Cooling Towers Real Time Performance Monitoring

EPRI Cooling Tower Technology Conference - 2018

Jeff Marion – Exelon
Greg Alder – Curtiss-Wright

Exelon Generation®

Cooling Tower Purpose

- Remove heat from circulating water system
- Principal of operation:

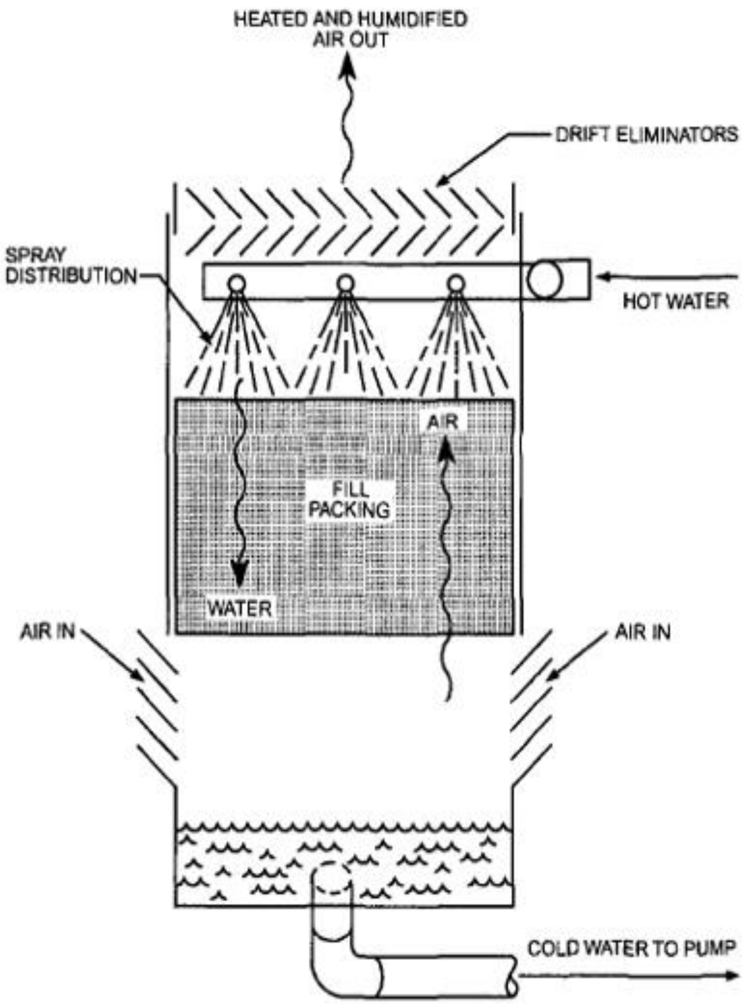
  Use cool air flow to remove sensible and latent heat from circulating water by heat transfer and evaporation

  Air is heated as it passes through the circulating water spray decreasing density and providing buoyancy to maintain flow (natural draft) or fans (mechanical draft) are used to push or pull air through the tower
- Types:

  Natural Draft Cooling Tower

  Mechanical Draft Cooling Tower

Cooling Tower Operational Theory



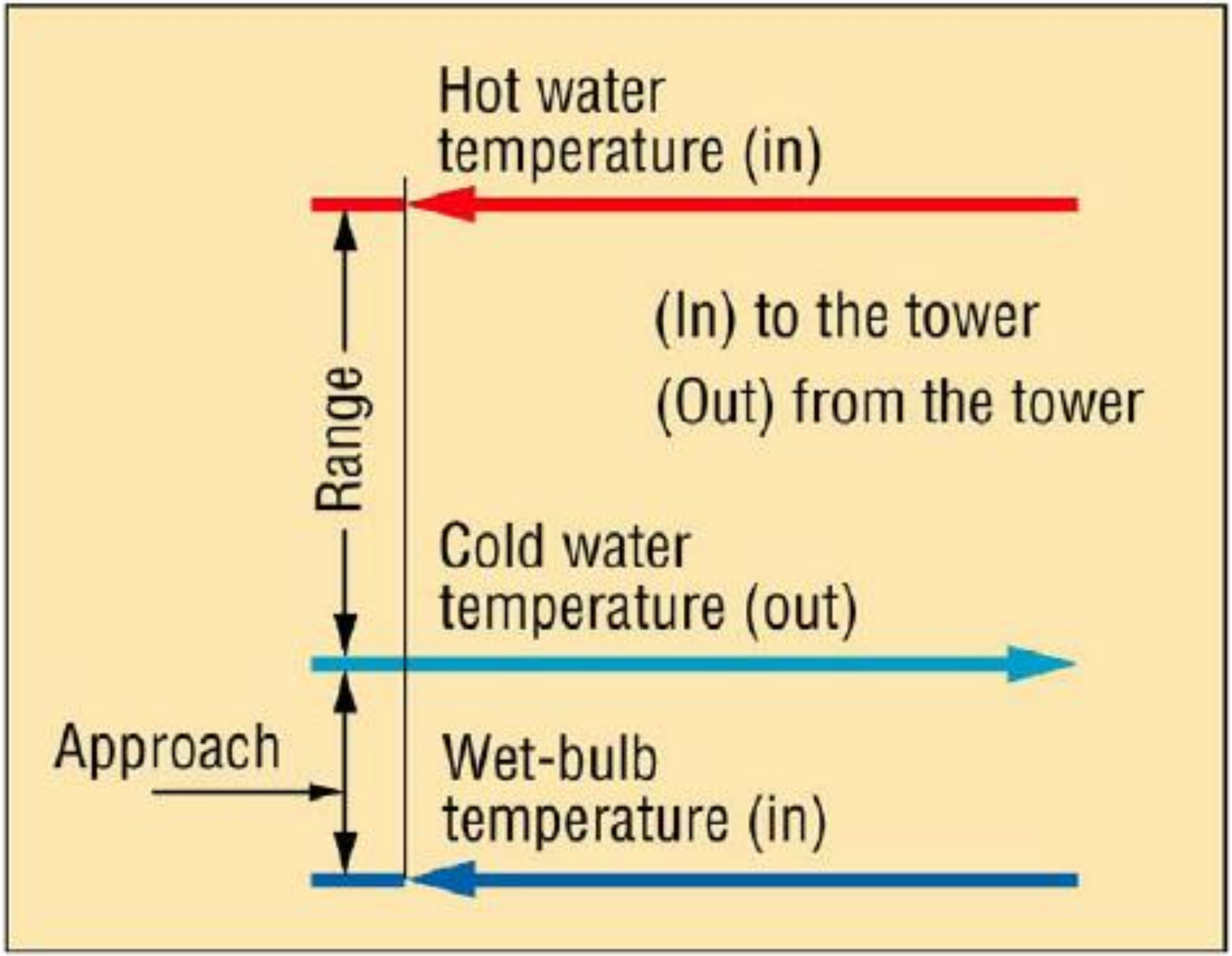
A cooling tower is a heat exchanger where two fluids (air and water) are brought into direct contact.

