWT concentration = 1720 ppm boron.

m. Shutdown cooling system volume = 3000 $ft^3$.

n. Boron concentration in the shutdown cooling system is equal to the boron concentration in the RCS at the time of shutdown cooling initiation for Case I.

o. Boron concentration in the shutdown cooling system is equal to the boron concentration in the RWT at the time of shutdown cooling initiation for Case II.

Table 3-12

Case I
Evaluation Results for Plant Shutdown to Cold Shutdown
with SDCS Concentration Equal to RCS Concentration
at the Time of Shutdown Cooling Initiation

| Temp (degrees) | Blending Ratio(*) | Pressure (psia) | Concentration (ppm boron) | Total BAMT Volume (gal) |
|---|---|---|---|---|
| 532 | -- | 2200 | 0 | 0 |
| 500 | -- | 2200 | 221.0 | 2,029.7 |
| 450 | -- | 2200 | 496.6 | 4,783.8 |
| 400 | -- | 2200 | 713.5 | 7,149.6 |
| 350 | 0.85:1 | 2200 | 799.8 | 8,446.5 |
| 325 | 1.53:1 | 275 | 800.0 | 9,299.9 |
| 325# | -- | 275 | 800.0 | 9,299.9 |
| 300 | 6.89:1 | 275 | 800.0 | 9,455.7 |
| 250 | 6.89:1 | 275 | 800.0 | 9,742.3 |
| 200 | 6.9:1 | 275 | 800.0 | 9,989.2 |
| 150 | 6.9:1 | 275 | 800.0 | 10,190.5 |
| 135 | 6.9:1 | 275 | 800.0 | 10,243.7 |

* Ratio of pure water to BAMT water at blending tee.
\# After shutdown cooling system alignment.

Table 3-13

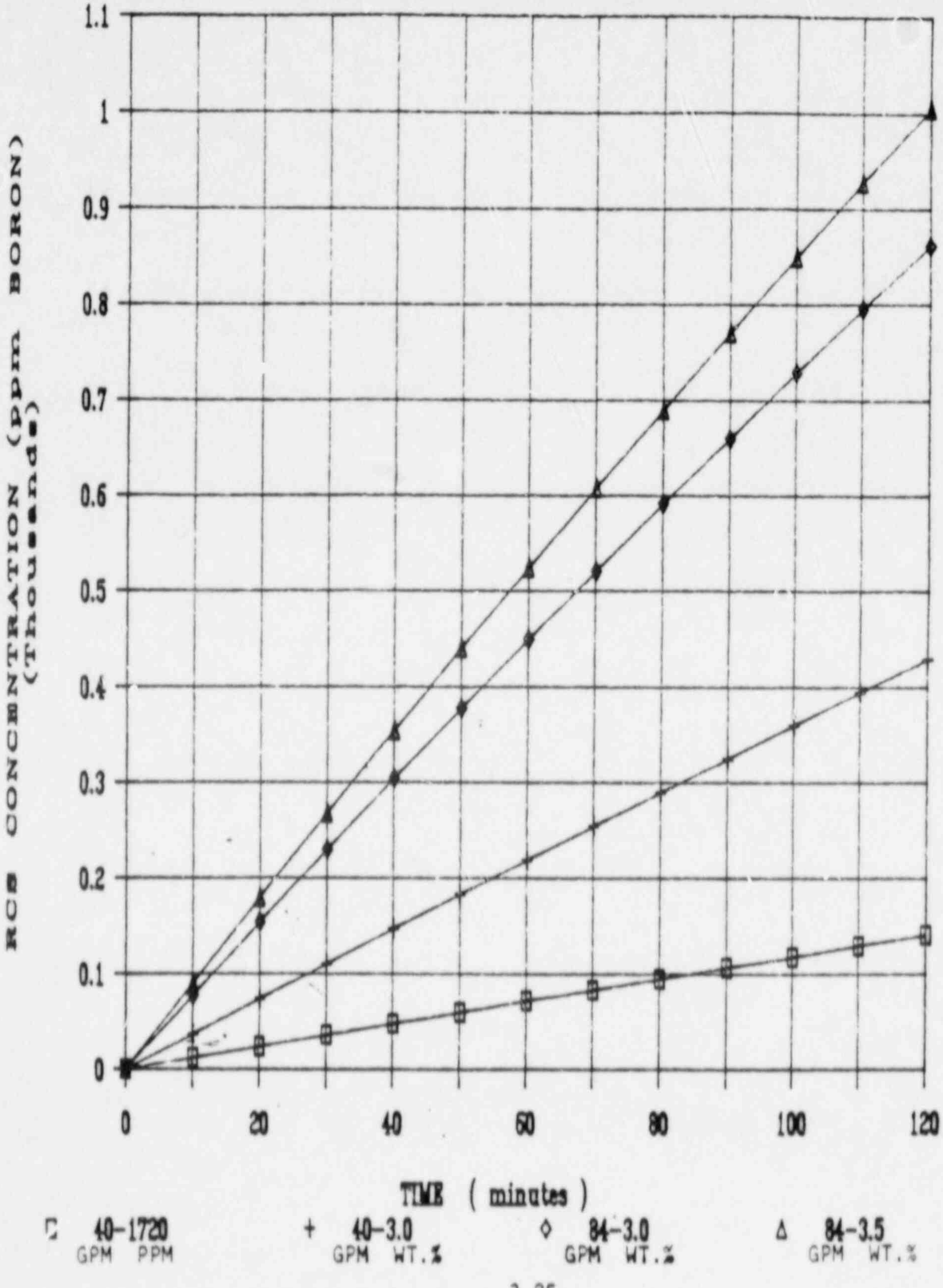
Case II
Evaluation Results for Plant Shutdown to Cold Shutdown
with SDCS Concentration Equal to RWT Concentration
at the Time of Shutdown Cooling Initiation

| Temp (degrees) | Blending Ratio(*) | Pressure (psia) | Concentration (ppm boron) | Total BAMT Volume (gal) |
|---|---|---|---|---|
| 532 | -- | 2200 | 0 | 0 |
| 500 | -- | 2200 | 221.0 | 2,029.7 |
| 450 | -- | 2200 | 496.6 | 4,783.8 |
| 400 | 5.1:1 | 2200 | 516.7 | 5,171.6 |
| 350 | 11:1 | 2200 | 517.0 | 5,346.5 |
| 325 | 2.97:1 | 275 | 517.0 | 6,303.6 |
| 325# | -- | 275 | 800.0 | 6,303.6 |
| 300 | 6.89:1 | 275 | 800.0 | 6,459.5 |
| 250 | 6.89:1 | 275 | 800.0 | 6,746.0 |
| 200 | 6.89:1 | 275 | 800.0 | 6,993.2 |
| 150 | 6.89:1 | 275 | 800.0 | 7,194.8 |
| 135 | 6.89:1 | 275 | 800.0 | 7,248.1 |

