Attachment 49 to PLA-6219
Calculation EC-PUPC-20605, Revision 1, Condenser & Circulating Water System EPU Evaluation and Task Report

(NRC Document Request 108)

NUCLEAR ENGINEERING CALCULATION COVER SHEET NEPM-QA-0221-1	1. Page 1 of 26 Total Pages 28

>2. TYPE: CALC >3. NUMBER: EC-PUPC-20605 >4. REVISION: 1

*>5. UNIT 3 *>6. QUALITY CLASS: N

>7. DESCRIPTION: Condenser & Circulating Water System EPU Evaluation and Task Report

8. SUPERSEDED BY: N/A

9. Alternate Number: N/A 10. Cycle: N/A

11. Computer Code/Model used: N/A 12. Discipline: M

>13. Are any results of this calculation described in the Licensing Documents?

☐ Yes, *Refer to NDAP-QA-0730 and NDAP-QA-0731* ☒ No

>14. Is this calculation changing any method of evaluation described in the FSAR and using the results to support or change the FSAR? (Refer to PPL Resource Manual for Definition of FSAR)

☐ Yes, *50.59 screen or evaluation required.* ☒ No

>15. Is this calculation Prepared by an External Organization?

☐ Yes ☒ No

EG771 Qualifications may not be required for individuals from external organizations (see Section 7.4.3).

	Print Name	Signature	Date
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>20. Accepted by:	*Print Name (EG771 Qualification Required) and comply with Section 7.9 of NEPM-QA-0221*		

CALCULATION REVISION DESCRIPTION SHEET
NEPM-QA-0221-2

REVISION NO: 1	CALCULATION NUMBER: EC-PUPC-20605

☐ FULL REVISION ☐ SUPERSEDED

☒ PAGE FOR PAGE ☐ VOIDED

Revised Pages	Add	Rpl	Rmv	Description of Revision on the Listed Pages
1	☐	☒	☐	Replace Cover Sheet
1a	☒	☐	☐	Add Revision Description Sheet
1b	☒	☐	☐	Add Technical Change Summary Page
23 - 26	☒	☐	☐	Add APPENDIX A
	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	
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TECHNICAL CHANGE SUMMARY PAGE
NEPM-QA-0221-5

Calculation: Number: EC-PUPC-20605 **Revision No.** 1

This form shall be used to (1) record the Technical Scope of the revision and (2) record the scope of verification if the calculation was verified. It should not be more than one page. Its purpose is to provide summary information to the reviewer, verifier, approver, and acceptor about the technical purpose of the change. For non-technical revisions, state the purpose or reason for the revision.

Scope of Revision: This calculation revision provides an additional analysis needed to support PPL's submittal of a post-EPU Consumptive Water Use Application and/or a post-EPU Surface Water Withdrawal Application to the Susquehanna River Basin Commission (SRBC). The analysis will conservatively estimate post-EPU maximum daily consumptive water use and maximum daily total water withdrawal from the Susquehanna River for SSES Units 1 and 2. This revision to the calculation is contained, in its entirety, in APPENDIX A.

Scope of Verification (If verification applies): N/A

TABLE OF CONTENTS

1.0 PURPOSE

This calculation will serve as the Extended Power Uprate (EPU) evaluation and Task Report for the CW system including the PUSAR input which is developed and included as attachment 1. The calculation evaluates the impact of (EPU) on the thermal performance of the SSES Main Condenser, Circulating Water (CW) and Cooling Tower Systems. The thermal performance of these systems is interdependent with the condenser serving as a heat sink for the turbine cycle, the circulating water system removing the turbine cycle heat from the condenser, and discharging the turbine cycle heat to the atmosphere using the cooling tower.

2.0 CONCLUSIONS

Operation at EPU conditions will not result in the HP condenser back pressure exceeding the 5.5" HgA limit, imposed to limit condensate temperatures, at wet bulb temperatures of 77°F and less with relative humidity's of 65% or greater. (65% relative humidity is the cooling tower design basis)

Section 6.0 contains a tabulation of EPU and CLTP calculation results for two wet bulb conditions for comparison of CLTP and EPU parameters

3.0 REFERENCES

1. EC-093-1047, Rev. 2, turbine heat balance WB-10444, 3952.8 MWt
2. Calculation EC-043-0502, Rev. 0
3. Calculation EC-PUPC-0526, Rev. 6
4. Cooling Tower Performance Curves FF105590 Sh. 0101, 0201, 0301, 0401 and 0501, all Rev.2.
5. Calculation EC-043-0507, Rev. 3
6. Heat Exchange Institute - Standards for Steam Surface Condensers, Seventh Edition
7. Calculation EC-042-0003, Rev. 0
8. Calculation EC-093-1030. Rev. 0
9. Condenser cross section drawings FF105530 Sh. 4401-R7, 4301-R6 & 4501-R5
10. IOM-111, Rev. 5
11. DCP 482087 Operational Readiness Form dated 5/12/04
12. EC-PUPC-20604, Rev. 0
13. NPDES Permit PA0047325
14. EC-041-0508, Rev. 3
15. 30 day average condenser pressure data attached to 11-9-05 Email from P. Witman
16. Calculation EC-041-0507, Rev 0
17. Figure 1, SPG-0648, Siemens Design Analysis Report-Section 19, Rev. 7

4.0 ASSUMPTIONS

1. The duty on each of the three condenser shells is independent of the inlet CW temperature and therefore the CW temperature rise across a condenser is a constant with changing cold CW temperatures. No later confirmation required.
2. The Condensate pump suction temperature will be conservatively (on the high side) estimated as saturated liquid at the HP condenser shell vacuum since this establishes the common operating conditions for the hotwell area below the false bottom in the LP and IP condensers through the hotwell interconnections. No later confirmation required. Heat duties on individual LP, IP, and HP condenser shells will be conservatively (on the high side) evaluated based on the saturated liquid enthalpy at the individual condenser shell pressure indicated on the heat balance.
3. The evaluation for condenser pressure using the HEI method will be restricted to the HP shell since this will be the shell that first reaches the vacuum alarm and trip setpoints for the turbine. No later confirmation required.
4. The NIMS data on tube plugging for the HP condenser indicates less than 1% plugged tubes. The EPU evaluation will assume 1% plugged tubes which will be accounted for as a 1% decrease in area for heat transfer. No later confirmation required.
5. The cooling tower performance will be based on the curve for a flow of 478,000 GPM with values extrapolated for a flow of 511, 000 GPM. The sum of post EPU SW and CW should approach but not exceed 511,000 GPM. No later confirmation of this conservative assumption is required.
6. The maximum condenser pressure allowed for EPU operation is 5.5 inches Hg per Ref. # 17. No later confirmation required.

