In Hot Water: A Cooling Tower Case Study

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Problem Statement

Vogtle Electric Generating Plant operated by Southern Nuclear Operating Company, a subsidiary of Southern Company, has found itself at a decision point. Vogtle depends on their natural draft cooling towers to remove heat from the power cycle. Depending on the efficiency of the towers, the cycle can realize more or less power output. The efficiency of the cooling tower is loosely defined by Vogtle personnel as how well the tower's actual performance compares to its original design performance. The primary goal here is to have the cooling tower produce the coolest water possible to re-enter the condenser. The performance, therefore, can be described as how close the temperature of this water gets to the expected (predicted) temperature of the original tower design. A one or two degree decrease in the cold water temperature can have a very significant impact on the company's ability to compete in the deregulated market.

When Plant Vogtle began producing power in 1989, the cooling tower only performed at 76% of expected efficiency. The original design was modified by the manufacturer in 1990 and resulted in an increased efficiency of 91%. In an effort to improve the efficiency of the towers from 91% to 100%, two modifications to the nozzle sizes and distribution pattern had been suggested by a cooling tower consultant, John Cooper, but had resulted in a decreased efficiency of 86% after the first modification and 79% following the second modification.
To control the distribution of the water in the tower, over 10,000 nozzles were used and nozzle sizes vary in diameter, allowing more or less water to fall in certain areas of the tower. The figures at right show the placement of nozzles of different diameter during 1989-1998.

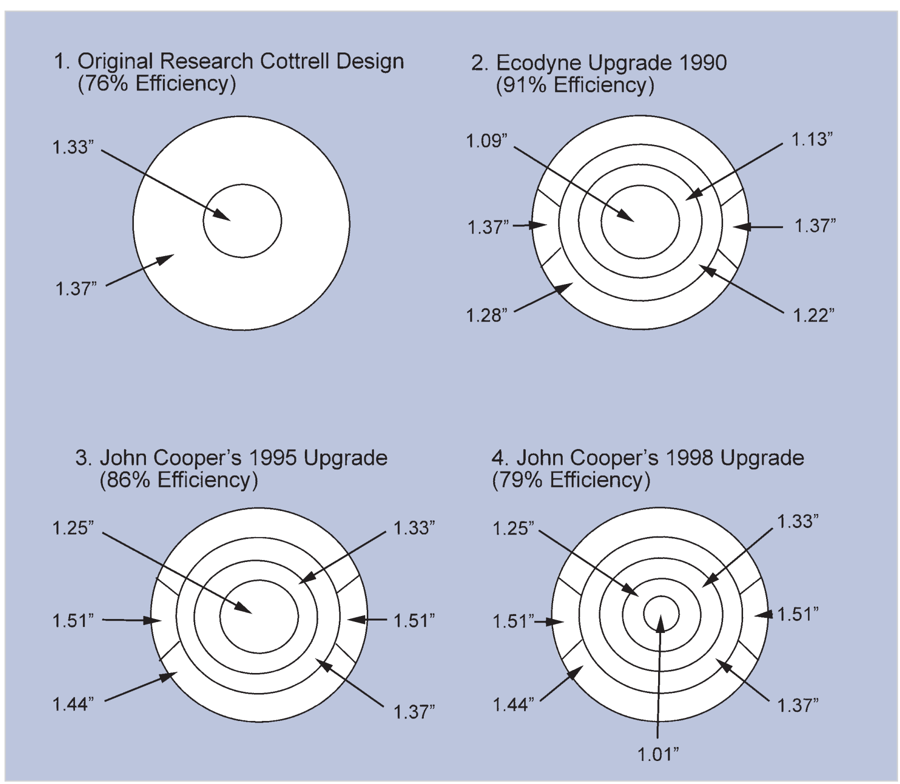
The outlet water temperature from the cooling tower can be affected by the spray nozzle configuration inside the tower. The diameter of the nozzles can be changed to affect where water is released in the tower and plays a vital part in the performance of the tower. Selection of the appropriate nozzle sizes and their placement in the tower, or distribution pattern, for maximum performance is at the center of Southern Company's dilemma. Calculations indicate restoring the tower to 100% capability has a present worth value of $10.2 to $11.9 million (in 1989 dollars) from 80% of design capability.

During Sept. 1999, John Cooper made a new recommendation for a further modification of the nozzle sizes in this tower, but it was unclear how effective the change would be. Therefore, the Southern Company had to make a decision: either choose to revert to the previous nozzle configuration of the tower with guaranteed 91% efficiency, or try the new modification in an attempt to reach the tower's expected capability of 100%.

Interact: Summarize and restate the problem statement.

July 23, 1999. 7:27 A.M.

Patrick Conley was standing by the window looking out toward the *cooling towers* in the east when Kerry Walton, Plant Vogtle's performance engineer, rushed into the conference room. The sun was peeking around the twin *hyperbolic* structures and after two years as a project engineer at Plant



Vogtle, Patrick was still enchanted by this view.

"I have some bad news, Patrick. We were able to get the efficiency measurements for the 1998 redesign only recently and it shows that the efficiency decreased from 86% in 1995 to 79% for the 1998 modification. The best efficiency we had obtained on this unit was during 1990 when it reached 91%. It is going to cost us a bundle until we come up with a better design."

Patrick's day had suddenly taken a turn for the worse. A strict, detailed analysis had been conducted by John Cooper, a cooling tower consultant. The Southern Company had reviewed this information and the modification was approved.

"Kerry, this isn't the 'good morning' I was expecting. Do we have any indications so far about the problem's source?"

Kerry now regretted his lack of cordiality, but there was a major problem and cordiality had to wait.

"Good morning," Kerry retorted with a smirk. "I apologize for my anxiety this morning. I know that we can't rush out to the tower and correct this problem today. After all, we have a planned shut down of each reactor only once every eighteen months. It may be more than seventeen months before we can fix this."

Robert Moye, the engineering supervisor, strolled into the conference room. He's a tall man, though he enters standard doorways without ducking. Robert always seems quite relaxed. This often perplexes his engineering team because of the pressure that supervisors can come under. 'Give the engineers some leeway to work,' Robert believes, 'and the engineers will surprise you with their output.'

"I have heard the news guys. What's the report?" Robert calmly asked.

Kerry stepped forward. "The cooling tower for unit two is not performing efficiently. At this point the only things we are sure of are that efficiency is down and we are losing money."

Robert turned toward the window and gazed intently at the cooling towers. As relaxed and as business-like as usual, he said, "We know the conditions. Let's go locate the problem and find a solution."

Interact: How could the modifications hurt the nuclear plant's efficiency?

Role of Cooling Towers in a Power Plant

Conceptually, there are two ways to get more power from an existing power plant: either produce more power by consuming fuel at a higher rate or reduce the amount of energy consumed by power production. Many power plants operate at their maximum capacity already, so the second alternative becomes the only alternative. Furthermore, at a nuclear facility, the maximum energy produced from the nuclear reactions is capped both by reactor capacity and regulations set by the Nuclear Regulatory Commission. Therefore, to improve the net output of a nuclear plant, the efficiency of the plant must increase.

There are many systems in a power plant where power is consumed, as it requires a certain amount of power to operate the facility. In some instances, power is simply lost due to inefficiencies. Some sources of inefficiency include the pumps that are used to circulate water, the friction that exists in various types of moving equipment and, heat energy that is not completely converted to electricity. Some of the inefficiencies are inherent in the equipment and processes, but others can be improved. One example of an area that can be improved is within the circulating water cycle, specifically the cooling tower.