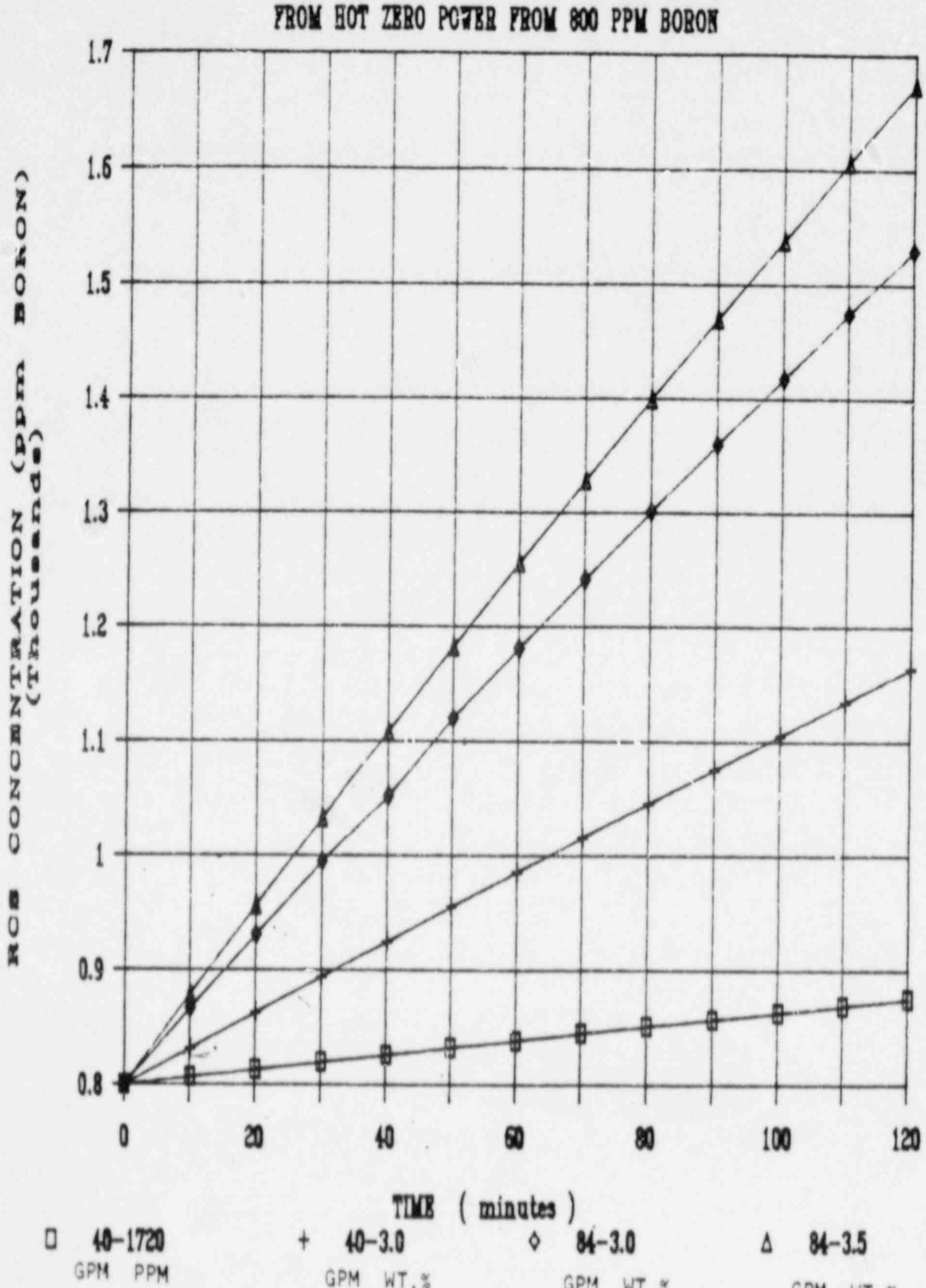
* Ratio of pure water to BAMT water at blending tee.
\# After shutdown cooling system is aligned and circulated.