The heat gained by the air equals the heat lost by the water

$G(h_2 - h_1) = L(t_1 - t_2)$

- G = Mass flow of dry air lbm/min
- h_1 = Enthalpy of entering air btu/lbm (dry air)
- h_2 = Enthalpy of leaving air btu/lbm (dry air)
- L= Mass flow of water lb/min
- t_1 = Hot water temperature entering tower
- t_2 = cold water temperature leaving tower

Cooling Tower Temperature Relationships



Cooling Tower Performance Calculation – Input Parameters

- WBT (Wet Bulb Temperature)
- DBT (Dry Bulb Temperature)
- RH (Relative Humidity)
- CWT (Cold Water Temperature)
- HWT (Hot Water Temperature)
- CW Flow (Circulating Water)
- Fan Horse Power

> When RH = 100%, the air is not able to hold any more water and so water will not evaporate in 100% humid air (WBT = . DBT). But when the RH is less than 100%, the WBT will be less than the DBT and water will evaporate.

Performance Calculation Results & Definitions

- Cooling Tower Range = HWT minus CWT
- Cooling Tower Approach = CWT minus WBT
  - lower is better; good parameter to trend
  - approach changes are inverse to airflow passing through tower
    - airflow in natural draft towers is a function of buoyancy from air density delta between inside to outside of tower
- Predicted CW Flow
  - obtained from manufacturer design curves and input parameters
- Capability = Ratio of actual and predicted CW flow
  - actual flow corrected for fan power in mechanical draft towers
- Predicted CWT
  - obtained from manufacturer design curves and input parameters
- Generation Impact
  - difference in generation based upon actual and predicted CWTs

Cooling Tower Capability

- The capability is an indicator of how close the tower is able to bring the CWT to the WBT of the incoming air (lower approach).
- A larger cooling tower [i.e. moves more air and/or has more fill] will produce a lower approach for a given heat load, flow rate and entering air condition.
- The lower the WBT (indicates either cool air, low humidity or a combination of the two) the better the tower can cool the water.
  - the thermal performance of the cooling tower is thus affected by the entering WBT

Cooling Tower Predicted CW Flow and Temperatures

- Obtained using set of manufacturers performance curves
- Curve outputs include:
  - CWT
- Curve inputs include:
  - WBT
  - Range
  - RH

The Following Slides Show Step by Step How to Calculate Predicted CW Flow and Capability

Step 1: Collect Curve Input Data (test or real-time)

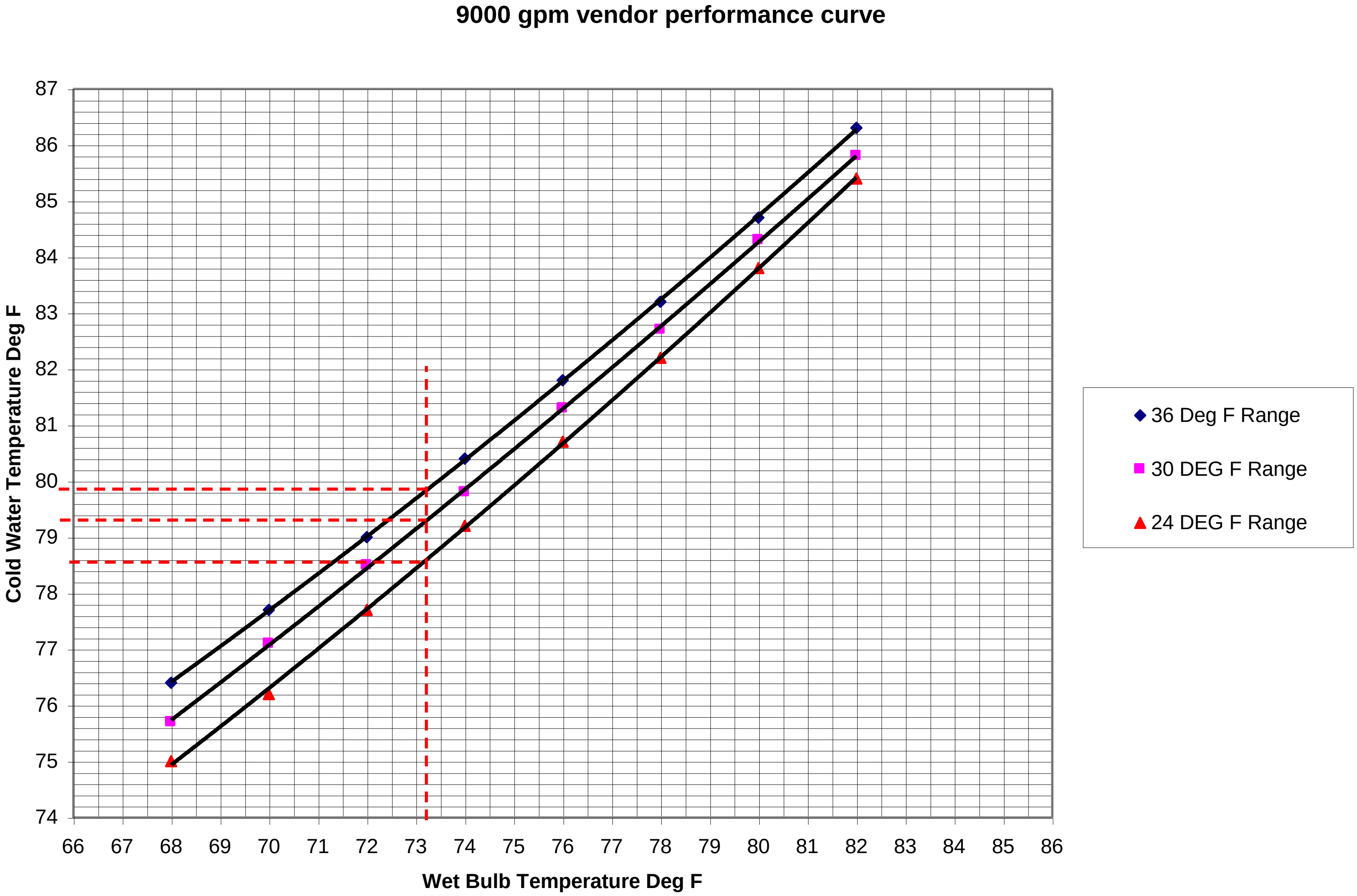
Step 1: Test Data		
Parameter	Reading	Units
Flow	9500	gpm
CWT	85	Deg F
WBT	79.8	Deg F
Range	28	Deg F
Fan Power	110	HP