This study focuses on reducing the temperature of the circulating water cycle. If this temperature can be reduced through improved cooling tower performance, it will result in improved condenser performance by reducing the *exhaust pressure* on the turbine. A reduction in turbine exhaust pressure, also called *backpressure*, increases the amount of work performed by each pound of steam and therefore increases the overall plant efficiency. By reducing the circulating water return temperature by 2 degrees, it can be shown that plant will gain approximately 5 MW. (Figure 1)

Condenser Heat Removal - Steam Side		
Condenser Inlet Water Temperature		93 pF
Steam In :		
	mass flow rate:	8269485 lb/hr
	enthalpy 1:	1020.3 BTU/lb
Steam Out Prior To Temperature Drop:		
	temperature:	120 pF
	pressure:	1.72 psia
	enthalpy 2:	88.5 BTU/lb
Steam Out After Temperature Drop (2 pF):		
	temperature:	118.6 pF
	pressure:	1.62 psia
	enthalpy 3:	86.5 BTU/lb
Increase in Energy due to 2 pF Temperature Drop:		
	Power = (mass flow rate)(enthalpy 2 - enthalpy 3)	
	Power = (8269485 lb/hr)(88.5 BTU/lb - 86.5 BTU/lb)	
	Power = 16538970 BTU/hr	
	Power = 4.8 MW	

Figure 1.

According to John Cooper, a cooling tower consultant, cooling tower performance is an important aspect in plant efficiency for several reasons. The prime reason relates to the negative pressure that is desired for the exhaust side of the turbine. To make electricity, the thermal energy of the reactor is converted to mechanical energy, which turns the turbine. The turbine is directly coupled to the generator, which produces electricity. By reducing the turbine exhaust pressure more energy can be extracted from the steam cycle, which increases the plant efficiency. To improve the steam cycle efficiency the cooling tower efficiency must be optimized. A cooling tower is a *heat exchanger*, which transfers heat out of the condenser into the environment. A cooling tower can be thought of as a waste heat disposal device.

John Cooper continues, "At a time when energy is at a premium some argue that something useful should be done with this heat. With *deregulation* and the heightened competition between utilities, all power plants in the United States are presently looking for ways to make power in a more cost effective way and the cooling tower is one of the first places that a lot of utilities are looking at to improve plant efficiencies. A one or two degree decrease in the cold water temperature can have a very significant impact on the electric utility's ability to compete in today's market."

Interact: Describe the basic necessity of a cooling tower at a power plant.

Describe how the cooling tower can improve plant performance.

Define enthalpy, temperature, pressure, power, BTU, and MW.

Cooling Tower Operation

In a *pressurized water reactor* (PWR) nuclear power plant there are three distinct water cycles (Figure 2). These include: *reactor water cycle* (yellow), *turbine water cycle* (white), and *circulating (circ) water cycle* (blue). The water, utilized for its high heat capacity and non-corrosiveness, is used as a medium for transferring heat to different areas of the plant. The circulating water cycle is described below since it is important in understanding this study. The reactor water cycle and the turbine water cycle are described in Appendix A.

The main component of the Circulating Water System (Figure 3) is the cooling tower, which is used as a heat removal device, and can be categorized as either *mechanical draft* or *natural draft* and *crossflow or counterflow*. Mechanical draft cooling towers use huge fans to force air across the hot water to cool it. Natural draft cooling towers generally are much larger than mechanical draft towers and use the tendency of heated air to rise for moving air across the hot water. Counterflow towers are designed so that the air path is generally parallel with the path of the hot water, while cross flow towers are designed to pass air perpendicular to the flow of the hot water. The cycle requires a large water source (Figure 2), but is contained primarily in a cyclical process. Some water, however, is lost due to evaporation and must be replenished.

At Plant Vogtle, a natural draft, counterflow cooling tower (Figures 3 and 4) is used to remove the heat from the circulating water system that was absorbed from the turbine water cycle. The concrete tower stands 541 feet tall and has a base diameter of 444 feet. The tower has its characteristic hyper-

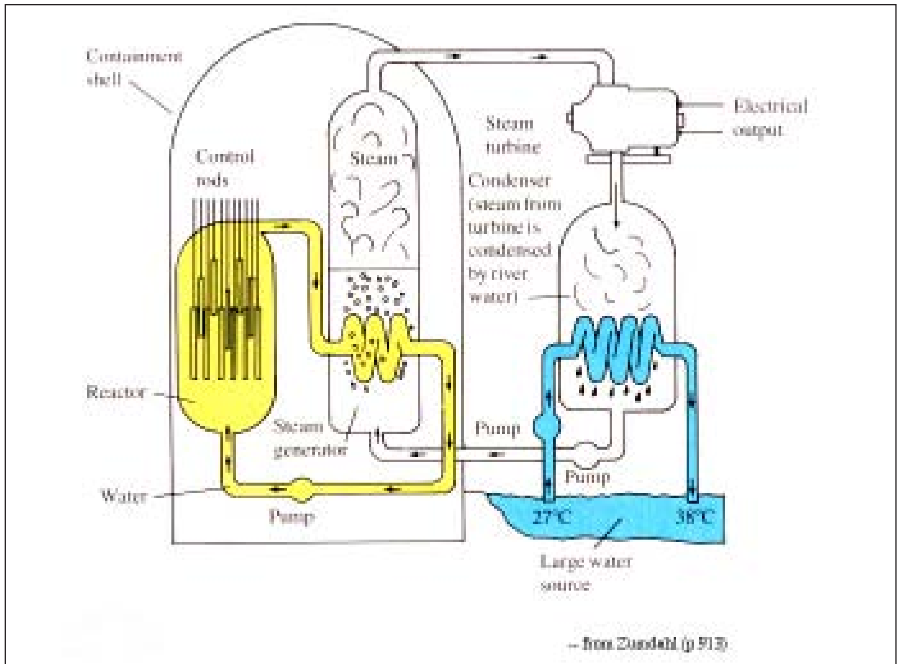


Figure 2.

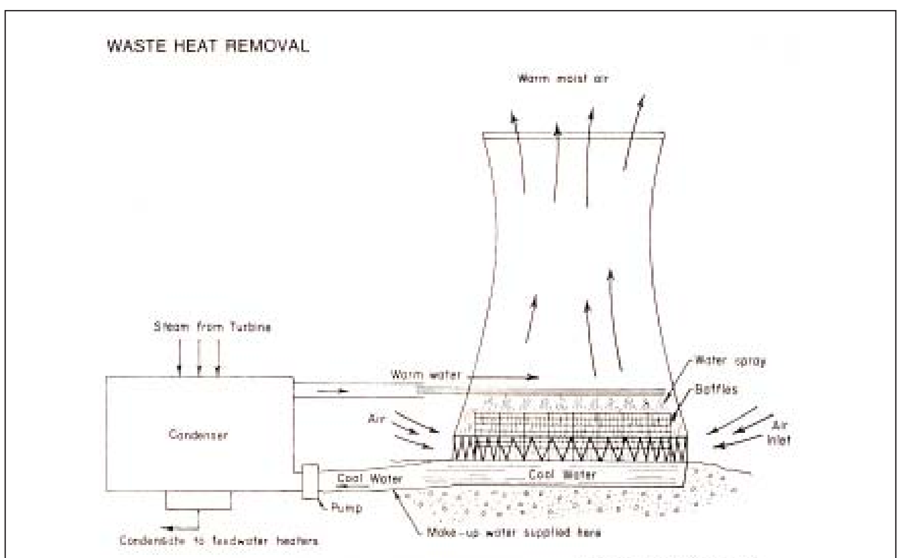


Figure 3.

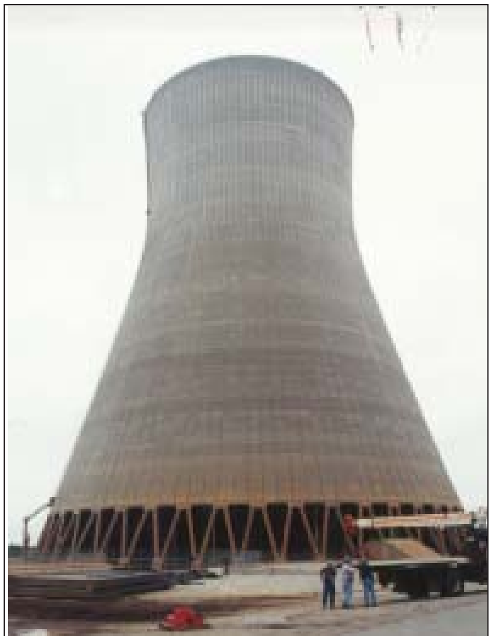


Figure 4.