5.0 METHOD

The Circulating Water (CW) System is the system that supplies cooling water to the condenser for the main turbine to remove cycle heat and rejects that heat to the Cooling Tower. Makeup water to the cooling tower is supplied from the Make-Up Water System and blowdown from the cooling tower basin is discharged to the Susquehanna River. The Condenser consists of three shells operating at three pressures with a common hotwell that is separated from the condensing area by a false bottom in the LP and IP shells.

Use Reference No. 5 (page 10) and the condenser pressures given on reference 1 to determine the EPU heat load on each of the three condenser shells and use this value to establish the EPU temperature rise for Uprate of the circulating water flowing through each of the condenser shells. Using the CW temperature rise (Range) and the cooling tower performance curves determine the cold water temperature for five wet bulb temperatures. Using the methodology of HEI determine the backpressure in the HP turbine hoods relative to the range of circulating water inlet temperature. Back pressure calculations will be performed at the CW flow with cooling tower operation at the five or more wet bulb temperatures.

The source of Circulating Water is from the Cooling Tower Basin through a set of fixed screens (one outer and one inner) to two suction headers. Each suction header supplies water to two of the four Circulating Water Pumps. Each pair of pumps discharges to a common 96" discharge pipe and then to two of the four Low Pressure (LP) Condenser inlet water boxes. The LP condenser outlet waterboxes discharge to the four Intermediate Pressure (IP) Condenser inlet waterboxes through four crossover pipes and through crossover pipes from the IP outlet waterboxes to the High Pressure (HP) Condenser inlet waterboxes. The HP condenser outlet waterboxes discharge to the cooling tower. The Service Water System also takes suction from the cooling tower basin and returns its discharge to the cooling tower. This requires adding the SW heat load to the condenser duty to obtain the total cooling tower duty.

The EPU heat loads on each condenser shell are calculated from the 100% EPU turbine heat balance (Ref. # 1) and are tabulated based on page 10 of reference #5. The EPU heat loads are used to calculate the CW temperature change across the condenser shell. The Current Licensed Thermal Power (CLTP) heat loads are determined using the heat load data tabulated in reference #5. The EPU heat loads will be used to determine the wet bulb conditions that result in a HP condenser back pressure of 5.5" Hga. The wet bulb temperature determined for the EPU condition will then be used to determine the CLTP cooling tower discharge temperature and the condenser backpressure corresponding to this wet bulb temperature.

The maximum average 30 day condenser pressure of 4.05" Hga from Ref. #15 will be used with the CLTP condenser duty to determine the average maximum effective wet bulb temperature. The average maximum effective wet bulb temperature will be used to calculate EPU performance and will be used to determine EPU water consumption. The cooling tower performance for CLTP and EPU at the two wet bulb temperatures described will be used to calculate the delta change in CW temperature leaving the cooling tower, HP condenser vacuum, and condensate temperature resulting from EPU.

Circulating Water Flow / Pressure Evaluation

From Ref. # 11 the Circulating Water Flow from four pumps with the new impellers is 484,000 GPM. This is a increase above the original design flow of 448,000 GPM given in Ref. # 10 for the condenser. The CW system pressure for EPU will stay at the current values.

EPU PERFORMANCE

Circulating Water Temperature Evaluation

The various EPU heat loads on the LP condenser from Reference No. 1 and 5 are tabulated below:

Description	Flow, lbm/hr	Enthalpy in Btu/lbm	Enthalpy out Btu/lbm	Heat Load, Btu/hr
LP Turbine exhaust	3,135,522	981.3	75.1	2,841,410,036
1/3 RFPT Line Drain	1373 (Ref. #5)	1198.8	75.1	1,542,840
MSIV drains + SJAE supply drain	4090 (Ref. #5)	1190.3	75.1	4,561,168
LP Turb Drains (Z)	74,047	116.8	75.1	3,087,760
1/3 SSR (P-T)	5502.6	1170.7	75.1	6,028,649
1/3 RFPT exh. (O)	81,514	969.3	75.1	72,889,819
OffGas Recomb. Condensate	3365 (Ref. #5)	108.0	75.1	110,708
1/3 RFP HP Seal Drain (N)	1317	375.3	75.1	395,363
1/3 RFP LP Seal (V)	18,770	93.3	75.1	341,614
1st stage SJAE steam (R)	23,198	180.2	75.1	2,438,110
SPE (S)	8,492	180.2	75.1	892,509
Total Heat Load				**2,933,698,576**

The Circulating Water temperature rise in the LP Condenser shell is equal to the heat load / CW flow in lb/Hr. The flow is converted to lb/hr at 95°F for conservatism (gives minimum expected water density at CW pump suction) which results in a water density of 62.06 lb/cu ft. The LP condenser temperature rise is 2,933,698,576/[(484,000 x 60 x 62.06/7.48] = 12.176°F.