# FIGURE 3-1 ST. LUCIE 2 FEED-AND-BLEED

**FROM HOT ZERO POWER FROM 0 PPM BORON**

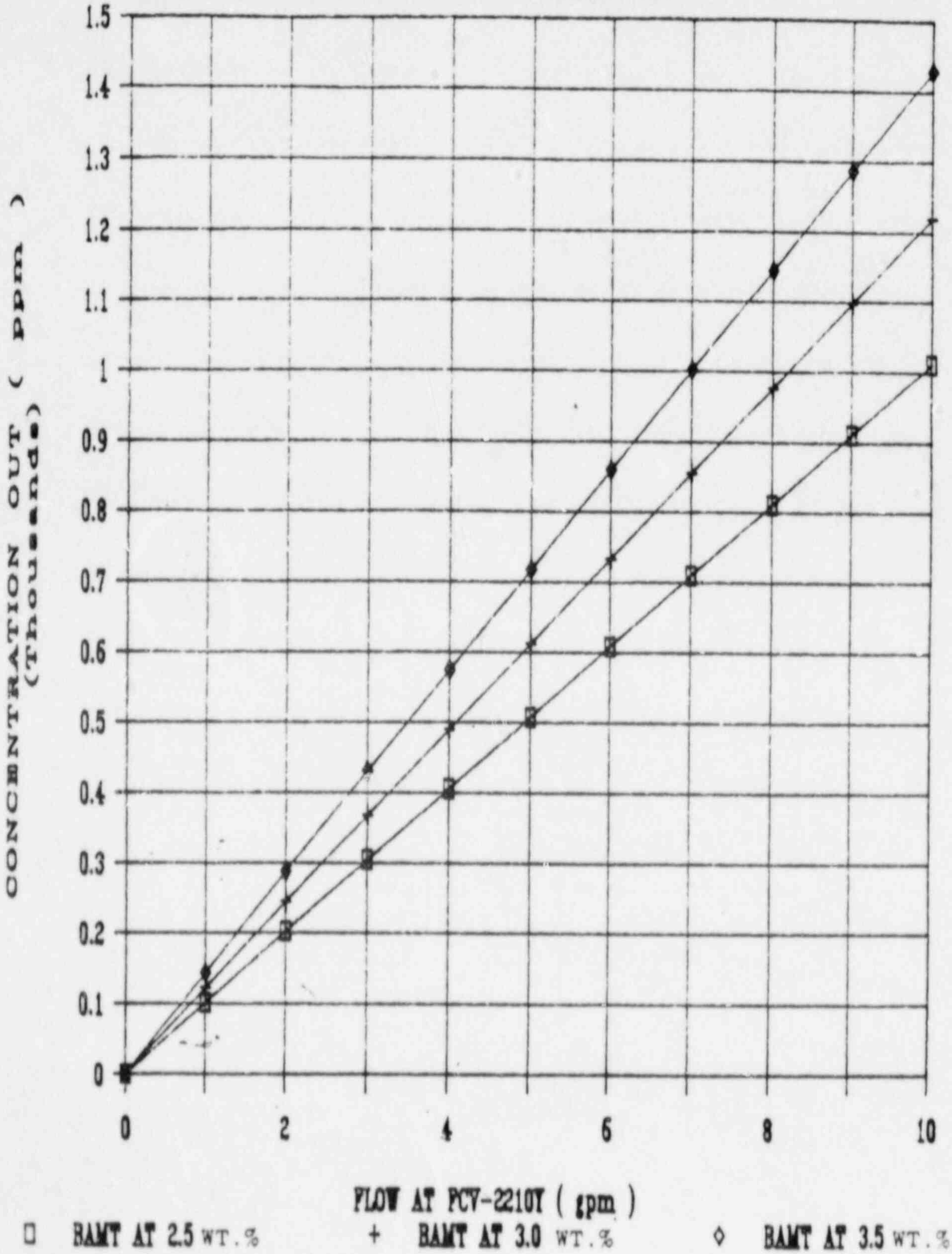


# FIGURE 3-2 ST. LUCIE 2 FEED-AND-BLEED



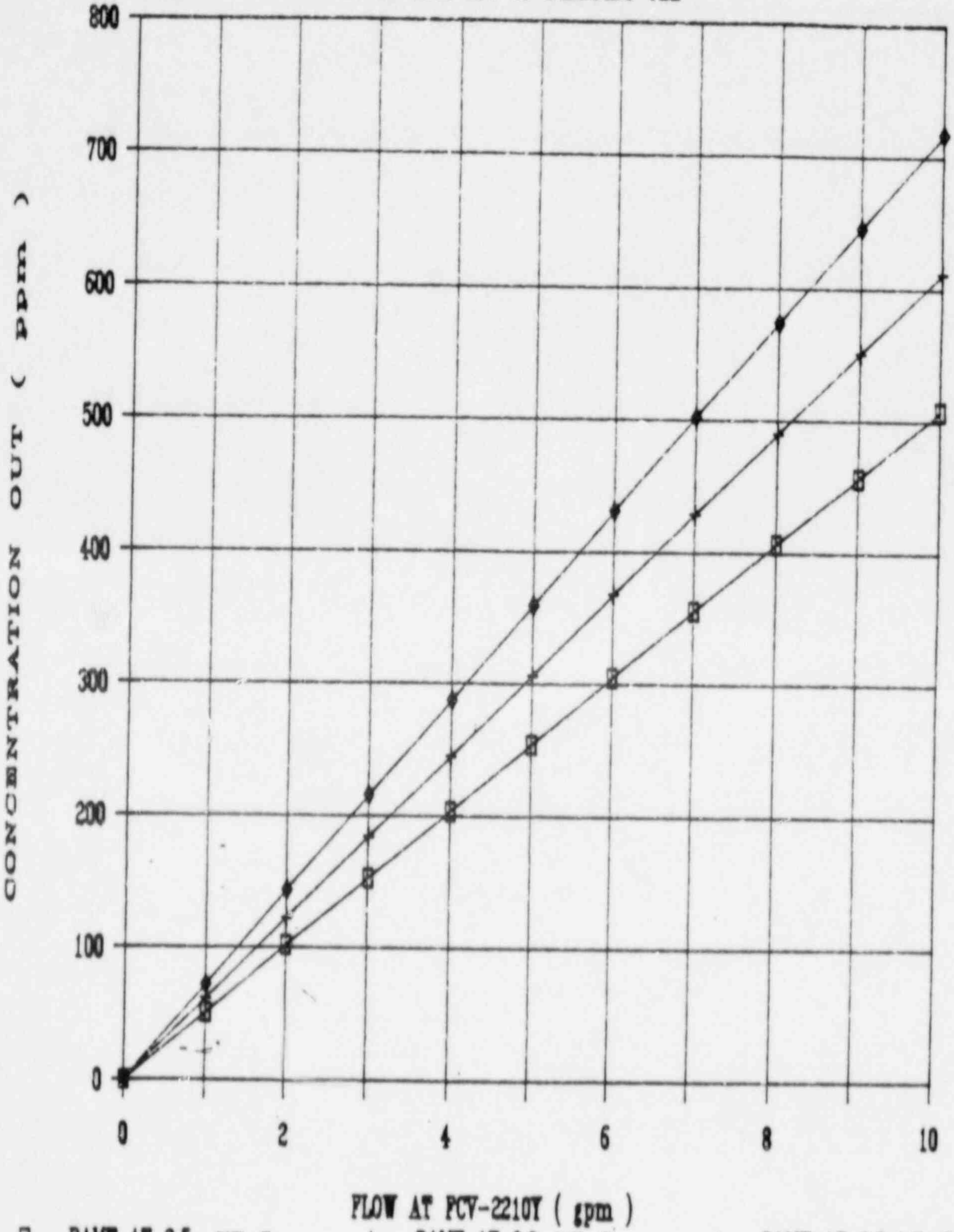
# FIGURE 3-3 BLENDED MAKEUP OPERATIONS

AT 44 GPM OUT OF BLENDING TEE



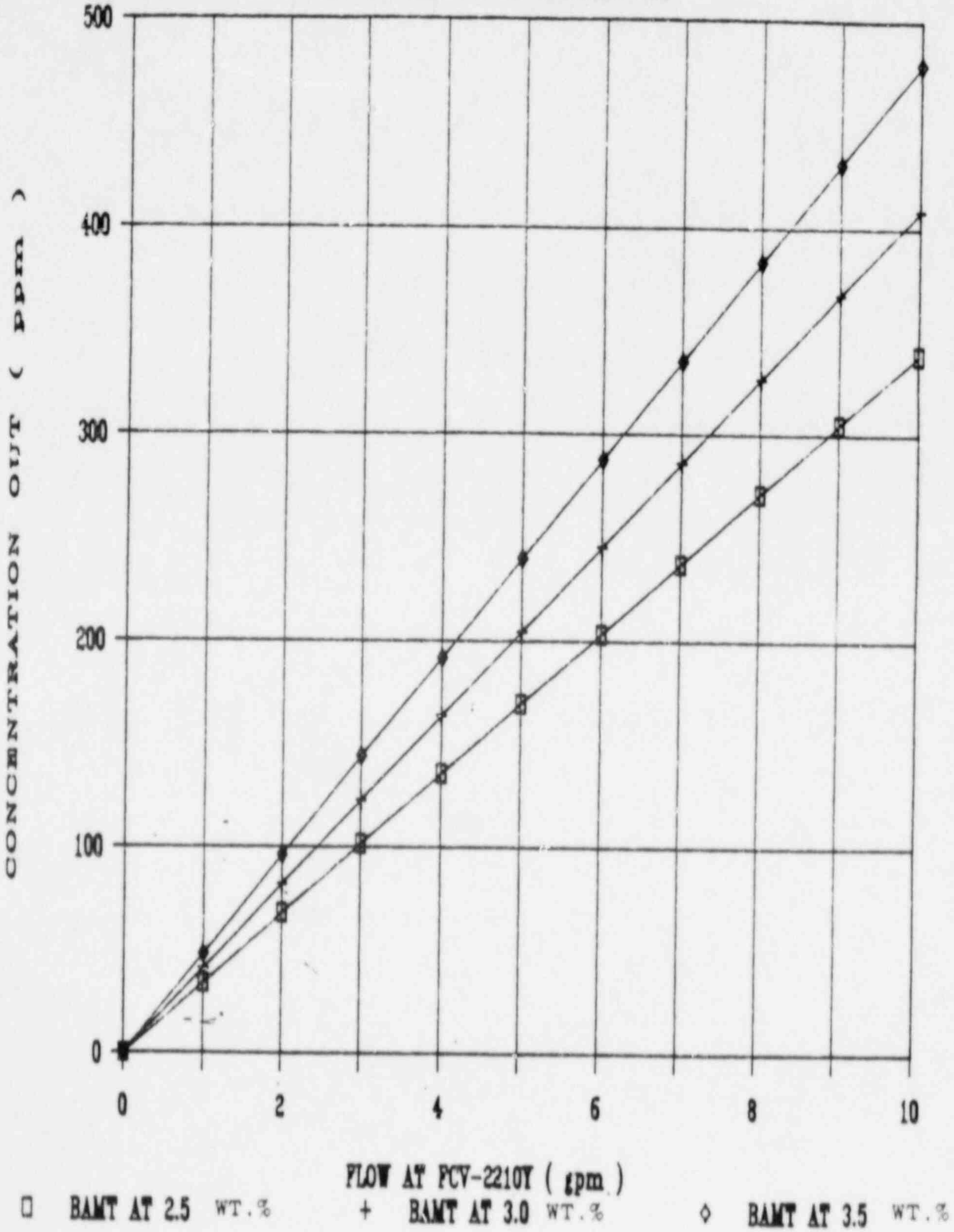
# FIGURE 3-4 BLENDED MAKEUP OPERATIONS

AT 88 GPM OUT OF BLENDING TEE



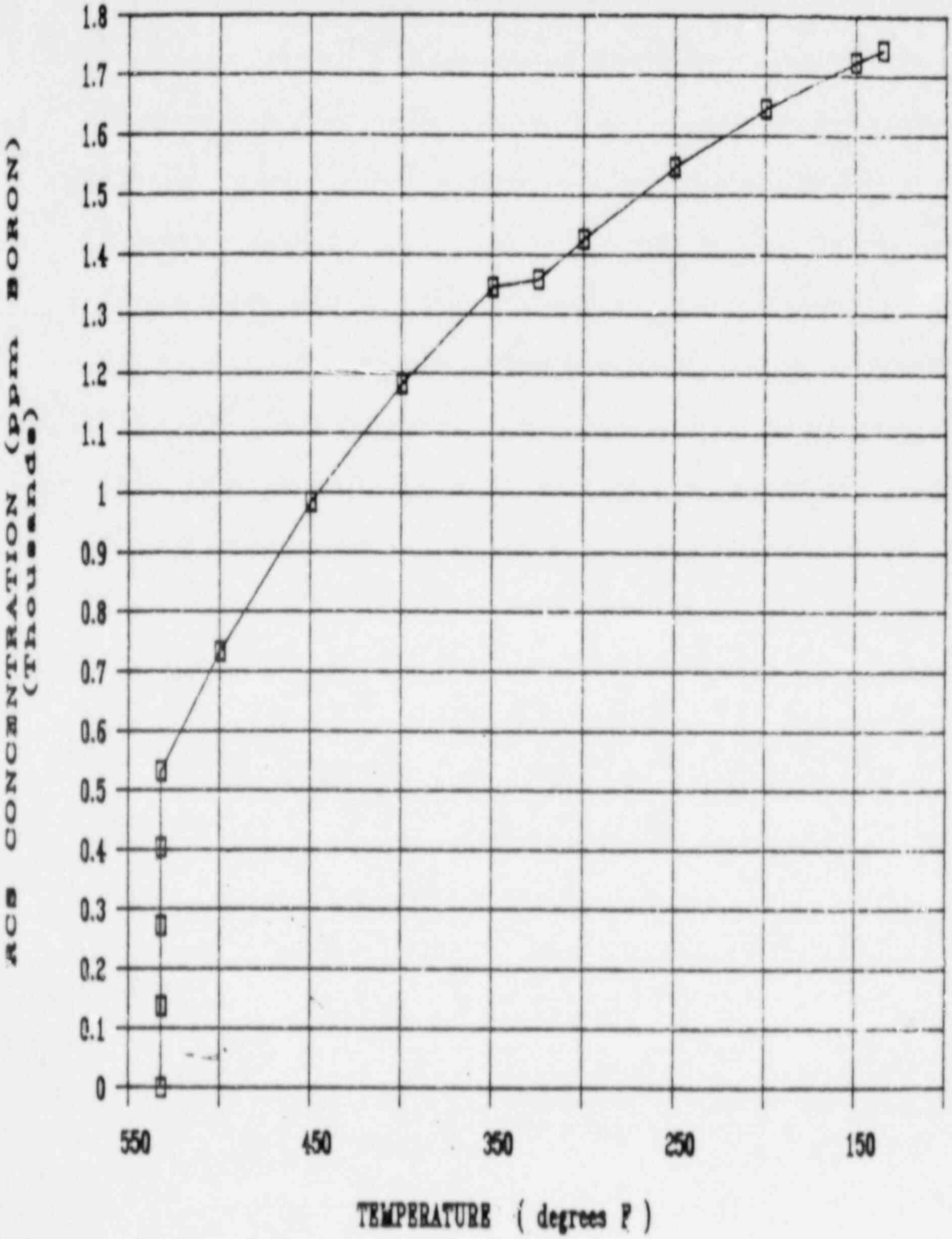
# FIGURE 3-5 BLENDED MAKEUP OPERATIONS

AT 132 GPM OUT OF BLENDING TEE



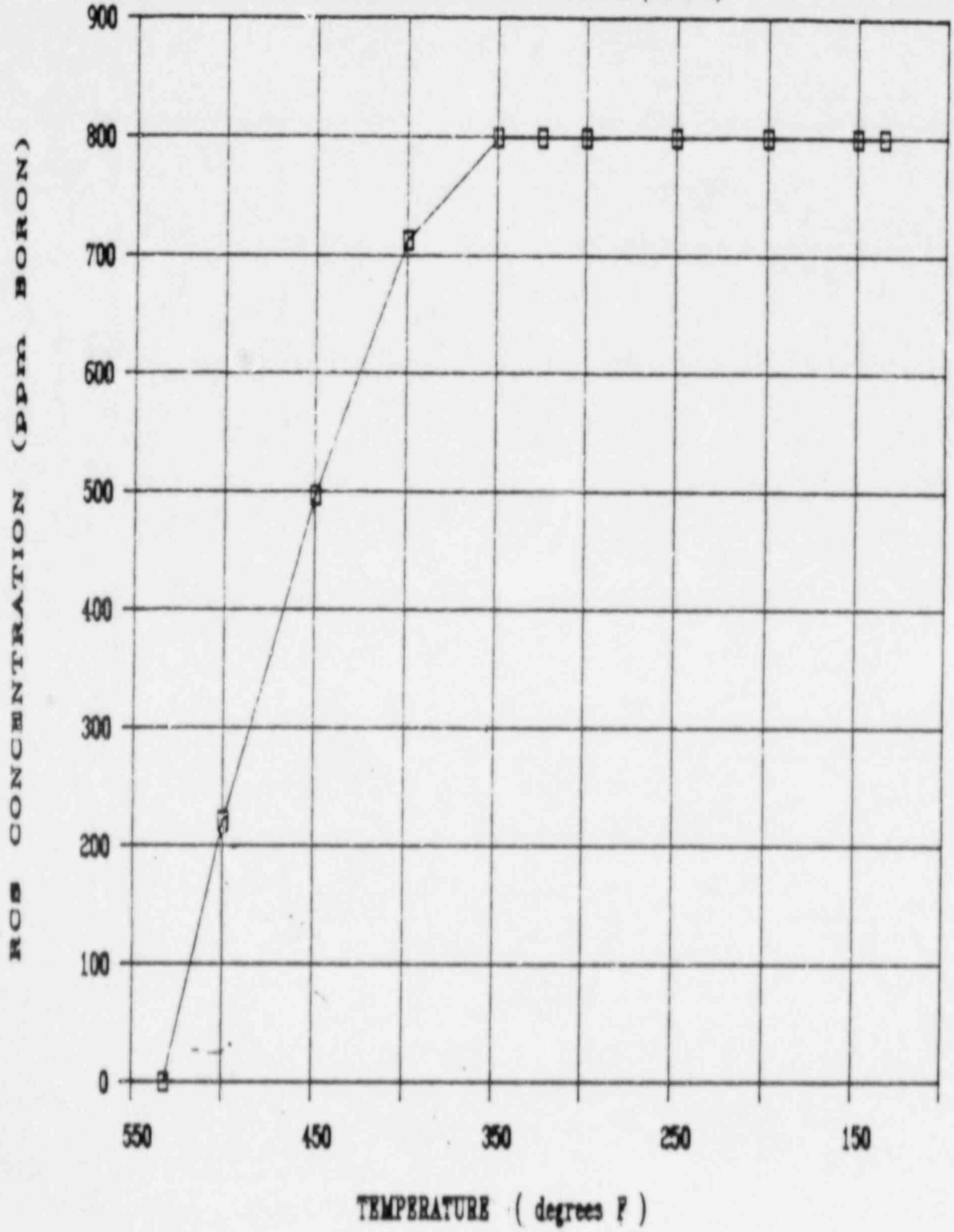
# FIGURE 3-6 ST. LUCIE 2 RCS BORON CONC

**vs TEMPERATURE FOR A REFUELING SHUTDOWN**



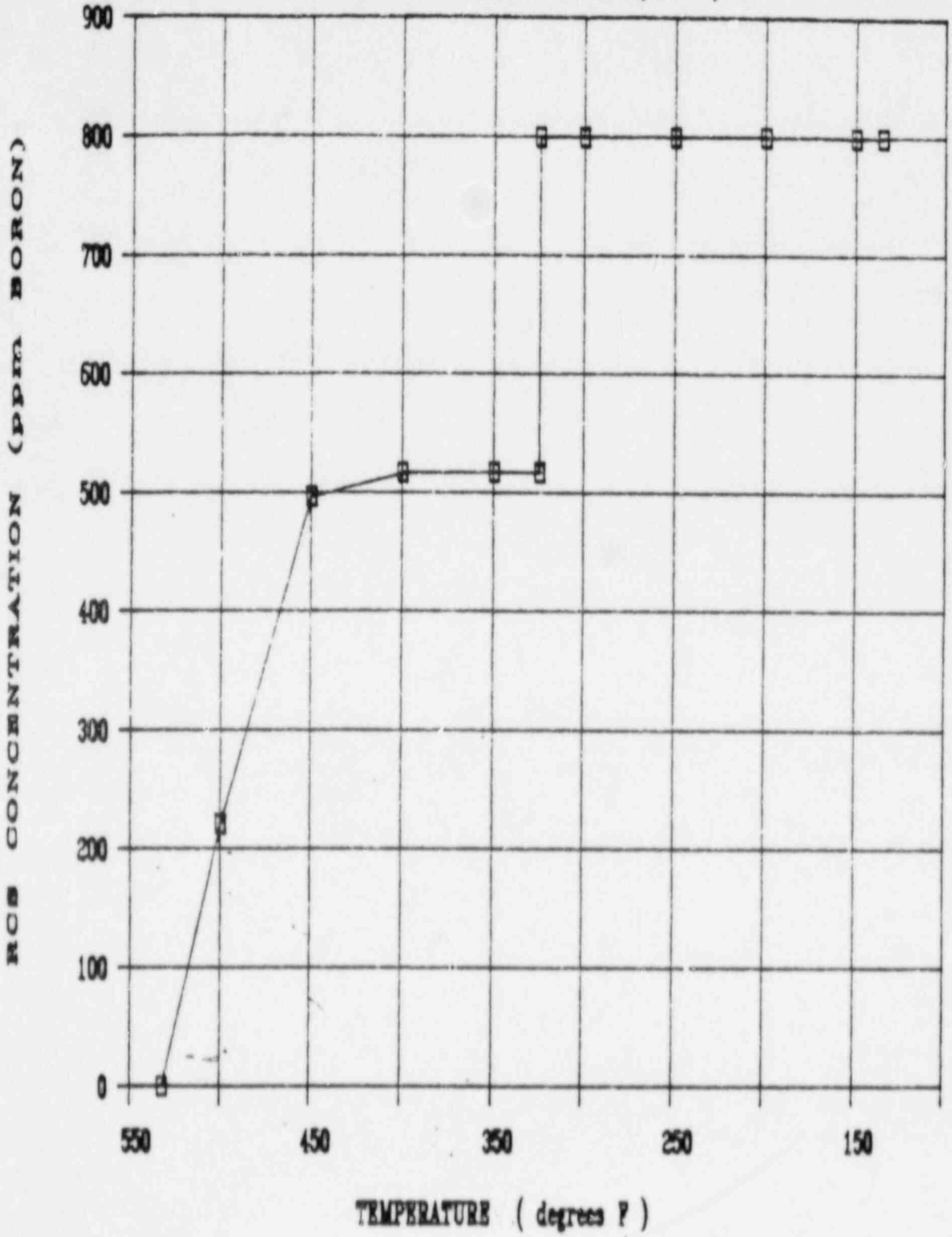
# FIGURE 3-7 ST. LUCIE 2 RCS BORON CONC

vs TEMP FOR A COLD SHUTDOWN (CASE 1)



# FIGURE 3-8 ST. LUCIE 2 RCS BORON CONC

vs TEMP FOR A COLD SHUTDOWN (CASE 2)