Step 2: Read Predicted Values from Curves

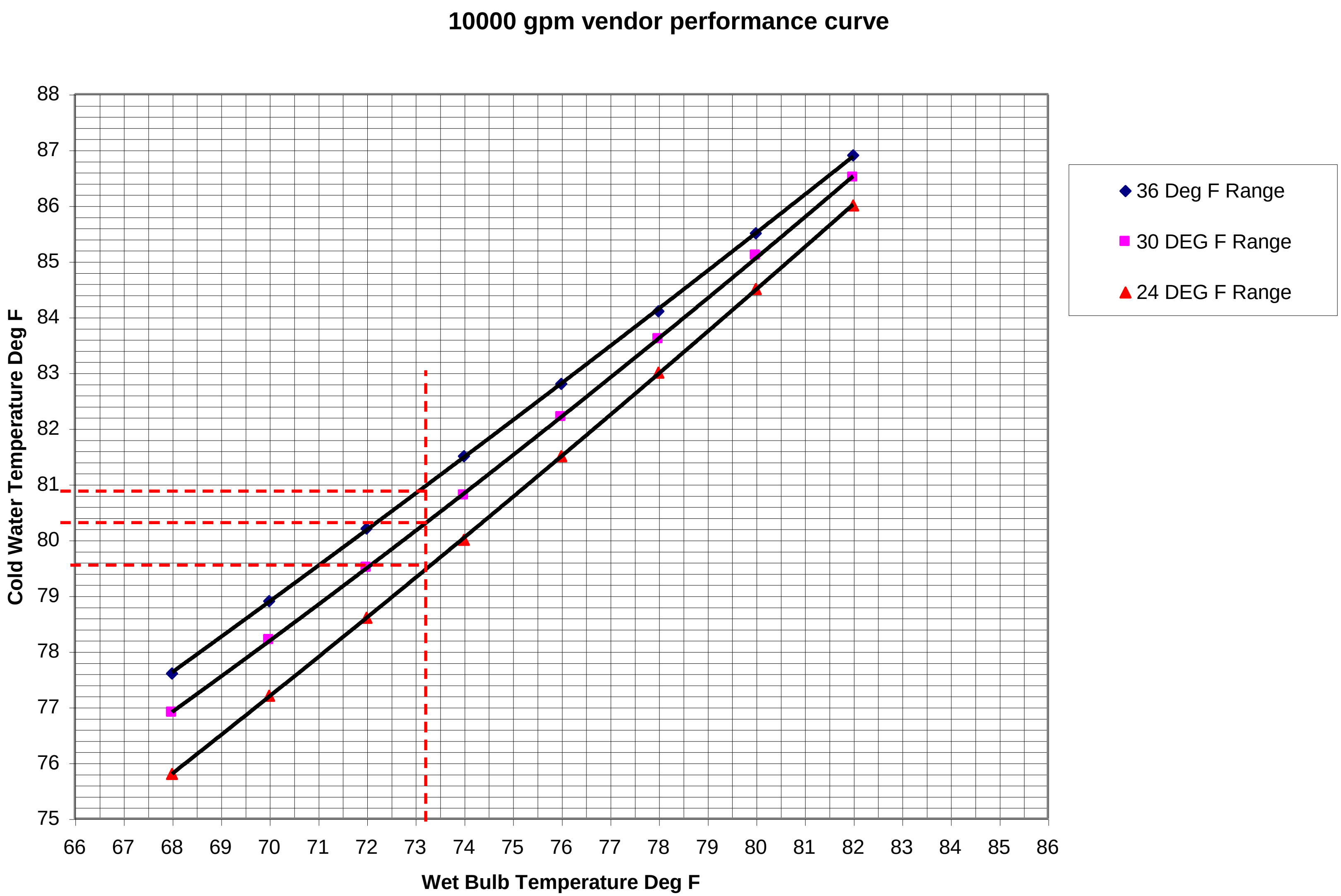
Step 2: Read Predicted Values From Vendor Supplied Performance Curves at Measured Wet Bulb Temperature and CW Flows

Step 2 Plot Perf. Curve Data			
Range	**9000**	**10000**	**11000**
24	83.9	84.5	85.0
30	84.3	85.1	85.9
36	84.5	85.2	86.4

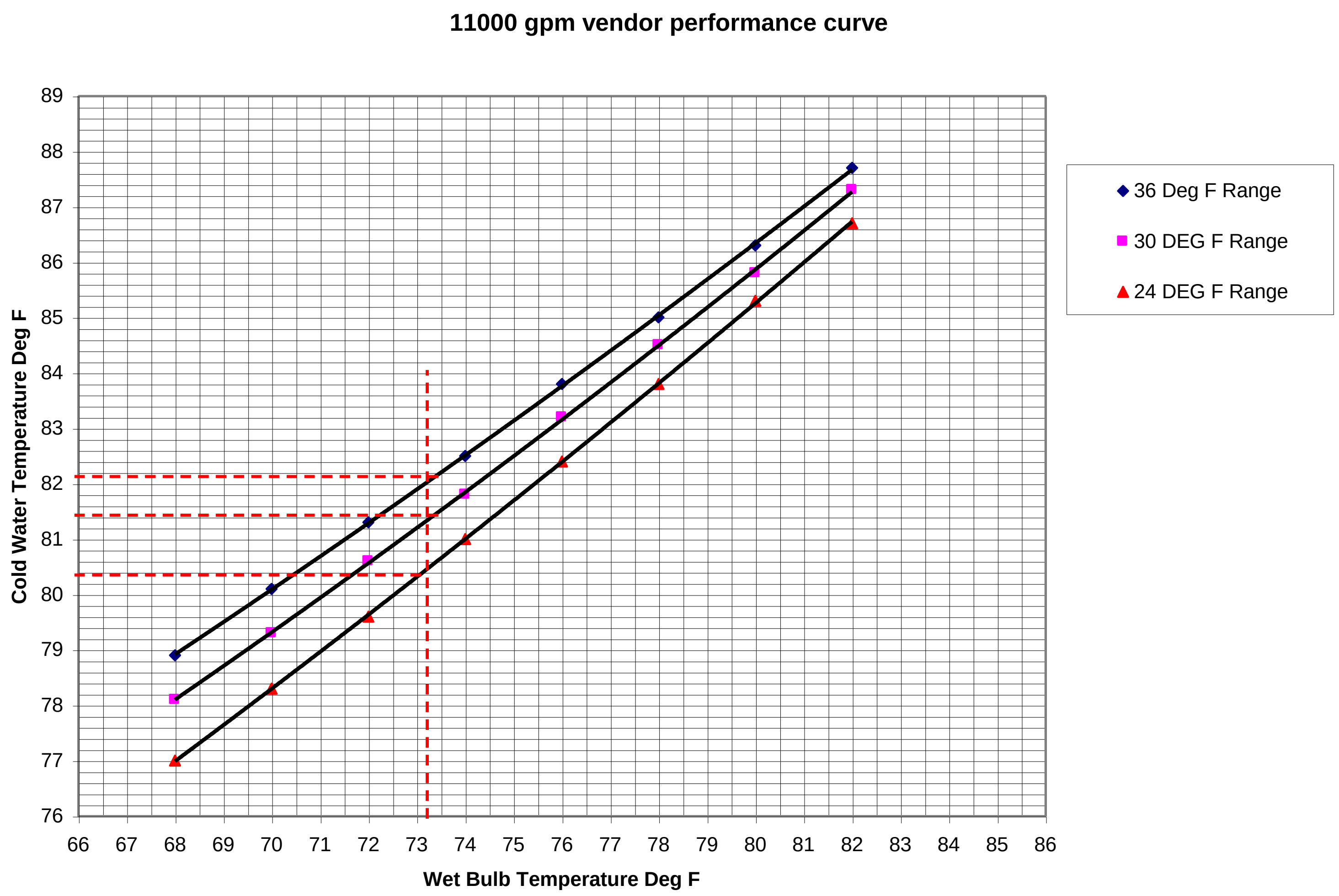
Cooling Tower Performance Curve – 9000 GPM