The various EPU heat loads on the IP condenser from Reference No. 1 and 5 are tabulated below:

Description	Flow, lbm/hr	Enthalpy in Btu/lbm	Enthalpy out Btu/lbm	Heat Load, Btu/hr
IP Turbine exhaust	3,137,303	985.4	80.2	2,839,886,676
1/3 RFPT Line Drain	1373 (Ref.#5)	1198.8	80.2	1,535,838
RFPT HP steam drain	1573 (Ref. #5)	1190.3	80.2	1,746,187
IP Turb Drains (2)	73,624	117.0	80.2	2,709,363
1/3 SSR (P-T)	5502.6	1170.7	80.2	6,000,585
1/3 RFPT exh. (O)	81,514	969.3	80.2	72,474,097
1/3 RFP HP Seal Drain (N)	1317	375.3	80.2	388,647
1/3 RFP LP Seal (V)	18,770	93.3	80.2	245,887
1/3 FW Htr Drains (M)	2,211,104.7	104.3	80.2	53,287,623
Total Heat Load				**2,978,274,903**

The Circulating Water temperature rise in the IP Condenser shell is equal to the heat load / CW flow in lb/Hr. The IP condenser temperature rise is 2,978,274,903/[(484,000 x 60 x 62.060/7.48] = 12.361°F.

The various EPU heat loads on the HP condenser from Reference No. 1 and 5 are tabulated below:

Description	Flow, lbm/hr	Enthalpy in Btu/lbm	Enthalpy out Btu/lbm	Heat Load, Btu/hr
HP Turbine exhaust	3,143,581	996.5	89.4	2,851,542,325
TB Valve Stem (F)	853	1190.3	89.4	939,068
Main steam and bypass drains	12,142 (Ref. #5)	1190.3	89.4	13,367,128
SJAE Supply Drain	212 (Ref. #5)	1190.3	89.4	233,391
1/3 RFPT Line Drain	1373 (Ref.#5)	1198.8	89.4	1,523,206
HP Turb Seal Leakoff (C+C)	9052	1095.1 (HP EXH)	89.4	9,103,596
HP Turb Drains (3)	74,457	116.8	89.4	2,040,122
1/3 SSR (P-T)	5502.6	1170.7	89.4	5,949,961
1/3 RFPT exh. (O)	81,514	969.3	89.4	71,724,169
1/3 RFP HP Seal Drain (N)	1317	375.3	89.4	376,530
1/3 RFP LP Seal (V) + CRD min flow of 10,000	28,770	93.3	89.4	112,203
2/3 FW Htr Drains (M)	4,422,209	104.3	89.4	65,890,914
Total Heat Load				**3,022,802,613**

Total Condenser Duty = 8,934,776,092 btu/hr

The Circulating Water temperature rise in the HP Condenser shell is equal to the heat load / CW flow in lb/Hr. The HP condenser temperature rise is 3,022,802,613/[(484,000 x 60 x 62.060/7.48] = 12.55°F.

The total CW temperature rise is the total heat load from the three condenser shells plus the SW heat load divided by the total flow (CW+SW) in Lbs/Hr. The total CW temperature rise is also equal to the cooling tower range. The cooling tower performance curves (Ref. # 4) and the range are used to determine the cold water temperature for five wet bulb temperatures at the design 65% RH. The data for the five wet bulb temperatures will be used to determine the wet bulb temperature that produces a HP condenser backpressure of 5.5 " Hga for EPU. This Wet Bulb condition will be used to calculate the evaporation for EPU and to calculate the cooling tower outlet temperature, HP condenser Pressure and evaporation for CLTP. Additional wet bulb temperature values were added to refine the calculation and to evaluate at other conditions resulting from the CLTP section of this calculation. The LP and IP condenser temperature rises are added to the tower outlet temperature to obtain the HP condenser CW inlet temperature. The SW System Calculation (EC-PUPC-20604, Ref. 12) gives a EPU SW heat load of 146.14 MBTU/HR and a flow of 26,936 GPM. Using the cooling tower flow of 511,000 gpm per assumption 5 the cooling tower range is = (8,934,776,092 + 146,140,000)/ [(511,000) x 60 x 62.06/7.48] = 35.7F.

The HP condenser CW inlet temperature is the tower outlet plus the LP and IP rise =12.18 +12.36 = 24.54°F.

Cooling Tower Performance Evaluation

The design basis conditions for the cooling tower, Reference 3 and 4:

WBT = 73°F ; RH = 65% ; Nominal Range 33.7° F

CW flowrate = 451,000 GPM per Ref. # 11.

Temperature Range for EPU = 35.7°F.

The following table contains cooling tower performance data from Ref. #4 at 65% RH and various wet bulb temperatures for a temperature range of 35.7°F which will be used to determine the tower performance at a flow of 511,000 GPM.

Wet Bulb	478,000 GPM Cold Water Temp	Range correct	478,000 GPM Corrected CW Temp	358,500 GPM Cold Water Temp	Range correct	358,500 GPM Corrected CW Temp	ΔT/1000 GPM	511,000 GPM Cold Water Temp (1)
50	72.8	+0.15	72.95	68.5	+0.1	68.6	0.0364	74.1
60	78.8	+0.1	78.9	74.8	+0	74.8	0.0343	80
65	81.8	+0	81.8	78.2	+0	78.2	0.0301	82.8
68.2	83.8	+0	83.8	80.4	+0	80.4	0.02845	84.7
70	85	+0	85	81.6	+0	81.6	0.02845	85.9
75	88.5	+0	88.5	85.2	+0	85.2	0.0276	89.4

Wet Bulb	478,000 GPM Cold Water Temp	Range correct	478,000 GPM Corrected CW Temp	358,500 GPM Cold Water Temp	Range correct	358,500 GPM Corrected CW Temp	ΔT/1000 GPM	511,000 GPM Cold Water Temp (1)
77	89.8	0	89.8	86.4	0	86.4	0.02845	90.7
78	90.5	0	90.5	87.5	0	87.5	0.0251	91.3
80	92	+0	92	89	+0	89	0.0251	92.8

(1) (511-478) (ΔT/1000) + 478,000 CW temp

Based on the Cooling Tower performance data tabulated above for a flow of 511,000 GPM the temperature of the CW returning from the cooling tower (i.e. condenser inlet temperature) temperature for five wet bulb temperatures and the corresponding HP condenser inlet CW temperatures were determined and are listed in the table below. The HP condenser CW outlet temperature is 12.55°F higher than the inlet.