## 4.0 REFERENCES


4.1 Technical Data Sheet IC-11, US Borax & Chemical Corporation, 3-83-J.W.

4.2 Combustion Engineering's Emergency Procedure Guidelines, CEN-152, Revision 2, May, 1984.

4.3 An Evaluation on the Natural Circulation Cooldown Test Performed at the San Onofre Nuclear Generating Station, compliance with the Testing Requirements of Branch Technical Position RSB 5-1, CEN-259, Combustion Engineering, January 1984.

4.4 U.S. Nuclear Regulatory Commission Standard Review Plan NUREG-0800 Section 5.4.7. "Residual Heat Removal (RHR) System" and Branch Technical Position (RSB) 5-1 "Design Requirements of the Residual Heat Removal System".

4.5 C-E Letter F2-CE-R-021, "St. Lucie Unit 2 Cycle 3 Physics Data for FP&L's Non-LOCA Transient Evaluation", E. A. Trapp to J. L. Perryman, dated August 12, 1985.

4.6 C-E Letter F2-CE-R-078, "Transmittal of St. Lucie Unit 2 Cycle 3 Startup Test Predictions and Physics Data Book Information", E. A. Trapp to J. L. Perryman, dated May 1, 1986.

Appendix 1

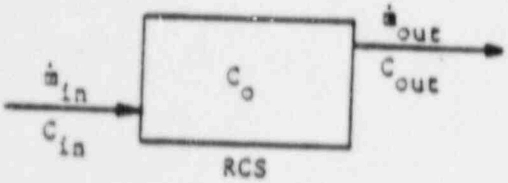
Derivation of the Reactor Coolant System
Feed-and-Bleed Equation

Purpose of Definitions

This appendix presents the detailed derivation of an equation which can be used to compute the reactor coolant system (RCS) boron concentration change during a feed-and-bleed operation. For this derivation, the following definitions were used:

$m_{in}$ = mass flowrate into the RCS
$m_{out}$ = mass flowrate out of the RCS
$m_b$ = boron mass flowrate
$m_w$ = water mass flowrate
$m_b$ = boron mass
$m_w$ = water mass
$C_{in}$ = boron concentration going into RCS
$C_{out}$ = boron concentration going out of RCS
$C_o$ = initial boron concentration
$C(t)$ = boron concentration as a function of time
$C_{RCS}$ = RCS boron concentration