Cooling Tower Performance Curve -10000 GPM



Cooling Tower Performance Curve -11000 GPM

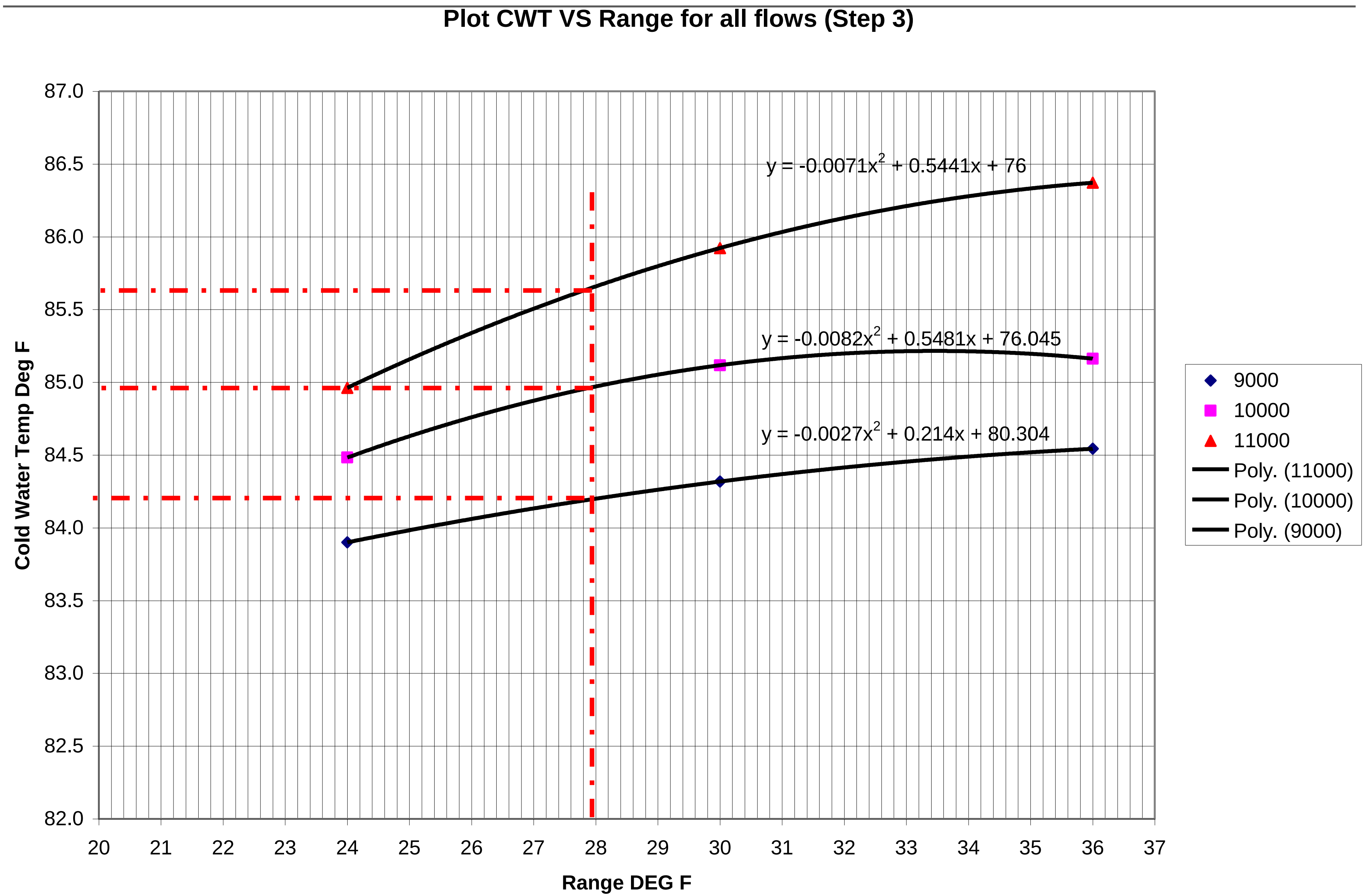


Step 3: Use Step 2 Data to Produce CWT/Range Curves

- Plot data from Step 2 to produce CWT vs. Range Curves.
- Solve for each flow curve at the range measured by the input data.