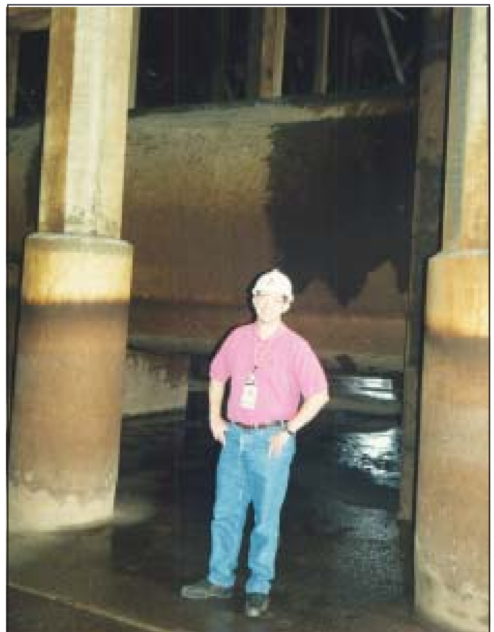


Figure 5.

bolic shape because of the shape's unique ability to support high wind loads (this is a crucial issue for large structures) with less material than a cylindrical tower. This shape also helps ensure the natural draft effect is maximized. The water passes from the condenser to the cooling tower through a pipe that is about 14 feet in diameter (Figure 5, behind Patrick).

This pipe carries approximately 535,000 gallons of water per minute. The hot water flows through this pipe underneath the cooling tower and splits into four *risers,* one of which is shown in Figure 6.

These risers are approximately 50 feet tall and each riser feeds two horizontal concrete *flumes* that span the tower. Smaller pipes split out the sides of the flumes (Figure 7) to distribute the water to the areas in between the flumes.

Figure 6.

Figure 7.

The *spray nozzles* are connected to these pipes (Figure 8) and consist of a *nozzle ring*, *nozzle*, and a *splashplate* (Figure 9). The nozzle is inserted into the nozzle ring from the top (Figure 10). The conical shape of the nozzle combined with gravity and water pressure ensures that the nozzle stays in place within the nozzle ring.

For a tower of this size, the distribution of water is important. There can be areas where water does not fall from the nozzles allowing air to flow by without cooling any water. There can also be areas where too little or too much water falls from the nozzles so that the heat transfer between the water and air is not maximized. To control the distribution of the water in the tower, over 10,000 nozzles are used and nozzle sizes are varied in diameter, allowing more or less water to fall in certain areas of the tower.

Figure 8.

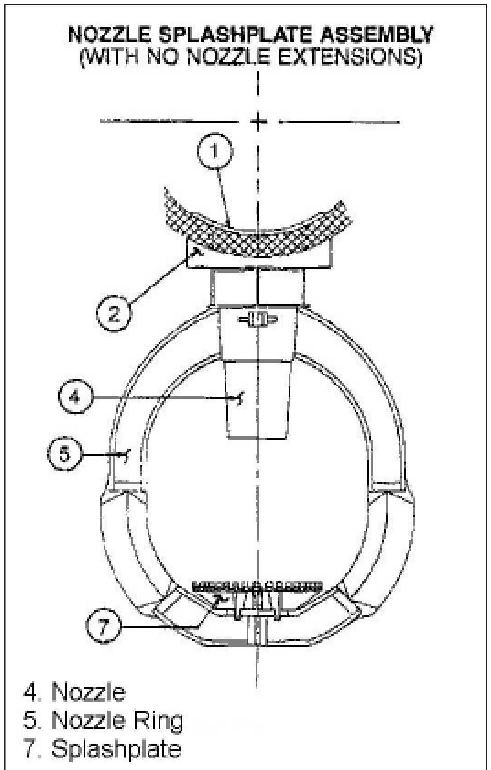


Figure 9.

Figure 10.

The splashplate aids in the effective distribution of water. As water pours out of the nozzle and impacts the splashplate, the water splatters in the form of a hollow cone leaving an area without water directly beneath the splashplate. The splashplate breaks up the water flow, creating a spray of water particles, thereby increasing the total surface area available for heat transfer. In an effort to utilize the full area of the tower, the nozzles are placed (Figure 11) so that the cones of water overlap each other to reach the areas beneath the neighboring nozzles. To prevent the nozzle rings from detaching due to water pressure (once a common occurrence), the piping was retrofitted with large hose clamps (Figure 11).

After the water splatters against the splashplate, the water particles fall onto the *fill matrices* visible beneath the nozzles in Figure 11. The fill is made of PVC (Figure 12) and provides many surfaces for the water to flow along and many cavities for air to pass through. Since heat transfer is heavily dependent on surface exposure, or surface area, the more surfaces for water to travel on, the better the heat transfer. This is why there are several layers of fill (as much as 9 feet thick in areas) in most of the tower. The fill also slows the water's descent, allowing more time for the water and air to exchange heat, affecting heat transfer also. Much of the heat is removed through partial evaporation of this water. Although this evaporative process removes 80% percent of the heat, only about 3% of the water actually evaporates.

As water flows over the fill at a rate of 535,000 gallons per minute, the structure becomes very heavy. To support this weight, a massive support structure (Figures 13, 14) for the fill must be provided underneath the tower. Large concrete columns are necessary throughout the tower for structural stability. Occasionally, deterioration develops in the support structure and part of the fill falls and must be replaced (Figure 15).

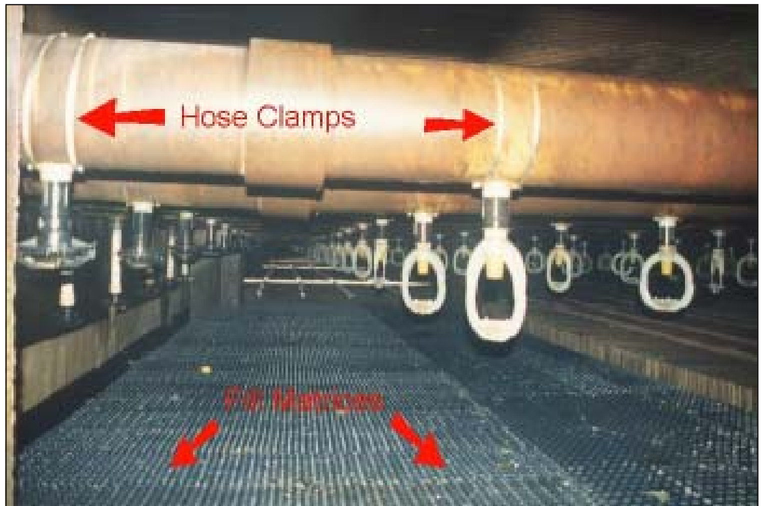


Figure 11.


Figure 12.


Figure 13.


Figure 14.

John Cooper states, "The purpose of fill is first to increase the hang time of the water inside the tower. Water droplets that are sprayed down hit the surface of the fill media and it takes a finite amount of time for the water to flow down through the matrix of surfaces. So it increases the time that the water has in contact with the cooling air stream. The second purpose of the fill material is to spread the water out over as large of a surface area as possible. In the Plant Vogtle tower, there are arrays of asbestos cement sheets, each 16 inches tall, which are stacked one on top of the other. At the deepest point, there are 7 tiers of 16 inch high sheets (thickness evident in Figure 16) that the water is sprayed on to give you as much surface area for contact between the air and the water."

Realizing that increased surface area means greater heat transfer, one might think that adding many layers of fill would help this process. The drawback of too much fill is the increased air resistance and a tendency to stifle the airflow through the tower. This resistance to flow would reduce the cooling tower's efficiency by eliminating the natural draft effect. After water trickles over the fill, it falls into the *basin* of the tower. The region between the fill and the basin is called the *rainzone* (Figure 17). The rainzone is the final opportunity for the water to be significantly cooled by air in the

Figure 15.

Figure 16.

Figure 17.

cooling tower. Cooled water flows from the basin into the channel (Figure 18) that leads to the circulating water pumps. The water is filtered (Figure 19) for large debris before it enters the two large pumps. These two large pumps (Figure 20) are responsible for pumping the circulating water throughout its journey. Each 50 percent capacity pump will force half of the water into a *manifold* underground that unites the two streams. The unified pipeline is about 14' in diameter.