Simplifying Assumptions




During a feed-and-bleed operation, the reactor coolant system can be pictured as shown in the figure as a closed container having a certain volume, a certain mass, and an initial boron concentration. Coolant is added at one end via the charging pumps. The rate of addition is dependent on the number of charging pumps that are running with the concentration being determined by the operator. Coolant is removed at the other end via letdown at a rate that is approximately equal to the charging rate and at a concentration determined by fluid mixing within the reactor coolant system. The mass flowrate into the reactor coolant system is given by the following equation:

$$\dot{m}_{in} = (\dot{m}_b + \dot{m}_w)_{in}.$$

For typical boron concentrations within the chemical and volume control system, $m_w$ is very much greater than $m_b$. (For example, a 3.5 weight percent boric acid solution contains only 0.04 lbm of boric acid per lbm of water). Therefore the above equation can be simplified to the following:

$$\dot{m}_{in} = (\dot{m}_w)_{in}. \qquad (1.0)$$

In a similar manner, the mass flowrate coming out of the reactor coolant system, given by

$$\dot{m}_{out} = (\dot{m}_b + \dot{m}_w)_{out},$$

can be simplified by again realizing that $m_w$ is very much greater than $m_b$ or

$$\dot{m}_{out} = (\dot{m}_w)_{out}. \qquad (2.0)$$

For a feed-and-bleed operation with a constant pressurizer level and a constant system temperature, the mass flowrate into the RCS will be equal to the mass flowrate out of the RCS, or

$$\dot{m}_{in} = \dot{m}_{out} = (\dot{m}_w)_{in} = (\dot{m}_w)_{out}. \qquad (3.0)$$

Finally, if it is assumed that the boron which is added to the reactor coolant system mixes completely and instantly with the entire RCS mass, the concentration of the fluid coming out of the system will be equal to the system concentration, or

$$C_{out} = C_{RCS}. \qquad (4.0)$$

<u>Derivation</u>

The rate of change of boron mass within the reactor coolant system is equal to the mass of boron being charged into the system minus the mass of boron leaving via letdown. In equation form, this becomes

$$\frac{d(m_b)_{RCS}}{dt} = \dot{m}_{in}C_{in} - \dot{m}_{out}C_{out}.$$

From Equation 3.0,

$$\frac{d(m_b)_{RCS}}{dt} = \dot{m}_{in}(C_{in} - C_{out}) = (m_w)_{in}(C_{in} - C_{out}). \qquad (5.0)$$

The concentration of boron in the reactor coolant system, i.e., the weight fraction of boron, is defined as follows:

$$C_{RCS} = \frac{m_b}{m_b + m_w}_{RCS}.$$

Since $m_w \gg m_b$,

$$C_{RCS} = \frac{m_b}{m_w}_{RCS}$$

Where $(m_w)_{RCS}$ is a constant for a constant system temperature. The rate of change of the RCS concentration is therefore

$$\frac{dC_{RCS}}{dt} = \frac{\frac{d(m_b)_{RCS}}{dt}}{(m_w)_{RCS}} . \qquad (6.0)$$

Substituting Equation 5.0 into Equation 6.0 yields the following:

$$\frac{dC_{RCS}}{dt} = \frac{(\dot{m}_w)_{in} (C_{in} - C_{out})}{(m_w)_{RCS}} ,$$

and from Equation 4.0

$$\frac{dC_{RCS}}{dt} = \frac{(\dot{m}_w)_{in} (C_{in} - C_{RCS})}{(m_w)_{RCS}} . \qquad (7.0)$$

Solving Equation 7.0 for concentration yields:

$$\frac{dC_{RCS}}{C_{in} - C_{RCS}} = \frac{(\dot{m}_w)_{in}}{(m_w)_{RCS}} dt'$$

or

$$\int_{C_o}^{C(t)} \frac{dC_{RCS}}{C_{in} - C_{RCS}} = \frac{(\dot{m}_w)_{in}}{(m_w)_{RCS}} \int_{o}^{t} dt .$$

Integrating from some initial concentration $C_o$ to some final concentration $C(t)$ and multiplying through by a minus one gives the following:

$$\ln (C_{RCS} - C_{IN}) \Big|_{C_o}^{C(t)} = - \frac{(\dot{m}_w)_{in}}{(m_w)_{RCS}} t,$$

or

$$\ln \frac{C(t) - C_{in}}{C_o - C_{in}} = -\frac{(\dot{m}_w)_{in}}{(m_w)_{RCS}} t .$$

Continuing to solve for C(t), this equation becomes:

$$\frac{C(t) - C_{in}}{C_o - C_{in}} = e^{-(\dot{m}_w)_{in} t / (m_w)_{RCS}} ,$$

or

$$C(t) = C_{in} + (C_o - C_{in}) e^{-(\dot{m}_w)_{in} t / (m_w)_{RCS}} . \qquad (8.0)$$

If we define the time constant T to be as follows:

$$T = \frac{(m_w)_{RCS}}{(\dot{m}_w)_{in}} ,$$

then Equation 8.0 becomes

$$C(t) = C_o e^{-t/T} + C_{in} (1 - e^{-t/T}) . \qquad (9.0)$$

## Appendix 2

## A Proof that Final System Concentration is Independent of System Volume

### Purpose of Definitions

This appendix presents a detailed proof that during a plant cooldown where an operator is charging only as necessary to makeup for coolant contraction, the final system concentration that results using a given boration source concentration will be independent of the total system volume. For this proof, the following definitions were used:

$c_i$ = initial boron concentration Plant 1
$m_{bi}$ = initial boron mass Plant 1
$m_{wi}$ = initial water mass Plant 1
$c_f$ = final boron concentration Plant 1
$c_a$ = boron concentration of makeup solution Plant 1
$m_{ba}$ = mass of boron added Plant 1
$m_{wa}$ = mass of water added Plant 1
$m_{bf}$ = final boron mass Plant 1
$C_i$ = initial boron concentration Plant 2
$M_{bi}$ = initial boron mass Plant 2
$M_{wi}$ = initial water mass Plant 2
$C_f$ = final boron concentration Plant 2
$C_a$ = boron concentration of makeup solution Plant 2
$M_{ba}$ = mass of boron added Plant 2
$M_{wa}$ = mass of water added Plant 2

### Proof

For this proof, consider two plants at the same initial temperature, the same initial pressure, and the same initial boron concentration. One plant, Plant 2, has exactly twice the system volume as the other plant,

Plant 1. Initially, boron concentration Plant 1 = boron concentration Plant 2,

or

$$c_i = C_i = \frac{m_{bi}}{m_{bi} + m_{wi}} = \frac{M_{bi}}{M_{bi} + M_{wi}} . \quad (1.0)$$

Since the volume of Plant 2 is twice that of Plant 1, $M_{wi} = 2m_{wi}$. Substituting this relationship into Equation 1.0 and solving yields the following:

$$\frac{m_{bi}}{m_{bi} + m_{wi}} = \frac{M_{bi}}{M_{bi} + 2m_{wi}} ,$$

$$m_{bi}M_{bi} + 2m_{bi}m_{wi} = m_{bi}M_{bi} + m_{wi}M_{bi} ,$$

and

$$M_{bi} = 2m_{bi} . \quad (2.0)$$

Therefore, the initial boron mass in Plant 2 is exactly twice the initial boron mass in Plant 1.