Wet bulb	Tower Outlet Temp	HP Cond. Inlet Temperature
50	74.1	98.6
60	80	104.5
65	82.8	107.3
68.2	84.7	109.2
70	85.9	110.4
75	89.4	113.9
77	90.7	115.2
78	91.3	115.8
80	92.8	117.3

The operating limit for high condenser backpressure alarm is 5.5" HgA. (Ref. # 17) As part of the SSES EPU efforts, turbine operations at a range of wet bulb temperatures is evaluated to determine the wet bulb temperature that corresponds to a HP condenser pressure of 5.5" HgA.

HP Condenser Vacuum Evaluation

Since the HP condenser will be the first one to reach a vacuum alarm or trip set point it will be evaluated for vacuum. The HP condenser vacuum conditions also establish the condensate temperature. The condenser vacuum and condenser discharge CW temperature will be evaluated at wet bulb temperatures ranging from 60 to 80°F to produce a tabulation of vacuum temperature vs wet bulb temperature.

Using the design circulating water inlet temperature of 87 °F (Ref. # 10), the following evaluation is used to determine the temperature of the condensing steam from which the saturation pressure of condensation can be determined. The HP condenser inlet CW temperature with a starting CW temperature of 87 °F is 87 °F plus the CW rise in the LP and IP condensers (87 + 24.5 = 111.5°F)

$$T_{sat} = [111.5 - (111.5+T_{CW\Delta})\exp^{(UA/(500Q))}] / (1-\exp^{(UA/(500Q))})$$

In this equation, $T_{CW\Delta}$ is the circulating water temperature rise across the HP condenser, U is the condenser overall heat transfer coefficient that must be adjusted for circulating water inlet temperature, tube material properties and cleanliness, A is the surface area and Q is the circulating water flow rate.

A cleanliness of 85% will be used for the evaluation. This is an assumed value and is more representative of an operating condition than the 95% cleanliness listed in Ref. # 10.

Calculate the tube velocity for the 4 CW pump operation with the cooling tower to determine the condenser U

Reference no. 2 provides the following tube data: 28,040, 1.0" 304 SS tubes of 22 BWG

22 BWG = 0.028" wall thickness Tube ID = 0.944" $A = 3.14\ D^2/(4 \times 144) = 0.00486$ sq ft

Velocity = {484,000/(60 x 7.48)}/[(28,040) x .00486] = 7.9 fps

U is equal to 740, obtained from Figure 3 of Reference no. 6. Correction factors for tube material and gage of 0.79 from Table 1 of Reference no.6 and for circulating water inlet temperature correction factor of 1.13 (@111.5°F) from figure 2 of Reference no. 6 are applied to U (740 x 0.79 x 1.13) to yield a U of 660.

Temperature corrections and U values for other CW temperatures

CW Inlet temperature	Temperature correction	U value	85% clean U value
98.6	1.1	643	546.5
104.5	1.115	651.8	554
107.3	1.12	654.7	556.5
109.2	1.12	654.7	556.5
110.4	1.125	657.6	559
113.9	1.13	660.6	561.5
115.2	1.13	660.6	561.5
115.8	1.13	660.6	561.5
117.3	1.14	666.4	566.5

A is equal to 367,000 ft^2 (Ref. # 8). Assuming 1% plugged tubes reduces the area to (0.99) x A = 363,330 ft^2. Q is equal to 484,000 GPM.

@ 98.6 F, 85% clean, UA/500Q = 0.820

T_{sat} = [98.6 - (98.6+12.55)$e^{(0.820)}$] / (1-$e^{(0.820)}$) = [98.6 - (111.15)(2.27)] / (1-2.27) = 121.0°F

@ 104.5 F, 85% clean, UA/500Q = 0.832

T_{sat} = [104.5 - (104.5+12.55)$e^{(0.632)}$] / (1-$e^{(0.832)}$) = [104.5 - (117.05)(2.30)] / (1-2.30) = 126.7°F

@ 107.3 F, 85% clean, UA/500Q = 0.836

T_{sat} = [107.3 - (107.3+12.55)$e^{(0.836)}$] / (1-$e^{(0.836)}$) = [107.3 - (119.85)(2.31)] / (1-2.31) = 129.4°F

@ 109.2 F, 85% clean, UA/500Q = 0.835

T_{sat} = [109.2 - (109.2+12.55)$e^{(0.835)}$] / (1-$e^{(0.835)}$) = [109.2 - (121.75)(2.30)] / (1-2.30) = 131.4°F

@ 110.4 F, 85% clean, UA/500Q = 0.839

T_{sat} = [110.4 - (110.4+12.55)$e^{(0.839)}$] / (1-$e^{(0.639)}$) = [110.4 - (122.95)(2.31)] / (1-2.31) = 132.5°F

@ 113.9 F, 85% clean, UA/500Q = 0.843

T_{sat} = [113.9 - (113.9+12.55)$e^{(0.843)}$] / (1-$e^{(0.843)}$) = [113.9 - (126.45)(2.32)] / (1-2.32) = 136.0°F

@ 115.2 F, 85% clean, UA/500Q = 0.843

T_{sat} = [115.2 - (115.2+12.55)$e^{(0.843)}$] / (1-$e^{(0.843)}$) = [115.2 - (127.75)(2.32)] / (1-2.32) = 137.3°F

@ 115.8 F, 85% clean, UA/500Q = 0.843

T_{sat} = [115.8 - (115.8+12.55)$e^{(0.843)}$] / (1-$e^{(0.843)}$) = [115.8 - (128.35)(2.32)] / (1-2.32) = 137.9°F

@ 117.3 F, 85% clean, UA/500Q = 0.850

T_{sat} = [117.3 - (117.3+12.55)$e^{(0.850)}$] / (1-$e^{(0.850)}$) = [117.3 - (129.85)(2.34] / (1-2.34) = 139.2°F

Wet Bulb Temperature	EPU Operation		
	CW Temperature	T_{SAT}	HP Condenser Backpressure in HgA
50	98.6	121.0	3.5
60	104.5	126.7	4.15
65	107.3	129.4	4.47
68.2	109.2	131.4	4.71
70	110.4	132.5	4.85
75	113.9	136.0	5.32
77	115.2	137.3	5.49
78	115.8	137.9	5.59
80	117.3	139.2	5.77

The backpressure limit is reached for EPU with a wet bulb temperature of 77°F

Water Discharge Temperature to the Susquehanna River

To maintain the CW quality within acceptable limits, a portion of the CW flow is discharged to the Susquehanna River as blowdown. The blowdown is taken from the tower basin (cold side) and is discharged through a sparger pipe to the river. The NPDES permit (Ref. # 13) does not establish discharge flow or temperature limits for outfall 071 (cooling tower blowdown) and therefore EPU has no impact on the present discharge limits.