Figure 18.

Figure 19.

Figure 20.

Apparent in the channel picture (Figure 18), the water used in the circulating water cycle appears murky like river water. This is because the water is drawn as needed from the Savannah River to make up water lost during the cycle (Figure 21). This leads to some accumulation of silt in the tower basin that must be cleaned out (Figure 22) when the entire unit is shutdown for a refueling outage. The nearby river provides a good source to replace the water that is lost due to evaporation during the cooling process. This *make-up water* is pumped into the circulating water cycle as needed using three lines (Figure 23) that simply dump the fresh water into the basin. The water level in the circulating water basin is maintained at a level between 32 and 33 feet, or approximately 6.1 million gallons of water. Once in operation, approximately 22,000 gallons per minute is used to maintain the appropriate water level in the circulating water canal.

Tower performance is a figure that relates how well the tower does its task of cooling water compared to what it is expected to do. In other words, the tower might be expected to cool the hot water 20 degrees Fahrenheit, and the tower performance is a reflection of how well this is achieved. To determine the expected performance of the cooling tower, many variables are used. The temperature of the incoming hot water from the condenser, the desired temperature of the cooled water leaving the tower, the mass flow rate of water, the size of the tower, and the typical climate for the area are the major factors. In the design phase of the tower, the size and water distribution pattern is chosen to maximize the cooling effect of the tower. Once the tower is constructed, the tower's performance, or efficiency, is compared to the design expectations. In normal operation, the mass flow rate of the water and its incoming temperature varies little. However, the temperature of the air and the humidity, or the amount of water vapor in the air, varies from day to day and seasonally, which varies the performance of the tower day to day and seasonally. Therefore, since the weather plays such an important role in the tower's efficiency, the design has to be based on typical climate conditions for the area. Consequently, the tower may have days that it cannot cool the circulating water to the expected, and desired, temperature, or there may be days that the tower, if configured properly, can exceed the expected capability, yielding an efficiency of greater than 100 percent. (This is why cooling towers are designated with the term design efficiency.) The climate figures used in the design are typically figures for the summer, when the load on the plant is highest and conditions are hot and humid.

If the existing tower is not performing as designed, or expected, and assuming that the tower is properly sized to begin with, the primary way to

Figure 21.

Figure 22.

Figure 23.

try to improve performance of the tower is to modify the water distribution pattern.

Interact: What are the benefits of natural draft-cooling towers over mechanical draft-cooling towers?

What is the purpose of fill matrices?

How can a cooling tower achieve over 100% design performance?

What are the variables that affect tower performance?

Intuitively, how should the water distribution pattern in the tower be configured?

Why is the fill needed? How much fill is used? What is the purpose of the columns in Figure 16?

Why not pour hot water into the Savannah River?

Why use cooling towers and recirculate water? Why not use direct feed from the river?

Are there other additional cooling means that are used in other power plants to decrease the circulating water temperature?

July 24, 1999. 12:12 p.m.

Kerry and Patrick often sit together at lunch and conversations range anywhere from football to children. Today, however, the tower's decreased performance was still on their minds.

Picking up a french fry, Kerry mused, "I thought of the tower all night. I really don't like to carry work home with me, but when something puzzles me, I can't get it out of my head."

"I know what you mean." The cafeteria had something different to choose from every day, but Patrick sat down with the routine, but surprisingly tasty, chicken fingers and fries. Patrick continued, "I thought about it myself for quite a while last night. I think what I would like to do is sit down and take a look at the cooling tower's history up until this point. I hope that by writing down exactly what changes have taken place, we can get a better feel of where we've been and where we are going."

"That will be an interesting report. I have some of the old information at my desk I can share with you. I've always heard that you learn more from mistakes than success, but we need to make sure that this is the last time this lesson is taught."

Patrick's History Report

The cooling tower for unit 2, manufactured by Research Cottrell Inc., began operating in 1989 when the second nuclear reactor went on-line for the first time. At this point, tests were run to determine how the towers were performing in relation to the design specifications. The tower was performing at only 76% of the expected performance. This was not satisfactory to the Southern Company and in the words of John Cooper, "Georgia Power held their tower designer's feet to the fire after the towers failed at the performance test."

A document (Figures 24 and 25) was generated by Russell Noble of Southern Company Services and presented to R. J. Bush, a project engineer at Plant Vogtle, on October 30, 1989. It outlined the expected gains in useful power output by reclaiming losses due to "tower malperformance." A decision was made to modify the tower water distribution pattern in an effort to reach the design performance.

Southern Company Services, Inc.
Post Office Box 2625
Birmingham, Alabama 35202
Telephone 205 870-6011

Southern Company Services

DATE: October 30, 1989

RE: Plant Vogtle Units 1 and 2 Cooling Towers
Unit Generation Effects and PVC Fill Information

FROM: R. T. Noble
Research and Environmental Affairs

TO: R. J. Bush
SONOPCO Project - Vogtle

As we discussed last week, the shortage in Plant Vogtle cooling tower performance has considerable Unit generation and economic impacts. An analysis was performed to estimate each of these problems.

The attached Table 1 lists predicted changes in Unit generation if the towers were upgraded from present ~80% of design capability to 100% capability. A condenser cleanliness factor of 0.90 was used for the calculations. The analysis shows that from 1 to 7 MWe are currently being lost due to cooling tower malperformance, depending on ambient conditions. In order to convert these values to dollars, accumulated present worth (APW) factors (@ 9.89% rate for life of plant) for Plant Vogtle were taken from the 'Worth of Unit Improvement Book' issued by Utility Services Department of SCS dated April 1989. Seasonal APW factors were 1300, 560 and 670 $/KW for summer, spring/fall and winter seasons, respectively. The present worth analysis was applied for two different ambient temperature scenarios as presented in Table 1. Calculations indicate restoring the towers to 100% capability has a present worth value of $10.2 to 11.9 million (mid 1989 dollars).

Since tower upgrade proposals will likely include provisions for adding high density PVC fill material, I have attached an R&EA memo which documents severe plugging of this type fill at Plant Bowen. We can discuss this further in our meeting with the Plant later this week.

Russell Noble

Attachments
:2565Y

cc: D. M. Boylan
C. H. Goodman
R. E. Rush

Figure 24.

Modification during 1990:

In 1990, the tower manufacturer (now Ecodyne, a subsidiary of Research Cottrell) came in with a modification idea that created more nozzle zones in an effort to more precisely distribute volumes of water according to their distance from the center. Five nozzle sizes were used in this tower arrangement. The fine-tuning of the water distribution was expected to lead to a more even air resistance and a more uniform cooling pattern across the tower area. This would result in a lower temperature for the circulating water prior to its return to the plant. This modification resulted in an improvement in tower efficiency. An efficiency of 91% was achieved.

Modifications during 1995:

Further improvements could be made. To obtain increased performance, John Cooper was contracted as a consultant in 1995. He measured the temperatures and air velocities at about 1000 points inside the operating tower. He used a computer to create color mappings (Figures 26, 27) to try and determine why the tower was underperforming the design. From John's temperature and velocity mappings, he determined that the air was too cold in the center of the tower, thereby indicating uneven cooling in the perimeter region. In an interview, John Cooper stated, "my upgrade design was an extrapolation of their [Research Cottrell] design." This design also used five nozzle sizes in a similar distribution pattern. However, all of the nozzles in each zone were larger in an attempt to shift more water toward the center. This modification resulted in a tower efficiency of 86%. This value was less than the previous scenario.

Modifications during 1998:

Obviously this modification was still better than the original design of the tower, but was a reduction from the previous layout and led to a degradation in the plant output. In 1998, the tower was again modified and smaller nozzles were placed in the center of the tower to force the water flow bias back toward the perimeter. The tests which followed this modification indicated that the tower had decreased in performance yet again to 79%.