Step 3: Plot CWT vs Range	
Flow rate	**CWT**
11000	85.7
10000	85.0
9000	84.2

Step 3: Use Step 2 Data to Produce CWT/Range Curves

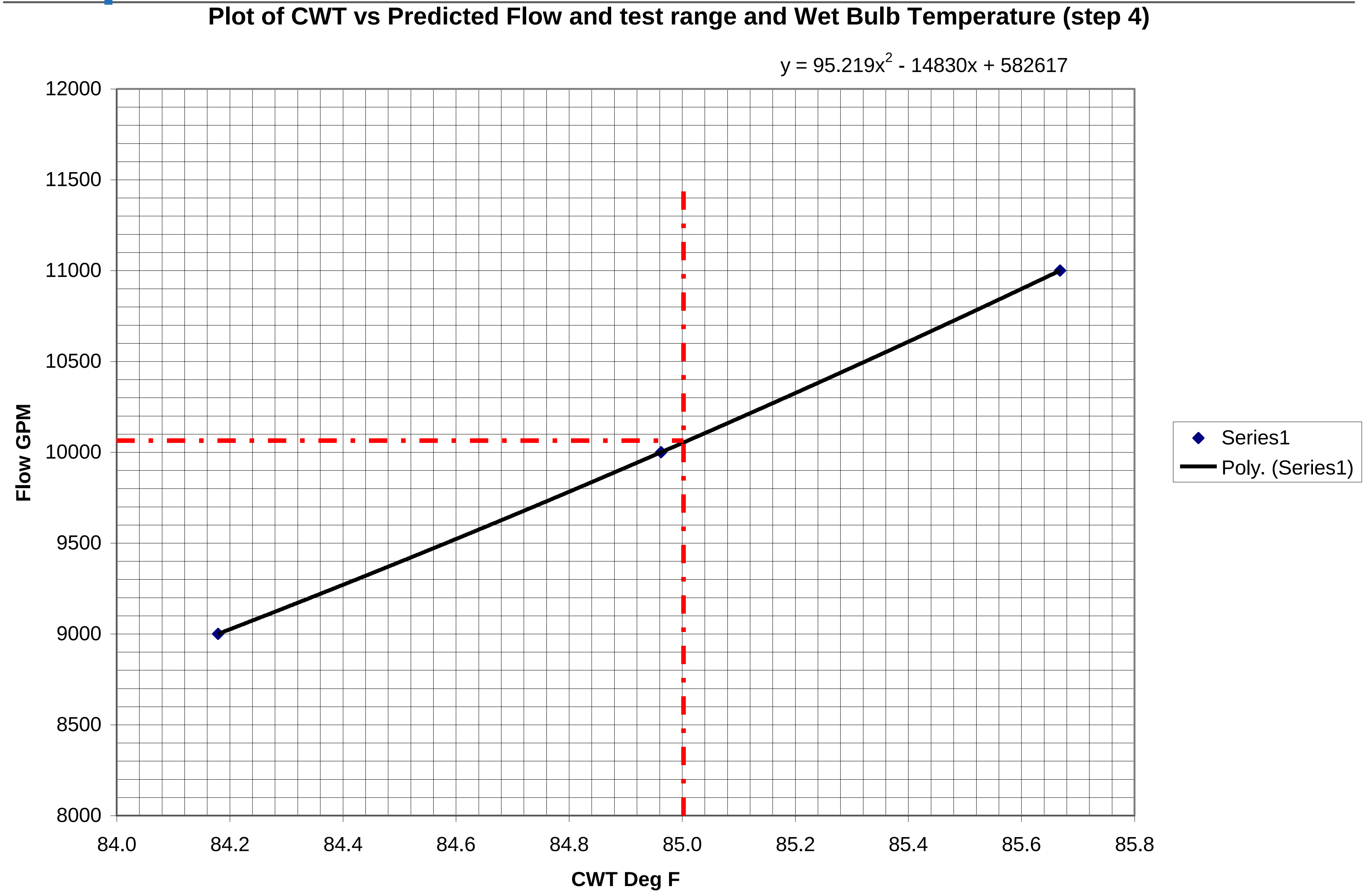


Step 4: Determine Predicted CW Flow

Step 4: Determine Predicted CW Flow

- Cross plot Step 4 graph to produce a CWT vs. Predicted CW Flow curve.
- Read from this curve the Predicted CW Flow at the measured CWT.

Step 4: Plot CWT vs. Predicted Flow



Step 5: Correct Actual CW Flow for Fan Power

Adjusted Test Flow =

Test Flow * (Design Fan HP/Test Fan HP)$^{1/3}$

Design Fan HP = 120

Measured Fan HP = 108

Adjusted Test Flow = 9500 *(120/108) $^{1/3}$ = 9780 gpm

Mechanical Draft only.
Natural draft has no flow correction.

Step 6: Calculate Cooling Tower Capability

$$\% \text{ CAPABILITY} = \frac{\text{ADJUSTED CW FLOW}}{\text{PREDICTED CW FLOW}} \times 100$$

$$\% \text{ CAPABILITY} = \frac{9780 \text{ GPM}}{10024 \text{ GPM}} \times 100 = 97.56\%$$

Exelon Nuclear Units with Cooling Towers

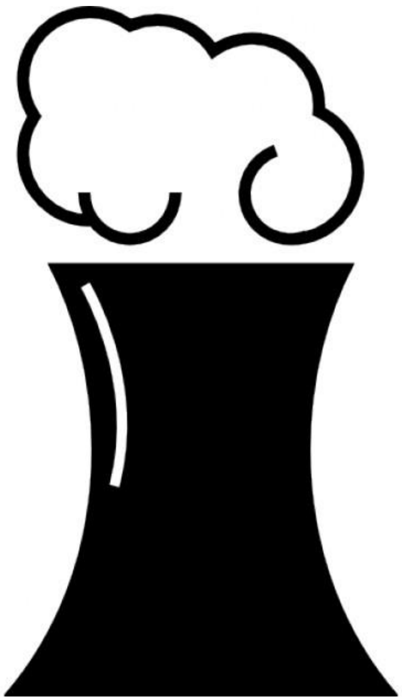
- Byron Unit 1 & 2 (Counterflow Conversion from Cross flow)
- Nine Mile Point Unit 2 (Counterflow)
- Limerick Unit 1 & 2 (Crossflow)
- TMI A (Counterflow Conversion) & B (Crossflow)
- Dresden 2 & 3 (Mechanical Draft, Counterflow)
- Peach Bottom 2 & 3 (Mechanical Draft, Crossflow)

Byron 1 & 2 (Counterflow Conversion from Crossflow)

Exelon Cooling Tower Thermal Performance Background

Background:

- Cooling tower monitoring with Excel lacked functionality due to software upgrades and using off-line data
- PMAX, a recently available real-time cooling tower monitoring tool needed verification to be used as a replacement to Excel based performance calculations



Goals:

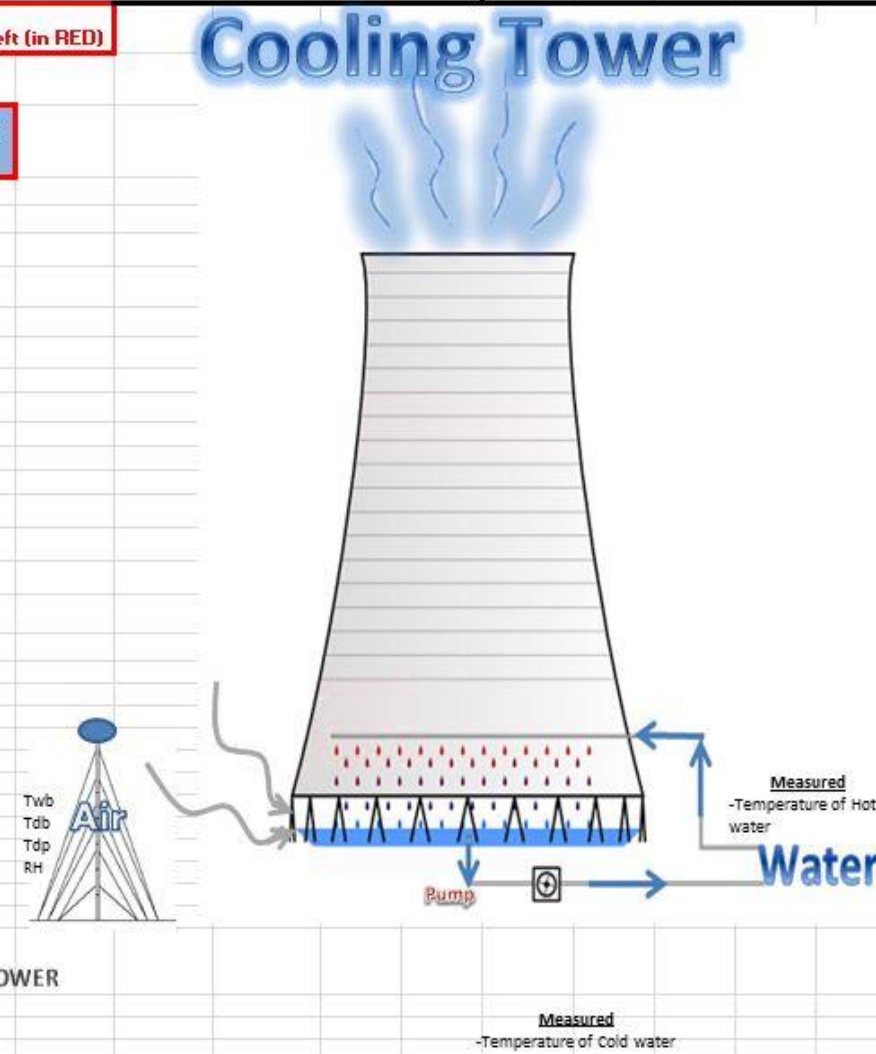
- Audit the site-specific spreadsheets and PMAX engineering models and then compare to ensure accurate performance monitoring of cooling towers
- Replace site-specific spreadsheets with PMAX

Exelon Cooling Tower Calculation (Excel Based)

Exelon Nuclear

Cooling Tower Capability Calculation (Q)
Exelon Nuclear Fleet

Byron 1 NDCT			Select site at left (in RED)
		These blocks are formulas DO NOT EDIT	
Start Date	mm/dd/yy hh:mm:ss	7/5/18 1:00 PM	Type in your start time at left
End Date	hrs	7/5/18 2:00 PM	
Window length	hrs	1	
Wet bulb temperature	deg F	72.7	
Dry bulb temperature	deg F	80.4	
Barometric pressure	psia	14.7	
Relative humidity	%	69.4	
Inlet (hot) water temperature	deg F	117.7	
Outlet (cold) water temperature	deg F	91.5	
Range	deg F	26.2	
MDCT only- Fan Driver Power (test)	bhp	#N/A	
MDCT ONLY-Fan Driver Powr (design)	bhp	#N/A	
Design Water Flow Rate	gpm	726750.000	
Circ water flow rate (test)	gpm	712154.8	
Predicted Circ Water Flow	gpm	753314.8	
Tower Capability (Q)	%	**94.54**	



PMAX Real-Time Cooling Tower Performance Displays (web based)

Exelon Real-Time Cooling Tower Performance Display

24-JUL-18 15:13:46 | BAD 16 | IVM 4 | Health | Alarm

Cooling Tower

Byron Nuclear Station Unit 1

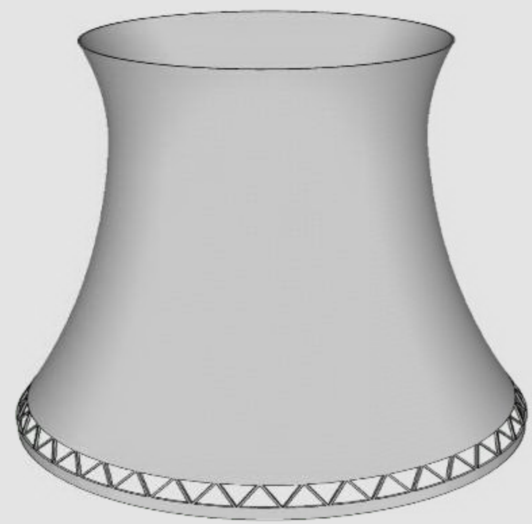
Gross MW	1235.1	Best Achievable (MW)	1238.2	Delta (MW)	-3.1
		Thermal Power (MWth)	3641.5	(%)	99.9

Lost MW Advisor | Plant Overview | Steam Generator | HP Turbine (LP A, LP B, LP C) | MSRs | Condensers | Cooling Towers | FWH (HP, LP) | Pumps | Generator | Cycle Isolation | Manual Inputs | What If? | Site Reports | PdP | Rules | BYR2 | Unit Compare | Exelon

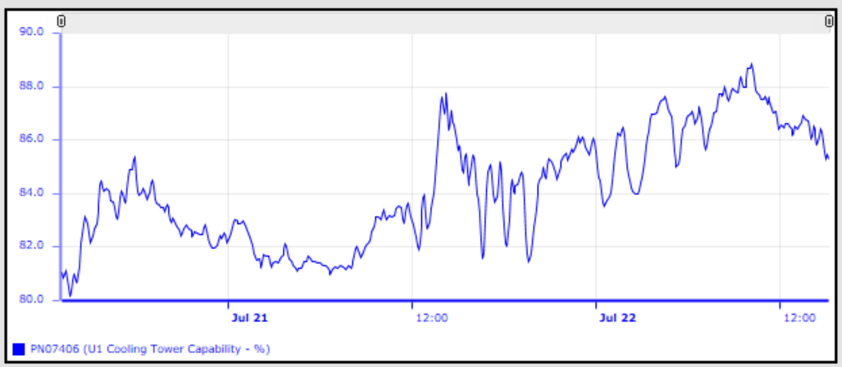
Ambient Conditions		Ground	Met Tower
Pressure	psia	14.7	
Pressure	in. hg	29.9	
Temperature	°F	80.6	80.4
Relative Humidity	%	55.1	
Wet Bulb Temperature	°F	68.8	
Dew Point Temperature	°F	62.8	62.8R

Wind		@ 30 Feet	@ 250 Feet
Speed	mph	9	11
Direction	deg	322	

Cooling Tower Performance		Value
Hot Water Temperature	°F	116.4
Cold Water Temperature	°F	93.6
Cooling Tower Range	°F	22.6
Cooling Tower Approach	°F	24.8
Circ Water Flow	GPM	727628
Circ Water Flow (predicted)	GPM	841476
Capability	%	86.5



		Actual	Expected	Δ
Basin Temp	°F	93.6	89.6	4.1



Start Time: 07/24/2018 13:07:49
End Time: 07/24/2018 15:07:49
Archive Rate: 5 minutes
Update Rate: 1 minutes