During the cooldown process for Plant 1, the final boron mass in the system will equal the initial boron mass plus the added boron mass, or

$$m_{bf} = m_{bi} + m_{ba} . \quad (3.0)$$

If, during this cooldown process, operators charge only as necessary to makeup for coolant contraction, water and boron will be added only as space is made available in the system due to coolant shrinkage. The final boron concentration from Equation 3.0 can therefore be expressed as follows:

$$m_{bf} = \left[m_{bi} + m_{ba} + m_{wi} + m_{wa}\right]\left[\frac{m_{bf}}{m_{bi} + m_{ba} + m_{wi} + m_{wa}}\right] .$$

If concentration is expressed in terms of weight percent, this last equation becomes

$$m_{bf} = \left[m_{bi} + m_{ba} + M_{wi} + m_{wa}\right] c_f. \qquad (4.0)$$

Similarly, the remaining two components of Equation 3.0 become

$$M_{bi} = \left[m_{bi} + m_{wi}\right] c_i \qquad (5.0)$$

and

$$m_{ba} = \left[m_{ba} + m_{wa}\right] c_a \qquad (6.0)$$

Substituting Equations 4.0, 5.0, and 6.0 into Equation 3.0 and solving for the final concentration yields the following:

$$c_f = \frac{\left[m_{bi} + m_{wi}\right] c_i + \left[m_{ba} + m_{wa}\right] c_a}{m_{bi} + m_{ba} + m_{wi} + m_{wa}} \qquad (7.0)$$

For Plant 2, Equation 7.0 becomes

$$C_f = \frac{\left[M_{bi} + M_{wi}\right] C_i + \left[M_{ba} + M_{wa}\right] C_a}{M_{bi} + M_{ba} + M_{wi} + M_{wa}} \qquad (8.0)$$

During a cooldown, the shrinkage mass, i.e., the mass of fluid that must be added to the system in order to keep pressurizer level constant, is calculated by dividing the system volume by the change in specific volume, or

$$m_{wa} = \frac{\text{System Volume Plant 1}}{\Delta \text{ Specific volume}} \qquad (9.0)$$

and

$$M_{wa} = \frac{\text{System Volume Plant 2}}{\Delta \text{ Specific volume}}, \qquad (10.0)$$

where System Volume Plant 1 = (1/2) System Volume Plant 2.

For a given cooldown, dividing Equation 9.0 by Equation 10.0 gives the following:

$$M_{wa} = 2m_{wa} \qquad (11.0)$$

In addition, if the charging source for both plants is at the same concentration and temperature,

$$C_a = c_a \, , \qquad (12.0)$$

and

$$M_{ba} = 2m_{ba} \, . \qquad (13.0)$$

Substituting Equations 2.0, 11.0, 12,0, and 13.0 into Equation 8.0 yields the following:

$$C_f = \frac{\left[2m_{bi} + M_{wi}\right] C_i + \left[2m_{ba} + 2m_{wa}\right] c_a}{2m_{bi} + 2m_{ba} + M_{wi} + 2m_{wa}}$$

Since the initial concentrations are the same, $C_i = c_i$, and since Plant 2 is twice as large as Plant 1, $M_{wi} = 2m_{wi}$,

$$C_f = \frac{\left[2m_{bi} + 2m_{wi}\right] c_i + \left[2m_{ba} + 2m_{wa}\right] c_a}{2m_{bi} + 2m_{ba} + 2m_{wi} + 2m_{wa}} = c_f \, ,$$

or

$$C_f = c_f \, . \qquad (14.0)$$

Therefore, for a cooldown where pressurizer level is maintained constant, the final boron concentration for Plant 2 is equal to the final boron concentration for Plant 1, i.e., the change in boron concentration is independent of the exact system volume.

## Appendix 3

### Methodology for Calculating Dissolved Boric Acid per Gallon of Water

#### Purpose

The purpose of this appendix is to show the methodology used to calculate the mass of boric acid dissolved in each gallon of water for solutions of various boric acid concentrations. Two solution temperatures were used corresponding to the minimum allowable refueling water tank temperature of 5 degrees and a boric acid makeup temperature of 70 degrees in the absence of tank heaters.

#### Methodology and Results

Boric acid concentration expressed in terms of weight percent is defined as follows:

$$C = \frac{\text{mass of boric acid}}{\text{total solution mass}} \times 100,$$

or

$$C = \frac{\text{mass of boric acid}}{(\text{mass of boric acid}) + (\text{mass of water})} \times 100. \qquad (1.0)$$

If we define $m_{ba}$ to be the mass of boric acid and $m_w$ to be the mass of water, and if we substitute these defined terms into Equation 1.0 and solve for the mass of boric acid we have the following:

$$C = \frac{m_{ba}}{m_{ba} + m_w} \times 100,$$

or

$$m_{ba} = \frac{C \times m_w}{100 - C}. \qquad (2.0)$$

From Appendix A of the Crane Company Manual (Flow of Fluids Through Valves, Fittings, and Pipe, Crane Co., 1981, Technical Paper No. 410), the density of water at 70 degrees is 8.3290 lbm / gallon and at 50 degrees is 8.343 lbm / gallon. Using these water masses and Equation 2.0 above, the mass of boric acid per gallon of solution is as follows:

| | Concentration | | Mass of acid per gallon of solution at | |
|---|---|---|---|---|
| source | wt. % boric acid | ppm boron | 50 degrees | 70 degrees |
| RWT | 0.98379 | 1720 | 0.08289 lbm | -- |
| RWT | 1.05815 | 1850 | 0.08923 lbm | -- |
| RWT | 1.14394 | 2000 | 0.09654 lbm | -- |
| RWT | 1.22974 | 2150 | 0.10387 lbm | -- |
| RWT | 1.31553 | 2300 | 0.11121 lbm | -- |
| BAMT | 2.50 | 4371 | -- | 0.21336 lbm |
| BAMT | 2.75 | 4808 | -- | 0.23552 lbm |
| BAMT | 3.00 | 5245 | -- | 0.25760 lbm |
| BAMT | 3.25 | 5682 | -- | 0.27979 lbm |
| BAMT | 3.50 | 6119 | -- | 0.30209 lbm |

## Appendix 4

## Methodology for Calculating the Conversion Factor Between Weight Percent Boric Acid and ppm Boron

### Purpose

The purpose of this appendix is to show the methodology used to derive the conversion factor between concentration in terms of weight percent boric acid and concentration in terms of parts per million (ppm) of naturally occurring boron.

### Results

For any species (solute) dissolved in some solvent, a solution having a concentration of exactly 1 ppm can be obtained by dissolving 1 lbm of solute in 999,999 lbm of solvent. An aqueous solution having a concentration of 1 ppm boric acid, therefore, can be obtained by dissolving 1 lbm of boric acid in 999,999 lbm of water, or

$$1\ \text{ppm} = \frac{1\ \text{lbm boric acid}}{1\ \text{lbm boric acid} + 999{,}999\ \text{lbm water}} = \frac{1\ \text{lbm boric acid}}{10^6\ \text{lbm solution}}.$$

For any species (solute) dissolved in some solvent, a solution having a concentration of 1 weight percent (wt. %) can be obtained by dissolving 1 lbm of solute in 99 lbm of solvent. An aqueous solution having a concentration of 1 wt. % boric acid, therefore, can be obtained by dissolving 1 lbm of boric acid in 99 lbm of water, or

$$\frac{1\ \text{wt. \%}}{100} = \frac{1\ \text{lbm boric acid}}{1\ \text{lbm boric acid} + 99\ \text{lbm water}} = \frac{1\ \text{lbm boric acid}}{100\ \text{lbm solution}},$$

Dividing these last two equations yields a ratio of $10^4$, or

$$1\ \text{wt. \% boric acid} = 10{,}000\ \text{ppm boric acid.} \qquad (1.0)$$

To convert from ppm boric acid (weight fraction) to ppm boron (weight fraction), multiply Equation 1.0 by the ratio of the molecular weight of boric acid (naturally occurring $H_3BO_3$) to the atomic weight of naturally occurring boron. From the Handbook of Chemistry and Physics, CRC Press,

$$1 \text{ wt. \% boric acid} = (10{,}000)\ \frac{10.81}{61.83}\ \text{ppm boron}\ ,$$

or

$$1 \text{ wt. \% boric acid} = 1748.34 \text{ ppm boron.}$$

## Appendix 5
## Bounding Physics Data Inputs

The following Physics Data Inputs for St. Lucie Unit 2 are provided to facilitate review of this effort. The conservatism, uncertainties, and biases incorporated in the BAMT Boric Acid Concentration Reduction effort for St. Lucie Unit 2 are contained in Table 1. The St. Lucie Unit 2 EOC Physics Data Inputs are contained in References 4.5 and 4.6. During future cycles, the new core parameters must be compared with these inputs to ensure that they are still bounding.