Thus we arrive at the present situation. Obviously there are some unknowns (John Cooper even refers to it as partially an 'art') in dealing with cooling tower setup, and in this case the expected results have failed to materialize. To graphically depict the modifications as they have occurred, the following diagram has been included (Figure 28). The numbers in Figure 28 represent nozzle sizes in the different regions of the tower. The different regions that are created by various nozzle sizes, denoted with diameter measurements, were an attempt to configure the flow pattern to improve effi-

Table 1
Plant Vogtle Units 1 and 2 Cooling Towers
Predicted Change in Unit Generation for
Upgrading Towers from 80% to 100% Capability

Ambient Conditions, DBT/WBT		Change in Gross Generation, MWe
100°F / 79°F	(hot day)	+7.1
93°F / 78°F	(design day)	+6.6
83°F / 73°F	(summer avg. 1)	+6.2
80°F / 70°F	(summer avg. 2)	+5.7
65°F / 55°F	(spring/fall avg. 1)	+4.9
60°F / 50°F	(spring/fall avg. 2)	+4.0
45°F / 37°F	(winter avg. 1)	+1.6
38°F / 32°F	(winter avg. 2)	+0.8

Notes: 1. Calculations based on 525,000 gpm condenser cooling flow, 29.2°F temperature rise, 90% condenser cleanliness factor, turbine output correction curve dated 12/4/87 from SCSI.
2. Summer (June-Sept.), Spring/Fall (April-May, Oct.-Nov.) and Winter (Dec.-March) averages are based on 24 hr temperature averages.
3. Two separate seasonal averages were used to place a bound on the predictions. Average #2 assumes cooler ambient conditions.
4. Predictions are per Unit, full load operation.

Figure 25.

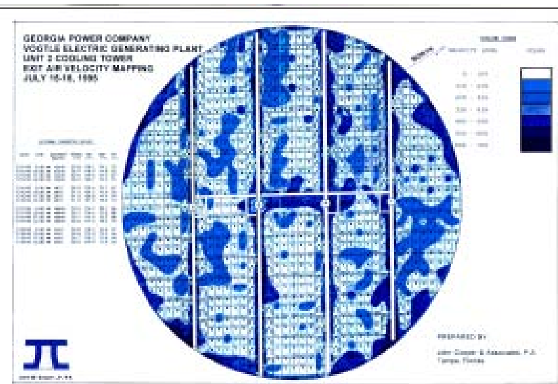


Figure 26.

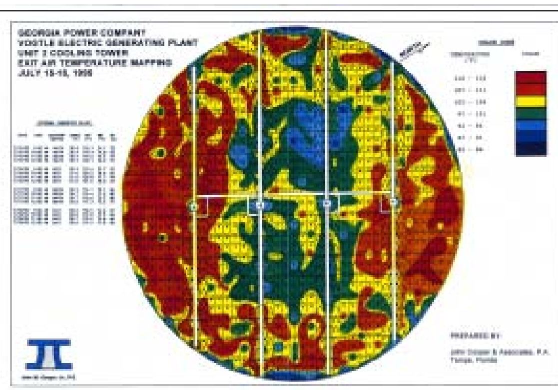


Figure 27.

ciency. John Cooper's new recommendation is included at the bottom of Figure 28 and will be discussed later. Within the parentheses, the efficiency that was achieved with each modification is included.

Interact: How has performance responded to the gradual zones of nozzle sizes? What do the patterns in the temperature and air velocity mappings tell you about the tower?

July 30, 1999. 3:26 p.m.

"I talked to John Cooper and he has come back to us with a new modification for the tower. He regrets that he was mistaken in his last modification, but wants to make it right, if we will allow him," Patrick began. "He says he knows where his analysis went wrong and is willing to provide the information for the new modification free of charge."

Robert leaned back in his chair a little. "Well I should hope so. It has cost us lots of money since the modification. It will cost us lots more if we don't correct it. Has anyone done an analysis on the amount of money we are losing due to the last modification?"

Kerry flipped through some papers. "With the tower performing at 79% efficiency, we are about 5 MW deficient based on our tower design expectations."

Patrick interjected, "I have been able to arrange a meeting with John Cooper to get more details about his opinion on what the error was and his new design. He will meet with us in two days."

Robert stood up. "In the meantime, to refresh our minds, let's look at how much a modification like this costs."

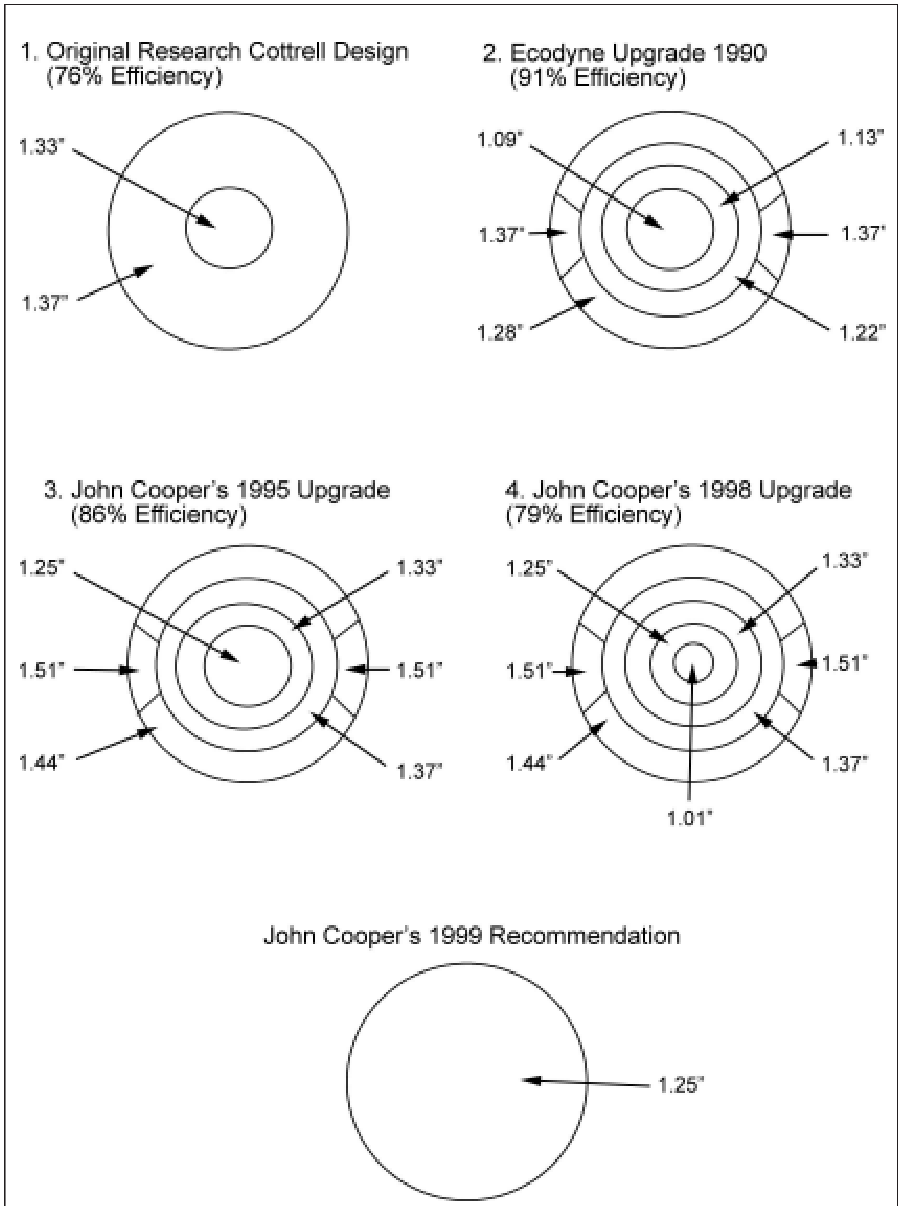


Figure 28.

Kerry's Report on Tower Modification Costs

Beginning with the tower modification in 1995, the Minor Design Change (MDC) No. 97-V2M047 lists that the material costs associated with the change was $116,000. The installation cost was about $50,000. This modification included adding 828 new nozzle locations in the tower for better distribution of water. It also included adding more fill in some regions and 8 stainless steel flow diverters. These items will not be repeated in subsequent modifications.