Exelon Real-Time Condenser Performance Display

24-JUL-18 15:27:29 | BAD 15 | IVM 4 | Health | Alarm

Condensers

Byron Nuclear Station Unit 1

Gross MW	Best Achievable (MW)	Delta (MW)	Thermal Power (MWth)	(%)
1234.8	1238.0	-3.2	3643.3	100.0

Lost MW Advisor | Plant Overview | Steam Generator | HP Turbine (LP A, LP B, LP C) | MSRs | Condensers | Cooling Towers | FWH (HP, LP) | Pumps | Generator | Cycle Isolation | Manual Inputs | What If? | Site Reports | PdP | Rules | BYR2 | Unit Compare | Exelon

Circ Water Conditions	Cond A	Cond B	Cond C
Inlet Temp (°F)	93.7	101.6	108.8
Outlet Temp (°F)	102.5	110.8	116.3
Temp Rise (°F)	8.0	7.4	7.4
Flow (mlb/hr)	357.1	357.1	357.1
Flow (kgpm)	718.9	718.9	718.9
Flow (kgpm)*	729.2	729.2	729.2

CWP OOS

CW Flow Normal

Circ Water Conditions	Wbox A	Wbox B	Wbox C	Wbox D
Waterbox DT (°F)	21.2	20.1	24.7	24.6

Performance Indices	Cond A	Cond B	Cond C
Heat Duty (MBtu/hr)	2858.0	2624.8	2611.6
Heat Duty (MBtu/hr)*	2892.4	2670.2	2672.1
HTC (Btu/hr-°F-ft)	384.6	418.9	412.5
TTD (°F)	16.5	15.3	13.7

*Power Method

Cleanliness Factor	Actual	Expected	Δ
Condenser A	0.94	0.90J	0.04
Condenser B	0.92	0.90J	0.02
Condenser C	0.92	0.90J	0.01

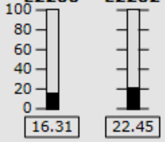
Subcooling (°F)	Actual	Expected	Δ	MW Effect
Condenser	0.0	0.0J	0.0	0.0

Steam Conditions	Cond A	Cond B	Cond C
Flow (mlb/hr)	2.78	2.77	2.78
Pressure (in hga)	3.27	3.86	4.50
Hood Temp (°F)	119.6	122.2	131.3
Hood Press (in hga)	3.41	3.66	4.69

Condenser Drain Inlet	Cond A	Cond B	Cond C
Flow (mlb/hr)	1.04	4.63	8.28
Enthalpy (Btu/lb)	317.0	94.64	97.1

Back Pressure (in hga)	Average	Expected	MW Effect
Condenser Performance	3.9	3.9	-0.28

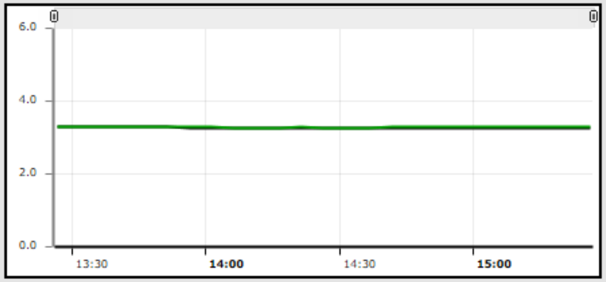
Hotwell Levels (inches)



Air In Leak Indicators	Cation	Specific
Conductivity (umhos)	23.99	10.18
Dissolved O2 (%)	23.24	

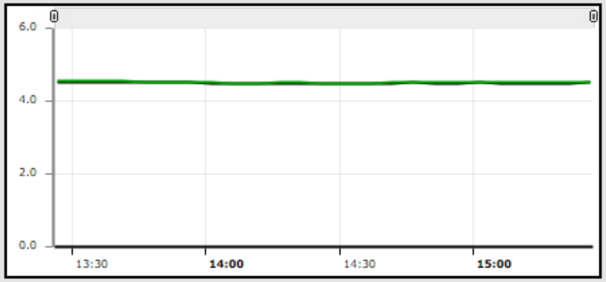
Total CW Flow	Actual	Design
Flow (kgpm)	718.9	741.0