The purpose of this section is to describe the methodology used to compute the core reactivity during the cooldown. This method has been devised to conservatively bound the reactivity affects of the natural circulation cooldown described in Section 2.2.1.1 of this report. The cooldown scenario and the method used to compute core reactivity are discussed in detail in the following paragraphs.

A description of the core reactivity affects is provided. In addition a brief description is provided to show that these assumptions conservatively bound all similar cooldowns at any time during the fuel cycle.

1. Conservative core physics parameters were used to determine the required boron concentration and the required Boric Acid Makeup Tank volumes to be added during plant cooldown.

    - End-of-cycle (EOC) initial boron concentration is assumed to be zero.
    - End-of-cycle moderator cooldown effects are used to maximize the reactivity changes during plant cooldown. End-of-Cycle moderator cooldown effects are used at the most Negative Technical Specification MTC.

Positive reactivity is added to the core as the moderator temperature is lowered during the cooldown. The moderator temperature effects on core reactivity vary over the fuel cycle. The moderator temperature effect at beginning-of-cycle (BOC) is very small while the moderator temperature effect EOC provides the maximum reactivity insertion.

EOC Inverse Boron Worths (Table 2) were extracted from Reference 4.6. End-of-cycle (EOC) inverse boron worth data was used in combination with EOC reactivity insertion rates normalized to the most Negative Technical Specification Moderator Temperature Coefficient (MTC) limit since it was known that this yields results that are more limiting than the combination of actual MTC and actual IBW values at all periods through the fuel cycle prior to end-of-cycle.

2. Scram Worth

A conservative scram worth was used in this calculation. The available scram worth was computed utilizing the hot zero power scram worth for all rods in minus the worst rod stuck full out. From this value the Power Dependent Insertion Limit worths were subtracted to obtain a net available scram worth. A Bias of -9% and Uncertainty of 13% was subtracted from the available scram worth for added conservatism. This scram worth is further reduced by subtracting an EOC reactivity value associated with the Full Power Defect.

3. Determination of Excess Scram Worth

Excess scram worth was determined by comparing the available scram worth at zero power and subtracting the required technical specification shutdown margin. Required Shutdown Margin:

| $T_{ave}$ | SDM |
|---|---|
| > 200°F | ≥ 5000 pcm |
| ≤ 200°F | ≥ 3000 pcm |

It was determined by this method that there was a 0.08 Δk/k excess scram worth available for temperatures above 200°F and an excess scram worth of 1.58 Δk/k for temperatures below 200°F.

4. Core Reactivity Effects

A reactivity calculation has been performed to account for positive reactivity insertion due to the decay of xenon and the positive reactivity due to the cooldown of the moderator and fuel. Uncertainties and biases were applied to all reactivity affects. Table 1 delineates the biases and uncertainties used in this calculation.

Xenon Reactivity Effects

As shown in Reference 4.6 of the xenon worth peaks at its most negative reactivity worth around eight hours after the reactor is shutdown. Xenon decay reduces the negative reactivity of the xenon back to its steady state operating value at approximately 26 hours after shutdown. At times after 26 hours the plant must be borated to compensate for the further reduction in xenon concentration. As an added conservatism this calculation never credited the extra negative reactivity inserted by the xenon peak that occurs after shutdown. Instead the plant was maintained at hot standby for 26 hours to allow xenon to return to the 100% steady state value and further xenon decay to add reactivity simultaneously with the plant cooldown effects. Reference 4.6 was used to determine the positive reactivity inserted into the core for times after 26 hours at discreet time intervals. Note that a slow cooldown rate will prolong the time required to reach Mode 5 where the shutdown margin drops from 5.0% Δk/k to 3.5% Δk/k and therefore would require a larger boron concentration to counteract xenon decay during the cooldown. A 12.5 degree per hour cooldown rate has been utilized in this calculation. It should be noted that this method accounts for xenon decay for a full 54 hours which is a much longer time frame than is expected to achieve cold shutdown.

Reactor Cooldown Effects

The affect of the reactor cooldown was calculated by determining the fuel temperature and moderator temperature reactivity effects for each incremental temperature decrease. Data from Reference 4.5 was utilized to determine these effects. It should be noted that these reactivity effects are independent of time and solely dependent on the change in temperature of the core.

Boration Requirements

Having determined the reactivity effects due to xenon, moderator cooldown and fuel temperature cooldown for discreet time intervals after the plant is shutdown, the necessary boron concentration to compensate for this reactivity change is determined. The Inverse Boron Worth values of Reference 4.6 were used to determine the ppm boron necessary in the RCS to compensate for the positive reactivities determined above. All the conservatism, uncertainties and biases applied to this calculation are included in Table 1.

Table 1

Conservatism, Uncertainties and Biases
Incorporated in the BAMT Boric Acid Concentration
Reduction Effort for St. Lucie Unit 2

1. The initial scram is assumed to proceed from the hot full power PDIL (power dependent insertion limit) to the all rods in, with the worst case rod stuck in the full out position conditions.

2. A bias of -9% and uncertainty of 13% was applied to the scram worth data.

3. A combined bias and uncertainty of 10% was applied to the moderator data.

4. A bias of 15% and an uncertainty of 15% was applied to the Doppler data.

5. The assumption that the cooldown begins at 26 hours is conservative in relation to the buildup and decay of Xenon.

Table 2

Inverse Boron Worth

| TEMP | IBW |
|---|---|
| 557.0 | 80.0 |
| 544.5 | 80.0 |
| 532.0 | 80.0 |
| 507.0 | 80.0 |
| 482.0 | 78.1 |
| 457.0 | 76.3 |
| 432.0 | 74.6 |
| 407.0 | 73.0 |
| 382.0 | 71.4 |
| 357.0 | 70.2 |
| 332.0 | 69.0 |
| 307.0 | 67.8 |
| 282.0 | 66.7 |
| 257.0 | 65.6 |
| 232.0 | 64.5 |
| 207.0 | 63.7 |
| 200.0 | 63.3 |
| 200.0 | 63.3 |
| 200.0 | 63.3 |
| 130.0 | 60.9 |

Table 3

Required Boron Concentration for a Cooldown from 557°F to 135°F

| Temperatures (Degrees F) | Concentration (ppm boron) |
|---|---|
| 557 | -71.2 |
| 510 | 133.0 |
| 490 | 203.0 |
| 480 | 235.5 |
| 470 | 262.3 |
| 460 | 289.8 |
| 450 | 314.1 |
| 440 | 338.0 |
| 430 | 350.6 |
| 420 | 382.0 |
| 410 | 403.4 |
| 400 | 423.5 |
| 390 | 443.0 |
| 380 | 461.2 |
| 370 | 474.5 |
| 360 | 488.7 |
| 350 | 500.9 |
| 340 | 512.6 |
| 330 | 523.5 |
| 325 | 528.7 |
| 310 | 543.6 |
| 285 | 568.8 |
| 260 | 589.9 |
| 235 | 608.7 |
| 210 | 627.6 |
| 200 | 634.9 |
| 199.9* | 539.9 |
| 199.9** | 570.3 |
| 190 | 577.4 |
| 180 | 584.5 |
| 170 | 591.6 |
| 160 | 598.6 |
| 150 | 605.7 |
| 140 | 612.8 |
| 135 | 616.3 |

* After shutdown margin change from 5.0% delta k/k to 3.5% delta k/k

** The boration requirement for a 3.5% shutdown margin and core is xenon free