It can be assumed that since the labor costs are in-house, that those costs remained about the same as in 1998. Several aspects of the modification were not carried out in 1998, therefore reducing the material costs somewhat. The total cost of the 1998 modification was $90,000.

August 1, 1999. 1:08 p.m. : The Meeting with John Cooper

Patrick, Kerry, and Robert entered the small conference room to meet with John Cooper. John seemed quite relaxed considering the potential for harsh criticism for previous miscues.

Patrick began the meeting. "John, thank you for coming in to meet with us about this. We are looking forward to hearing your opinion about our problem, both what created it and how we can fix it."

John smiled. He had known this audience for some time and expected calm behavior, but was unsure if that was what he would receive this time. After all, it was his recommendation before that hurt the tower's, and therefore the plant's, efficiency. "I should be thanking you for allowing me this opportunity to come back here in light of the present situation. I will begin by talking some about my previous approach. I will also talk about what I think the problem is and how I plan to fix it.

"The problem with the Vogtle tower and all of these Belgian-designed towers that I know of, and I'm pretty familiar with most of them, is that all of them fail to meet their original performance-guaranteed levels because of water distribution problems. It's not that the towers are too small or not tall enough, it's just that there is not sufficient detail, not enough attention was paid to detail for the design of the distribution systems.

"Consequently, Georgia Power held their tower designer's feet to the fire after the towers failed at the performance test. The tower manufacturer spent over two million dollars out of their own pockets to try to upgrade their towers. They successfully raised their design performance from about 76% (1989) to about 91% (1990), which left them about a degree and a half deficient even after their best efforts.

"After the Plant Vogtle tower had been modified by the original designer of the tower, the hydraulics were pretty fouled up. My upgrade design is an extrapolation of their design. Although I did all the things that I've done in all my other upgrade packages, I didn't undo what the manufacturer had done to the tower. So my design didn't work. It took some thought and additional analysis for me to understand why my upgrade did not work for this cooling tower. Once I realized what I had done, it was a simple matter of correcting it.

"One of the things that the tower manufacturers did in the Plant Vogtle towers was to bias the water loading towards the perimeter of the tower. I've seen this done before. It is not an unusual thing to do. The coolest air in the cooling tower is in the perimeter. Air that goes through the center of the tower is warm because it's preheated by flowing through all the rain zone of the fill. The tower designer biased the water loading to the extreme however. In the process, they raised the static head over the water distribution system by about 8 inches, which caused some problems in the riser pipes.

"Excessively high *riser water levels* didn't exist until after the upgrade mods were put in the tower by the tower designer in 1989. In fact, that high water level was created when they reduced the nozzle size of the interior of the tower. Originally, all of the nozzles in the interior of the tower were 1.33 inches in diameter. The tower manufacturer reduced them all to 1.09 inches in their modification. My exit air mappings back in 1995 showed that the entire interior of the tower was cold. I had assumed that was by virtue of the fact that all of the interior nozzles were reduced in size. But, I know now that's only partially true. The riser water level is high because of the back pressure that's put on the riser pipes at the flume-riser interface.

"The cold air that I saw in the mappings (Figures 29, 30) in the interior of the tower was largely caused by the presence of large eddies interfering with the normal flow of water between the risers and the flume. The flow vectors, or the direction of

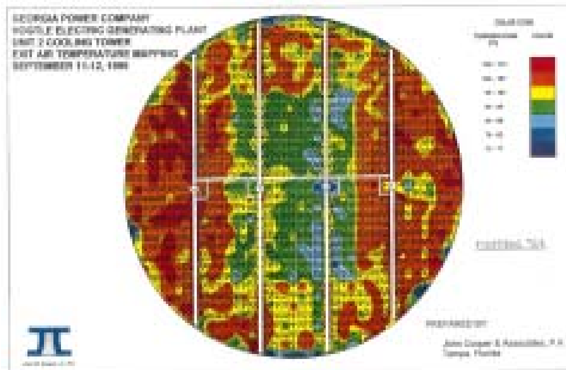


Figure 29.

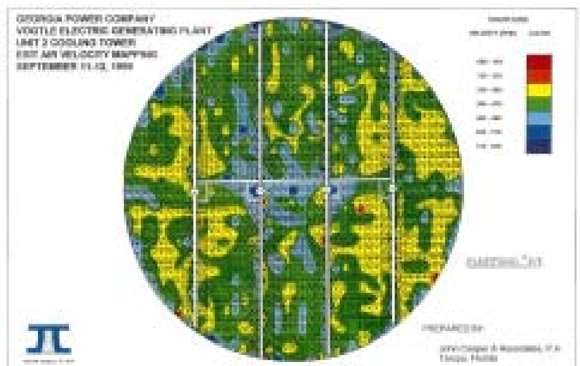


Figure30.

flow, were no longer such that water flowed from the riser, making a gradual bend of 90 degrees in the flumes (Figure 31), but instead water in the riser was flowing upward, bypassing the entrance to the flume, then bending down in a circular motion (Figure 32). It is a vertical eddy in front of the flume face. There is a significant head loss associated with that flume and riser flow pattern. Once I realized that was the root cause of the hydraulics problem, it's a simple matter for me to formulate a corrective action to eliminate the turbulent flow at the riser-flume interface.

"When I first approached the Vogtle cooling tower performance problem, I noted that the riser water levels were excessively high. Generally these water levels should be only two inches, but with respect to walkway elevations, the water levels of the Vogtle towers were almost five feet above that. Unlike all the other upgrade designs I've been involved in, rather than trying to maintain the existing water levels, I tried, along with redistributing the water, to reduce the water level in the riser. That was a critical mistake. By attempting to reduce the water level by a foot, I, in effect, reduced the static head of all the nozzles by a foot. That put the static head in the water distribution system at a level that was lower than it was in the original design. After adding over a thousand nozzles to the original design, it created water distribution problems at the perimeter of the tower and at the center of tower. Some nozzles in the longer pipes had no water whatsoever coming out of them. So there was not enough static head to reach all of the lateral distribution pipes.

"As I say, it took me a while to understand where I went wrong. After modeling the original design and discovering that the tower manufacturer had raised the *static head* by 8 inches, it was clear to me that what needed to be done was the original water level needed to be reestablished. The extreme bias of the water from the center of the tower to the perimeter of the tower had to be dissolved. In other words, the nozzle sizes had to be varied to release more water in the center of the tower and less at the perimeter.

"I am currently working on a computer model of the Vogtle tower to consider both the water distribution and the need to lower the riser water level. I feel quite certain that the modified computer program will produce results better than this facility has seen. Once the model has been verified, I will generate a report citing the history we have discussed here today and the problems I believe to exist in the tower. It will also include my suggestion for modification of the cooling tower."

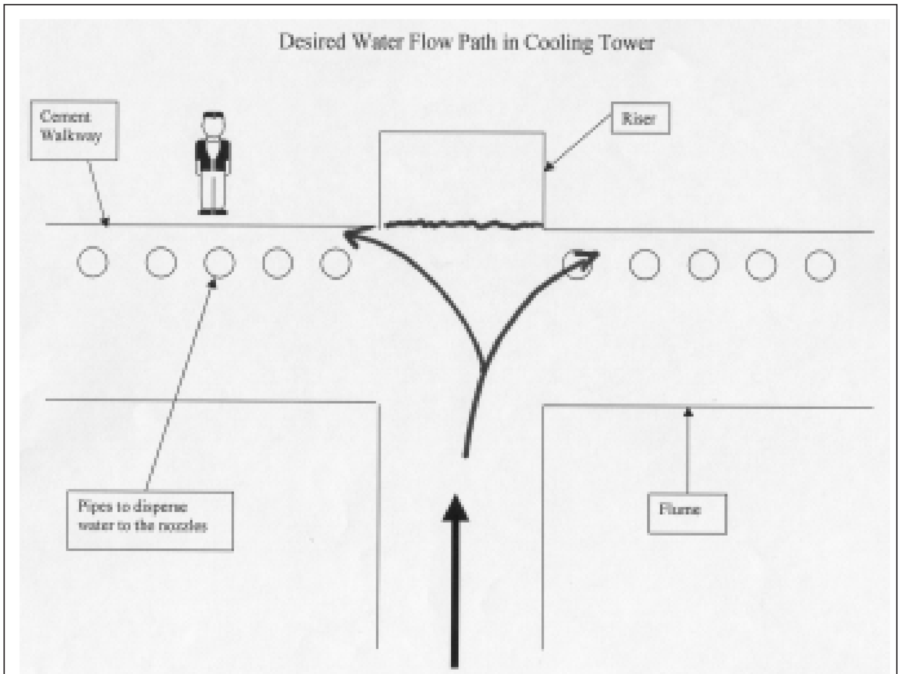


Figure 31.