A BP (Actual) 3.27 A BP (Expected) 3.29

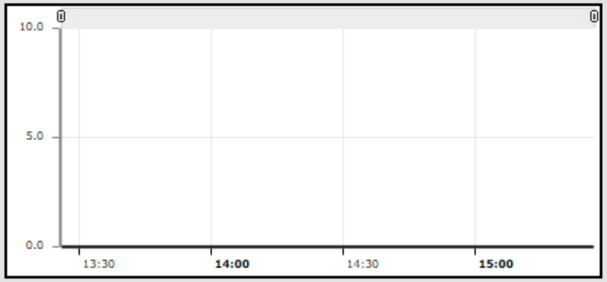


B BP (Actual) 3.86 B BP (Expected) 3.87

C BP (Actual) 4.50 C BP (Expected) 4.52

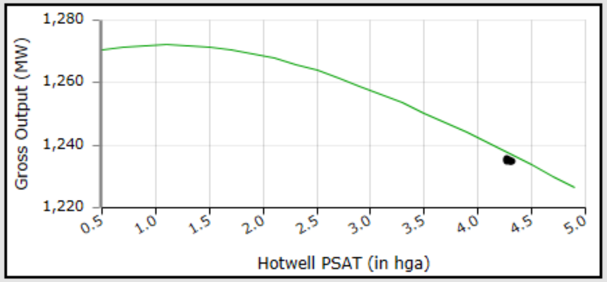


Condenser Sub Cooling



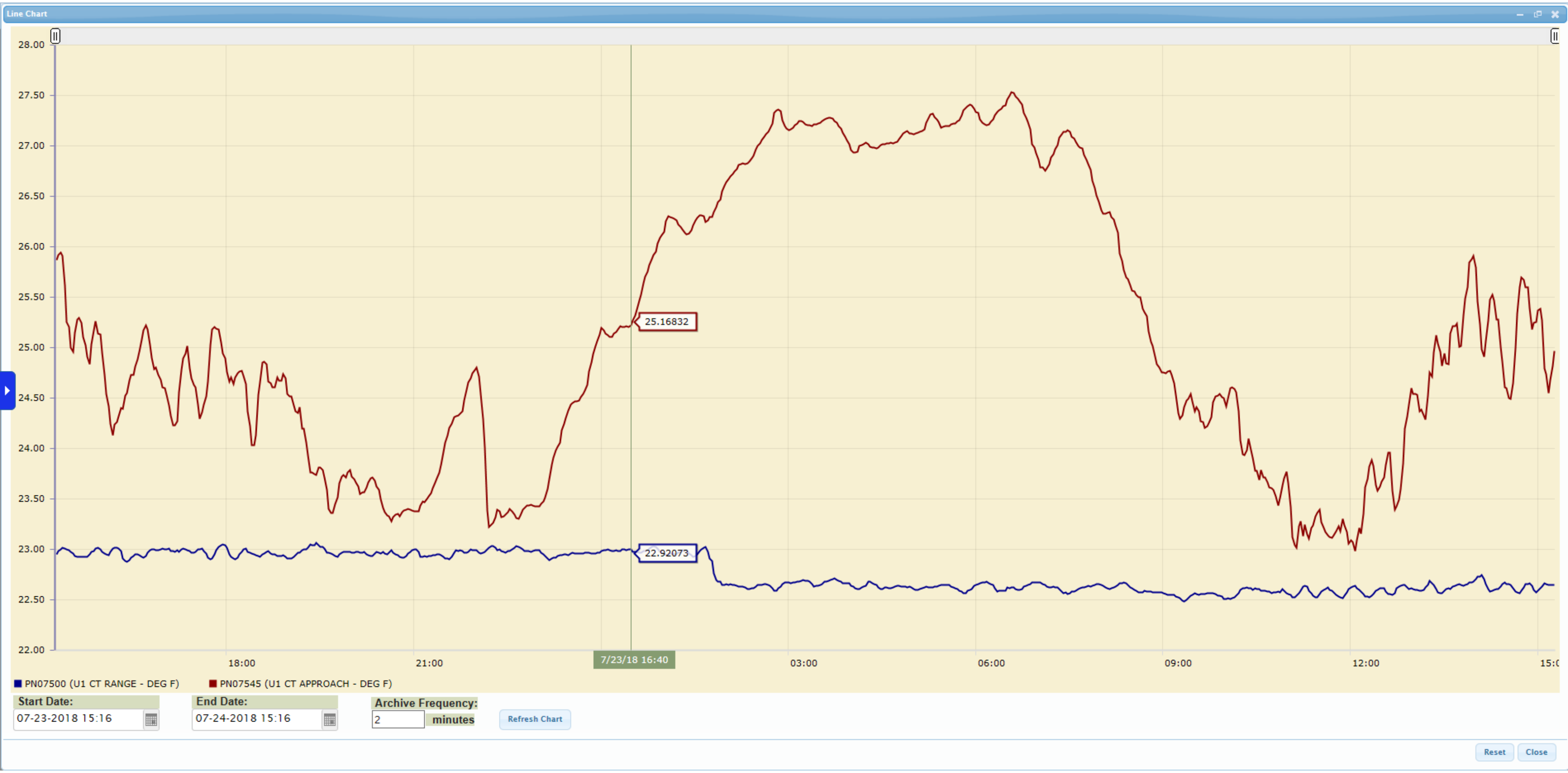
Generation vs ABP

Actual (MW) Expected (MW)



Exelon Generation.

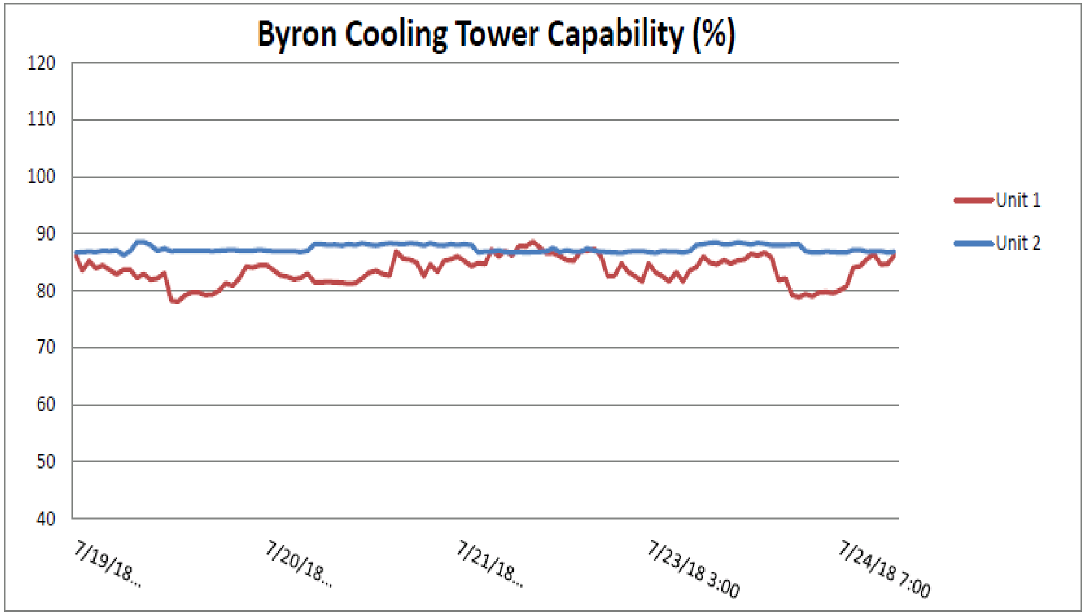
Sample Cooling Tower Performance Trend – Approach and Range



Sample Cooling Tower Performance Weekly Report

Cooling Tower Report

Byron Nuclear Station		7/24/2018	
Tag Description	**Units**	**Unit 1**	**Unit 2**
Wet Bulb Temperature	Deg F	68.5	64.2
Dry Bulb Temperature	Deg F	80.3	80.3
Dew Point Temperature	Deg F	62.5	62.4
Barometric Pressure	psia	14.7	14.7
Relative Humidity	%	55.1	40.8
Inlet Water Temperature	Deg F	116.4	113.6
Outlet Water Temperature	Deg F	93.7	89.5
PMAX Calculated Water Flow Rate	gpm	728330	694984
Predicted Water Flow Rate	gpm	848677	799430
Tower Capabilty	%	85.8	86.9
Predicted Outlet Water Temp	Deg F	89.4	87.6
Range	Deg F	22.6	24.1
Approach	Deg F	25.2	25.3
MW Impact	MWe	-9.1	-3.2



Exelon Cooling Tower Thermal Performance Overview

Results :

- Excel spreadsheets and PMAX models were reviewed and updated as needed
- Side by side comparison was made between spreadsheets and PMAX using the same input data
- Deltas identified between PMAX and spreadsheets and modifications made as needed to ensure accuracy in the PMAX including instrument validation
  - CW flow interpolation issue found and resolved

Benefits:

- Will allow M&D center to trend real-time cooling tower performance reliably using web based displays and utilities
- PMAX will also monitor long term performance (archived results), which facilitates maintenance decisions
- Excel sheet will be replaced using PMAX
  - PMAX uses real-time data and validates input
  - PMAX has a more accurate methodology for calculating flow

Conclusion

- Cooling tower performance results are calculated and presented in real-time
- Instruments can be validated before entering performance calculations
- Cooling tower performance calculation inputs and results are archived and available for trends, reports (automated and manual), alarm checks, and diagnostics
- Web based displays presenting cooling tower performance information are available to all users within the utility to assist with quickly finding thermal performance issues quickly

Questions?