Evaporation and blowdown quantities at EPU

Ref. # 4 indicates an evaporation rate of 3.08% of the cooling tower flow at EPU for 65% RH and 77 F wet bulb with a range of 35.7°F. This results in an evaporation rate of 15,739 GPM for EPU. Ref. # 14 states that the blowdown rate equals [evaporation / (concentration factor – 1)] – drift. Ref. # 14 gives a concentration factor of 3.7 and a value of 0.02% for drift. At 511,000 GPM the drift loss is 102 GPM and the blowdown rate is 5727 GPM. This is equal to a make-up water requirement of 21,568 GPM at EPU.

The cycles of concentration is confirmed using the following formulae from Ref. #16.

$(1-1/F) = V_E/V_M$

Where F = cycles of concentration

V_E = Evaporation losses

V_M = Make-up

$V_E/V_M = 15{,}739/21{,}568 = 0.73$

$(1-1/F) = 0.73$

$-1/F = -0.27$ $F = 3.70$

CLTP PERFORMANCE

Circulating Water Temperature Evaluation

The CLTP heat load on the LP condenser from Reference No. 5 is 2,563,303,214 btu/hr.

The Circulating Water temperature rise in the LP Condenser shell is equal to the heat load / CW flow in lb/Hr. The flow is converted to lb/hr at 95°F for conservatism (gives minimum expected water density at CW pump suction) which results in a water density of 62.06 lb/cu ft. The LP condenser temperature rise is 2,563,303,214/[(484,000 x 60 x 62.06/7.48] = 10.64°F.

The CLTP heat load on the IP condenser from Reference No. 5 is 2,600,125,593 btu/hr.

The Circulating Water temperature rise in the IP Condenser shell is equal to the heat load / CW flow in lb/Hr. The IP condenser temperature rise is 2,600,125,593/[(484,000 x 60 x 62.060/7.48] = 10.79°F.

The CLTP heat load on the HP condenser from Reference No. 5 is 2,628,514,817 btu/hr.

The Circulating Water temperature rise in the HP Condenser shell is equal to the heat load / CW flow in lb/Hr. The HP condenser temperature rise is 2,628,514,817/[(484,000 x 60 x 62.060/7.48] = 10.91°F.

Total Condenser Duty = 7,791,943,624 btu/hr

The total CW temperature rise is the total heat load from the three condenser shells plus the SW heat load divided by the total flow (CW+SW) in Lbs/Hr. The total CW temperature rise is also equal to the cooling tower range. The cooling tower performance curves (Ref. # 4) and the range are used to determine the cold water temperature for five wet bulb temperatures at the design 65% RH. The LP and IP condenser temperature rises are added to the tower outlet temperature to obtain the HP condenser CW inlet temperature. The SW System CLTP heat load is 141.8 MBTU/HR and a flow of 26,008 GPM (Ref. #12). The cooling tower temperature range is = (7,791,943,624 + 141,800,000)/ [(484,000 + 26,008) x 60 x 62.06/7.48] = 31.2F.

The HP condenser CW inlet temperature is the tower outlet plus the LP and IP rise =10.64+10.79 = 21.43°F.

Cooling Tower Performance Evaluation

The design basis conditions for the cooling tower, Reference no. 3 and 4:

WBT = 73°F ; RH = 65% ; Nominal Range 33.7° F

CW flowrate = 451,000 GPM per Ref. # 11.

Temperature Range for CLTP = 31.2°F

The following table contains cooling tower performance data from Ref. #4 at 65% RH and various wet Bulb temperatures for a temperature range of 31.2 F which will be used to determine the tower performance at a flow of 510,000 GPM.

Wet Bulb	478,000 GPM Cold Water Temp	Range correct	478,000 GPM Corrected CW Temp	358,500 GPM Cold Water Temp	Range correct	358,500 GPM Corrected CW Temp	ΔT/1000 GPM	510,000 GPM Cold Water Temp (1)
50	72.8	-0.3	72.5	68.5	-0.2	68.3	0.0351	73.6
60	78.8	-0.2	78.6	74.8	-0.1	74.7	0.0326	79.6
65	81.8	-0.1	81.7	78.2	+0	78.2	0.0293	82.6
70	85	+0	85	81.6	+0	81.6	0.02845	85.9
75	88.5	+0	88.5	85.2	+0	85.2	0.0276	89.4
77	89.8	+0.1	89.9	86.7	+0.1	86.8	0.0259	90.7
80	92	+0.1	92.1	89	+0.1	89.1	0.0251	92.9

(1) (510-478) (ΔT/1000) + 478,000 CW temp

Based on the Cooling Tower performance data tabulated above for a flow of 510,000 GPM the CW returning from the cooling tower (i.e. condenser inlet temperature) temperature for five wet bulb temperatures and the corresponding HP condenser inlet CW temperatures were determined and are listed in the table below. The HP condenser CW outlet temperature is 10.91°F higher than the inlet.

Wet bulb	Tower Outlet Temp	HP Cond. Inlet Temperature
50	73.6	95.03
60	79.6	101.03
65	82.6	104.03
70	85.9	107.33
75	89.4	110.83
77	90.7	112.13
80	92.9	114.33

CLTP condenser performance is calculated at the maximum EPU operating wet bulb temperature of 77 F and at a range of wet bulb temperatures to determine the wet bulb temperature that produces a condenser pressure of 4.05" HgA.