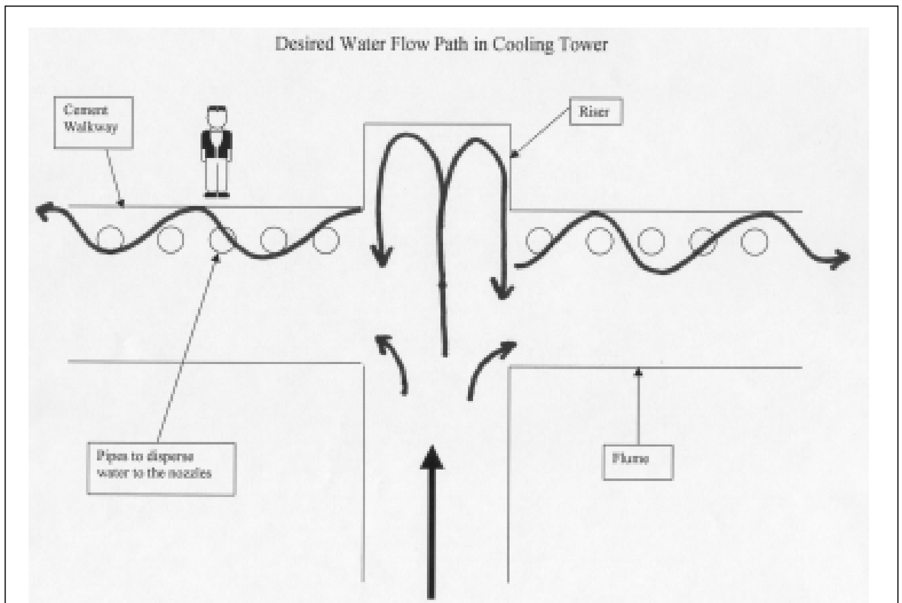


Figure 32.

Interact: What does John Cooper consider the problem with the Vogtle cooling towers?

Intuitively, how might high riser water levels affect the tower's performance?

How might the riser-flume interface be configured differently to reduce turbulence?

Kerry's Memo on the Cost Impact of Cooling Tower Malperformance

For a tower operating at 80%, the cold water temperature exiting the tower is about 2.5 to 3 degrees too hot. This translates to 5-7 MW of power in the summertime. With the loads that the plant normally has in the summer, every Megawatt counts. We have had to start up our peaking plants to supply additional power during the summers and this power costs the company more to produce than it would at Plant Vogtle. For the sake of comparison, according to the Georgia Power website, the cost of power at a nuclear plant per Kilowatt-hour (KWh) is $0.005. The cost of power per KWh at a natural gas or diesel plant, like our peaking plants, is between $0.0417 and $0.0466. This shows the importance of producing as much of the needed power as possible at a base load plant like Vogtle. Furthermore, if our base plants in conjunction with our peaking plants cannot supply the needs of the power grid, we have to buy power from our competitors. This power may cost as much as $1.00 per KWh.

Therefore, in extreme demand periods we are faced with two costs: the unrealized profits for inefficiency and the cost of buying from our neighbors, either internal or external to the Southern Company.

For a plant producing 1200 MW, a few extra Megawatts of power seems insignificant. However, this incremental saving extended over the life of the facility, which is expected to be another 30 years or so, is quite substantial.

Interact: Compute potential cost saving per year for 1% improvement in efficiency.

September 21, 1999. 7:45 a.m.

John Cooper's 1999 Recommendation

"Thermal performance testing of Plant Vogtle Unit 2 cooling tower carried out in July 1999 proved conclusively that upgrade design modifications developed by John Cooper and Associates, P.A. for Georgia Power Company in 1995 and in 1998 have resulted in a reduction in cooling tower thermal performance efficiency." — John Cooper, Technical Report No. JCA-GPC-1099082, August 23, 1999

Patrick had been eagerly awaiting the report from John Cooper for several days and was excited to hear that it had been delivered late yesterday afternoon. Everyone had been wondering exactly what John's recommendation would be this time for the tower. Patrick took the time to sift through the report and found that much of the preliminary material was similar to the August 1st meeting's discussion, only with more numbers. As he further perused the document, Patrick came to the new recommendation and some new tower mappings. Since the team was meeting at 10:00 this morning anyway, Patrick decided to make himself familiar with the report.

1999 Cooling Tower Mappings

Patrick looked carefully at the color mappings (Figures 29, 30) of the cooling tower. At first glance, there was an obvious difference between the temperatures (about 15-20 degrees) at the center of the tower and at the perimeter. This told Patrick that the air reaching the center of the tower had an easy path out of the tower, never fulfilling its purpose to cool the hot water. Increasing the flow of warm water in the tower's center should block this path of least resistance that the air was taking.

The velocity mapping further confirmed what was occurring in the tower. The blue regions demonstrated that cold air was rushing through at a high velocity, making the center part of the tower less efficient. From the data shown graphically in Figures 29 and 30, Patrick realized that the tower needed more water flow in the center, but not so much as to make the perimeter ineffective. This additional water would provide more resistance to the cold air rushing through the center, increasing contact time between the water and the air. The ideal temperature mapping would show a uniform temperature, i.e. a single color.

10:00 a.m.

"I have had an opportunity to look over the report," Patrick began. "I think we should all look at it in detail later. For now, I will just highlight some excerpts about the actual tower modification he suggests."

"In order for the Vogtle Unit 2 cooling tower to be upgraded to 100%, or better, thermal performance capability, it is imperative that the head versus flow characteristics of the cooling tower water distribution system be restored to the original setting. This will eliminate the excessively high riser water levels in the cooling tower and the associated abnormal water flow patterns at the flume-riser interface points. A computer hydraulic model of the original Vogtle cooling tower design shows that the average effective flume water elevation required to produce the original measured circulating water flow rate value of 535,200 gallons per minute (gpm) is 51.69 feet." (Cooper Report, August 23, 1999, p.11-12)

"If we completely eliminate the outward biasing of water flow to the perimeter of the cooling tower by using a single nozzle orifice size (Figure 28) throughout the cooling tower and select a nozzle orifice size that maintains our anchor point hydraulic conditions, i.e., 535,000 gpm at effective flume water elevation of 51.69 feet, then our thermal performance enhancement goals should be achieved." (Cooper Report, August 23, 1999, p.12)

Robert smiled. He wondered if this was really the solution to the cooling tower problem. "I would like for everyone here, including myself, to become familiar with as much of the cooling tower story as possible including this new report. Kerry, could you please look at the potential risks involved with taking on this project. Patrick, could you make some phone calls and find out how much money we're talking about to do this modification, parts and labor. Feed these numbers to Kerry for his financial assessment of this change."

Interact: How does the suggested water distribution configuration compare to previous configurations?

Financial Assessment for the Modification

Patrick walked into Kerry's office and placed a fax down on his desk. "Kerry, I've gathered the numbers that you need for the financial analysis of the modification. I've talked to maintenance and they've estimated the labor costs to be about $40,000 for this change. I also talked to Mid-South Nuclear and this is the quote for the nozzles needed according to the report."

Kerry thumbed through some files to find the minor design change (Appendix B) for the cooling tower modification back in 1995. He hoped to find the complete analysis, but was unsure if it was included in this document. The front page of the MDC listed the savings for the plant as about $3 million over the plant's lifetime of at least 32 more years.

"The benefit gained from modifying the tower in 1995 was expected to be $3 million over the lifetime compared to no benefit if the tower was not modified," Kerry began. "Similar analyses can be done for the new proposed modification. Note that the benefit is based on expected gains in performance, and since 1995, we haven't realized those. Future analyses for modifications of the cooling tower should possibly consider the benefits of partial success."