HP Condenser Vacuum Evaluation

Since the HP condenser will be the first one to reach a vacuum alarm or trip set point it will be evaluated for vacuum. The HP condenser vacuum conditions also establish the condensate temperature. The condenser vacuum and condenser discharge CW temperature will be evaluated at wet bulb temperatures ranging from 50 to 80°F to produce a tabulation of vacuum temperature vs wet bulb temperature that will be used to determine the wet bulb that produces a HP condenser pressure of 4.05"HgA.

Using the Maximum Wet Bulb temperature of 77F determined for EPU and the associated cooling tower outlet temperature of 90.7F design, the following evaluation is used to determine the temperature of the condensing steam from which the saturation pressure of condensation can be determined. The HP condenser inlet CW temperature with a starting CW temperature of 90.7 °F is 90.7 °F plus the CW rise in the LP and IP condensers (90.7 + 21.43 = 112.13°F)

$$T_{sat} = [112.13 - (112.13+T_{CW\Delta})\exp^{(UA/(500Q))}] / (1-\exp^{(UA/(500Q))})$$

In this equation, $T_{CW\Delta}$ is the circulating water temperature rise across the HP condenser, U is the condenser overall heat transfer coefficient that must be adjusted for circulating water inlet temperature, tube material properties and cleanliness, A is the surface area and Q is the circulating water flow rate.

A cleanliness of 85% was used for the EPU calculation and will also be used for the CLTP calculation.

The tube velocity value calculated for EPU (7.90 fps) also applies to CLTP.

U is equal to 740, obtained from Figure 3 of Reference no. 6. Correction factors for tube material and gage of 0.79 from Table 1 of Reference no. 6 and for circulating water inlet temperature correction factor of 1.125 (@112.13°F) from figure 2 of Reference no. 6 are applied to U (740 x 0.79 x 1.125) to yield a U of 658.

Temperature corrections and U values for other CW temperatures

CW Inlet temperature	Temperature correction	U value	85% clean U value
95.03	1.09	637.2	541.6
101.03	1.1	643.1	546.6
104.03	1.11	648.9	551.6
107.33	1.12	654.8	556.6
110.83	1.125	657.7	559.0
112.13	1.125	657.7	559.0
114.33	1.13	660.6	561.5

A is equal to 367,000 ft^2 (Ref. # 8). Assuming 1% plugged tubes reduces the area to (0.99) x A = 363,330 ft^2. Q is equal to 484,000 GPM.

@ 95.03 F, 85% clean, UA/500Q = 0.813

T_{sat} = [95.03 - (95.03+10.91)$e^{(0.813)}$] / (1-$e^{(0.813)}$) = [95.03 - (105.94)(2.25)] / (1-2.25) = 114.7°F

@ 101.03 F, 85% clean, UA/500Q = 0.821

T_{sat} = [101.03 - (101.03+10.91)$e^{(0.821)}$] / (1-$e^{(0.821)}$) = [101.03 - (111.94)(2.27)] / (1-2.27) = 120.5°F

@ 104.03 F, 85% clean, UA/500Q = 0.828

T_{sat} = [104.03 - (104.03+10.91)$e^{(0.828)}$] / (1-$e^{(0.828)}$) = [104.03 - (114.94)(2.29)] / (1-2.29) = 123.4°F

@ 107.33 F, 85% clean, UA/500Q = 0.836

T_{sat} = [107.33 - (107.33+10.91)$e^{(0.836)}$] / (1-$e^{(0.836)}$) = [107.33 - (118.24)(2.31)] / (1-2.31) = 126.6°F

@ 110.83 F, 85% clean, UA/500Q = 0.839

T_{sat} = [110.83 - (110.83+10.91)$e^{(0.839)}$] / (1-$e^{(0.839)}$) = [110.83 - (121.74)(2.31)] / (1-2.31) = 130.1°F

@ 112.13 F, 85% clean, UA/500Q = 0.839

T_{sat} = [112.13 - (112.13+10.91)$e^{(0.839)}$] / (1-$e^{(0.839)}$) = [112.13 - (123.04)(2.31] / (1-2.31) = 131.4°F

@ 114.33 F, 85% clean, UA/500Q = 0.843

T_{sat} = [114.33 - (114.33+10.91)$e^{(0.843)}$] / (1-$e^{(0.843)}$) = [114.33 - (125.24)(2.32] / (1-2.32) = 133.5°F

Wet Bulb Temperature	CLTP Operation		
	CW Temperature	T_{SAT}	HP Condenser Backpressure in hga
50	95.03	114.7	2.97
60	101.03	120.5	3.51
65	104.03	123.4	3.79
70	107.33	126.6	4.2
75	110.83	130.1	4.5
77	112.13	131.4	4.70
80	114.33	133.5	4.97

By inspection a wet bulb temperature of 68.2 will provide a condenser back pressure of 4.05 in. HgA.

Evaporation and blowdown quantities for CLTP at Maximum Avg Backpressure of 4.05" HgA

Ref. # 4 indicates a evaporation rate of 2.55% of the cooling tower flow at CLTP for 65% RH, 31.2 F range, and 68.2 F wet bulb. This results in an evaporation rate of 13,005 GPM for CLTP. Ref. # 14 states that the blowdown rate equals [evaporation /(concentration factor – 1)] – drift. Ref. # 14 gives a concentration factor of 3.7 and a value of 0.02% for drift. At 510,000 GPM the drift loss is 102 GPM and the blowdown rate is 4715 GPM. This is equal to a make-up water requirement of 17,822 GPM at CLTP. The water consumption (Evaporation + drift) is 13,107 GPM

The cycles of concentration is confirmed using the following formulae from Ref. #16.

$(1-1/F) = V_E/V_M$

Where F = cycles of concentration

V_E = Evaporation losses

V_M = Make-up

$V_E/V_M = 13{,}005/17{,}822 = 0.73$

$(1-1/F) = 0.73$

$-1/F = -0.27$ $F = 3.70$

EPU values for operation at the same average wet bulb that produces an average backpressure of 4.05 at CLTP

Ref. # 4 indicates an evaporation rate of 2.95% of the cooling tower flow at EPU for 65% RH, 35.7°F range, and 68.2°F wet bulb. This results in an evaporation rate of 15,074 GPM for EPU. Ref. # 14 states that the blowdown rate equals {evaporation / (concentration factor – 1)] – drift. Ref. # 14 gives a concentration factor of 3.7 and a value of 0.02% for drift. At 511,000 GPM the drift loss is 102 GPM and the blowdown rate is 5481 GPM. This is equal to a make-up water requirement of 20,657 GPM at EPU. The water consumption (Evaporation + drift) is 15,176 GPM

The increase in consumptive water usage due to EPU at 68.2°F WB may therefore be approximated as (15,176 gpm / 13,107 gpm) or 15.8% and the consumptive water for both units at SSES at EPU conditions and 68.2°F WB is 15,176 x 60 min/hr x 24 hr/day x 2 units = 43.7 MGD

Evaporation and blowdown quantities for CLTP at a wet bulb of 77°F

Ref. # 4 indicates a evaporation rate of 2.67% of the cooling tower flow at CLTP for 65% RH, 31.2 F range, and 77 F wet bulb. This results in an evaporation rate of 13,617 GPM for CLTP. Ref. # 14 states that the blowdown rate equals [evaporation /(concentration factor – 1)] – drift. Ref. # 14 gives a concentration factor of 3.7 and a value of 0.02% for drift. At 510,000 GPM the drift loss is 102 GPM and the blowdown rate is 4941 GPM. This is equal to a make-up water requirement of 18,660 GPM at CLTP. The water consumption (Evaporation + drift) is 13,719 GPM.

6.0 RESULTS

Operating Parameters for the cooling tower/condenser system for both CLTP and EPU were calculated for two wet bulb conditions. These are the average wet bulb condition that results in a maximum 30 day average condenser back pressure of 4.05" HgA at CLTP and the wet bulb temperature that results in a condenser back pressure of 5.5" HgA at EPU conditions. This data is summarized in the following tables:

Operation at the wet bulb that produces a EPU backpressure of 5.5"HgA or less

Operating Condition	Wet Bulb °F	HP Condenser Pressure "HgA	Cooling Tower Cold Water °F	Condensate Temperature °F	Make-up Flow GPM/unit
CLTP	77	4.70	90.7	131.4	18,660
EPU	77	5.49	90.7	137.3	21,568
Change	0	0.79	0	5.9°	2908

Operation at the wet bulb that produces a CLTP backpressure of 4.05 " HgA

Operating Condition	Wet Bulb °F	HP Condenser Pressure " HgA	Cooling Tower Cold Water °F	Condensate Temperature °F	Average Water Consumption GPM/unit
CLTP(1)	68.2	4.05	84.7	125.4	13,107
EPU	68.2	4.71	84.7	131.4	15,176
Change	0	0.66	0	6.0°	2069

(1) CLTP from interpolation between 65F and 70F WB values

ATTACHMENT 1: PUSAR INPUT

6.4.2 Main Condenser/Circulating Water/Normal Heat Sink Performance

(Note: The published version of the PUSAR may contain editorial/non-technical changes from the inputs shown herein. Those editorial/non-technical changes will be verified under EPU task 1104, and thus, do not require a revision to this task report attachment.)

The main condenser, circulating water, and normal heat sink (cooling tower) systems are designed to remove the heat rejected to the condenser and thereby maintain the condenser backpressure as recommended by the turbine vendor. Maintaining adequately low condenser pressure assures the efficient operation of the turbine-generator and minimizes vibratory stress on the turbine last stage blades.

CPPU operation increases the heat rejected to the condenser and, therefore, reduces the difference between the operating pressure and the recommended maximum condenser pressure. The maximum condenser operating pressure has been established to limit the condensate temperature entering the condensate demineralizers. If condenser pressures approach this maximum limit, a reactor thermal power reduction would be required thereby reducing the heat rejected to the condenser and maintaining condenser pressure and condensate demineralizer inlet temperatures within established limits.

The main condenser, circulating water, and heat sink systems are not being modified for CPPU operation. The thermal performance of these systems was evaluated for CPPU. This evaluation was based on the 100% CPPU power design duty over the actual range of circulating water inlet temperatures, and confirms that the condenser, circulating water system, and cooling tower (heat sink) are adequate for CPPU operation. The evaluation of the circulating water system at CPPU conditions indicates sufficient system capacity to ensure that the plant maintains adequate condenser backpressure while meeting all environmental permit conditions related to the plant cooling towers. The effect of CPPU on the flooding analyses is addressed in Section 10.1.2. Current condensate temperature limitations may require load reductions at the upper range of the anticipated circulating water inlet temperatures.

APPENDIX A – Additional Analysis in support of SRBC Applications

Purpose and Scope:

This APPENDIX A to the calculation provides an additional analysis needed to support submittal of a post-EPU Consumptive Water Use Application and/or a post-EPU Surface Water Withdrawal Application to the Susquehanna River Basin Commission (SRBC).

Specifically, this APPENDIX A provides analysis that estimates post-EPU maximum daily consumptive water use and maximum daily total water withdrawal from the Susquehanna River for SSES Units 1 and 2 based on the original cooling tower performance data and conservative environmental input parameters. Use of these conservative environmental input parameters (i.e., 77 °F Wet Bulb and 40% Relative Humidity) is intended to produce maximum consumptive water use and water withdrawal estimates from the Susquehanna River post-EPU.

Analysis:

The following definitions apply to this analysis:

- Consumptive Water Use = cooling tower evaporative loss + cooling tower drift loss.
- Total Water Withdrawal = Consumptive Water Use + cooling tower blowdown.

All other potential uses of river water at SSES are assumed inconsequential to this analysis.

Previously in this calculation, post-EPU cooling tower evaporative losses, drift losses, and blowdown where estimated (see page 14, **Evaporative and blowdown quantities at EPU**) via Ref. # 4, SH. 0101 based on the following input data:

- post-EPU cooling tower water flow rate = 511,000 gpm (as previously documented in this calculation).
- post-EPU cooling tower range = 35.7 °F (as previously documented in this calculation).
- concentration factor = 3.7 (as previously documented in this calculation).
- ambient wet bulb temperature (WBT) = 77 °F (approximate WBT resulting in a HP condenser back pressure of 5-1/2 In.Hga at analyzed EPU conditions; as previously determined in this analysis).
- ambient relative humidity = 65% (cooling tower design parameter).

With the above inputs, the cooling tower losses/blowdown were determined to be:

- evaporative loss per tower = 511,000 gpm x 0.0308 = 15,739 gpm.
- drift loss per tower = 511,000 gpm x 0.0002 = 102 gpm.
- blowdown per tower = [15,739 / (3.7 – 1)] – 102 = 5,727 gpm.

Thus,

- Total Consumptive Use per tower = 15,739 + 102 = 15,841 gpm.
- Total Water Withdrawal per tower = 15,841 + 5,727 = 21,568 gpm.

In order to interject additional conservatism, another post-EPU analysis of cooling tower losses will be made assuming a lower (more conservative) relative humidty of 40% with all other inputs remaining unchanged. Thus, for this (more conservative) case:

- post-EPU cooling tower water flow rate = 511,000 gpm (as previously documented in this calculation).
- post-EPU cooling tower range = 35.7 °F (as previously documented in this calculation).
- concentration factor = 3.7 (as previously documented in this calculation).
- ambient wet bulb temperature (WBT) = 77 °F (approximate WBT resulting in a HP condenser back pressure of 5-1/2 In.Hga at analyzed EPU conditions; as previously determined in this analysis).
- ambient relative humidity = 40% (lower (more conservative) value assumed in order to maximize evaporative losses; see NOTE 1, below).

Again, Cooling Tower Performance Curve FF105590, SH. 0101, Rev. 2 by RESEARCH-COTTRELL, INC. (Reference 4) is used to determine the cooling tower evaporative losses. For graphical interpretation and completeness purposes, the original Cooling Tower Performance Curve (FF105590, SH. 0101, Rev. 2) has been revised by PPL to include an additional cooling tower water flow rate data line for 511,000 gpm (see FF105590, SH. 0101, Rev. 3; graphic in lower, left-hand quadrant). 511,000 gpm is the anticipated maximum cooling tower water flow rate at post-EPU operating conditions. The end points of this 511,000 gpm data line are determined as follows:

- at an evaporation rate of 1.4% of water flow (see FF105590, SH. 0101, Rev. 3; horizontal axis of graphic in upper, left-hand quadrant), the evaporation loss per tower expressed in gpm = 0.014 x 511,000 gpm = 7,154 gpm.
- at an evaporation rate of 4.0% of water flow, the evaporation loss per tower expressed in gpm = 0.04 x 511,000 gpm = 20,440 gpm.

1

NOTE 1:
As stated above, the intent of this evaluation is to estimate a daily, maximum post-EPU cooling tower evaporative loss by selecting a low (40%) relative humidity in conjunction with a high (77 °F) WB temperature. These selected environmental conditions are considered to be conservative, particularly when considering the high dry bulb (DB) temperature that would have to exist for a continuous 24 hour period at these conditions (i.e., approximately 97.5 °F DB, see standard ASHRAE Psychrometric Chart at 29.92 IN.Hga). On the other end of the environmental spectrum (i.e., colder weather operation), it should be realized that even though relative humidities less than 40% are attainable, the concurrent colder WB temperatures produce lower tower evaporative losses. This conclusion is supported by Table 2 of PPL Calculation EC-041-0508 (Reference 14).

Based on the above data (i.e., WBT, relative humidity, and cooling tower range) and the Cooling Tower Performance Curve, the cooling tower evaporation loss expressed as a percentage of cooling tower water flow rate is 3.22%. Thus, the evaporative loss per cooling tower expressed in gpm is:

evaporative loss per tower = 511,000 gpm x 0.0322 = 16,454 gpm.

As previously determined in this analysis, the cooling tower drift loss is approximated as 0.02% of the tower water flow. Thus, the drift loss per cooling tower is:

drift loss per tower = 511,000 gpm x 0.0002 = 102 gpm.

As previously determined in this analysis, cooling tower blowdown is approximated as:

blowdown per tower = [evaporation / (concentration factor – 1)] – drift.

Assuming a concentration factor = 3.7 (as previous assumed in this analysis) the blowdown becomes:

blowdown per tower = [16,454 / (3.7 – 1)] – 102 = 5,992 gpm.

Thus, this more conservative estimate of post-EPU consumptive water use and total water withdrawal at SSES is:

consumptive water use per tower = cooling tower evaporative loss + cooling tower drift loss = 16,454 + 102 = 16,556 gpm, and

total water withdrawal per tower = consumptive water use + cooling tower blowdown = 16,556 + 5,992 = 22,548 gpm.

For both units at SSES,

- consumptive water use = 2 x 16,556 = 33,112 gpm x 60 min/hr x 24 hr/day = 47.7 x 10^6 gal/day.
- blowdown = 2 x 5,992 = 11,984 gpm x 60 min/hr x 24 hr/day = 17.3 x 10^6 gal/day.
- total water withdrawal = consumptive water use + blowdown = 47.7 x 10^6 + 17.3 x 10^6 = 65.0 x10^6 gal/day.

Conclusions:

Based on the above analysis, the following post-EPU results are determined:

For both units at SSES,

- consumptive water use = 47.7 x 10^6 gal/day.
- blowdown = 17.3 x 10^6 gal/day.
- total water withdrawal = 65.0 x 10^6 gal/day.

These results are believed to be conservative and represent maximum anticipated daily values.