September 27, 1999. 9:45 a.m. : Risk Discussion and Decision Point

Robert had been thinking for some time about this project. There were two options to choose. Robert had asked Patrick and Kerry to present the two alternatives.

Patrick presented Option 1. "The first option is the safe option. This is simply to revert to the modification that produced a tower efficiency of 91% during 1990. This modification is 100% reliable. The configuration is known to us and will require the labor to implement, but little material cost since the old nozzles were stored."

Kerry presented Option 2. "The second option is to modify according to John Cooper's new recommendation to implement a single nozzle orifice size. This option may result in one of three outcomes: an increase in performance, a decrease in performance, or no change. The likelihood of these three outcomes is unknown."

Kerry continued, "To simply accept the tower's operation below design performance for option 1 seems passive. Higher demand on the power industry from both competition and consumption makes this option impractical from a financial perspective. We know the payoff if the modification is successful."

Patrick interjected, "How many times can we spend the money trying this? 91% is a solid performance number. Don't get me wrong, I like John Cooper, but whether or not he knows what he's talking about is a different story altogether. We have heard of his success, but we have also seen his modifications not only fail to improve our tower, but actually hurt its performance. Twice."

Robert entered the discussion. "We know the risk is minimal if we choose Option 1, but we also know its limitations. We also know there is more risk in choosing Option 2 and based on the track record we have here, that's scary. However, the potential payoff is greater than Option 1. A good question is how to assess the risk involved here, the reliability of John Cooper's ideas, and the likelihood he's wrong for a third time. This is critical to the decision and I have no idea how to get a handle on it."

Glossary

backpressure – see exhaust pressure.

basin – the reservoir beneath the cooling tower where cooled water collects and flows to the pumps for recirculation through the condenser.

circulating (circ) water cycle – the water cycle that is responsible for removing the heat from the turbine water cycle. This cycle flows through the cooling tower and condenser.

control stage – initial set of turbine blades that control the amount of steam admitted to the turbine.

cooling tower – a large heat exchange device utilizing air and evaporative properties of water to remove heat from the water and place it in the atmosphere.

counterflow cooling tower – a cooling tower in which the air path is the opposite of the water path during heat exchange.

crossflow cooling tower – a cooling tower in which the air path flows perpendicular to the water path during heat exchange.

deregulation – the recent governmental change that opened the power industry to competition from other power producers.

electric heated pressurizer - a tank or vessel that acts as a head tank (or surge volume) to control the pressure in a pressurized water reactor.

exhaust pressure – (also backpressure) the pressure on the condenser side of the turbine that results in less work output per pound of steam fed into the turbine. Reducing this pressure has a positive effect on power output.

feedwater - water supplied to the reactor pressure vessel (in a Boiling Water Reactor) or the steam generator (in a Pressurized Water Reactor) that removes heat from the reactor fuel rods by boiling and becoming steam. The steam becomes the driving force for the plant turbine generator.

fill matrix – a volume of many different surfaces used to increase the contact surface area between the air and water for maximum heat transfer. This asbestos or plastic matrix also increases the duration of the water's descent for greater heat transfer.

flumes – in the Plant Vogtle towers, horizontal, rectangular concrete pipes that carry water from the risers to the lateral distribution pipes. These concrete pipes also serve as walkways inside the cooling tower.

generator – a device utilizing the principles of induced current (rotating a magnet inside a coil of wire to produce an electric current) to produce power for distribution to customers. The generator rotor is rotated by its connection to the turbine rotor, which is driven by steam pressure.

governor valves - hydraulically controlled valves that control the admission of steam to the turbine.

heat exchanger – a device that passes two fluids by each other to cool one stream and heat the other. The streams may or may not mix. A heat exchanger that mixes streams is found in the Plant Vogtle cooling towers. A heat exchanger that does not mix streams acts as the condenser at Plant Vogtle.

hotwell - attached to the bottom of the condenser, collects water as it is condensed from the turbine exhaust.

hyperbolic – refers to a shape that follows the general function, $x=y^2$. This shape has some unique strength properties and it is used commonly in large natural draft cooling towers to gain more strength using less materials.

main and auxiliary feedpumps - pumps that are used to raise the feedwater pressure before it enters the steam generator.

make-up water – the stream of water added to the circulating water cycle to replace the amount that is lost due to evaporation during cooling tower operation.

manifold – a union of multiple pipes typically resulting in a larger single pipe.

mechanical draft cooling tower – a cooling tower that uses fans to force air through the tower to cool water.

natural draft cooling tower – a cooling tower that utilizes the principles of gas laws to cause air flow through the tower. More specifically, hot air rises due to lower density, so as air enters the cooling tower and is warmed, it has a tendency to rise, similar to a chimney effect, thereby requiring no external input to force air flow.

nozzle – in Plant Vogtle towers, the plastic orifice that sprays water onto the splashplate. The orifice size can be varied to distribute water in certain patterns across the tower.

nozzle ring – the circular plastic component that holds the nozzle and splashplate in place. It is connected to the lateral distribution pipes.

nuclear reactions – in a nuclear power plant, this involves bombarding uranium atoms with neutrons in order to split the atoms, a process called fission, which releases large amounts of heat. This heat is used to drive the power cycle at a nuclear plant.

Nuclear Regulatory Commission — Federal Agency that oversees all nuclear related activities throughout the United States. See http://www.nrc.gov The Nuclear Regulatory Commission (NRC), part of our government, makes sure nuclear power plants in the United States protect public health and safety and the environment. The NRC licenses the use of nuclear material and inspects users to make sure they follow the rules for safety.

pressurized water reactor (PWR) - a reactor in which heat is transferred from the core to an exchanger by high temperature water kept under high pressure in the primary system. Steam is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.

rainzone – the region between the fill matrices and the basin where the water is in freefall. The region has an appearance similar to rain. This is the final significant opportunity for heat transfer in the circulating water cycle.

reaction blade stages – the turbine stages where the design of the turbine blades equally divides the total pressure drop between the stationary and rotating blades.

reactor vessel - cylindrical vessel at the heart of the nuclear reactor with a hemispherical bottom and a flanged and gasketed, removable upper head. The vessel contains the core (fuel cells), core support structures, control rod clusters, thermal shield, and other parts directly associated with the core.

reactor water cycle – the highly purified water cycle that is used to transfer the immense amount of heat from the nuclear reactions to the turbine water cycle for power production.

regenerative feedwater heating cycle - series of heat exchangers that preheats the feedwater before returning it back to the steam generators. Used to improve efficiency.

reheat steam - steam that passes from the high pressure turbine through the moisture separator reheater before entering the low pressure turbine.

riser – the large vertical pipe that carries water from the base of the cooling tower to the distribution level.

riser water level – the level that water is pumped to in the vertical riser pipe. According to John Cooper, the riser water level should be about 1 foot above the flumes. At Plant Vogtle, the riser levels have been about 5 feet above the flumes.

splashplate – a surface for the nozzle to splatter water on to produce more water particles, thereby increasing the surface area of the water stream and increasing the resulting heat transfer. The splashplate creates a hollow cone pattern beneath itself, requiring overlap of cones from neighboring spray nozzles.

spray nozzle – consists of the nozzle ring, nozzle, and splashplate and is connected to the lateral distribution pipes in the cooling tower. Constructed of plastic.

static head – the vertical distance in feet between the free level of the source of supply and the point of free discharge or to the level of the free surface of discharge. At Vogtle, this refers approximately to the distance vertically from the pump level to the height in the risers that water reaches. Some error is involved, as it is unknown here how far beneath pump level the water travels.

steam generator - the heat exchanger used in some reactor designs to transfer heat from the primary (reactor coolant) system to the secondary (steam) system. This design permits heat exchange with little or no contamination of the secondary system equipment.

steam jet air ejector - used to remove air and noncondensable gases from the condenser. It consists of a suction chamber, diffuser, and steam nozzle.

turbine water cycle – the water cycle that is turned to steam in the steam generator. This steam is used to spin the turbine rotor and, in turn, spin the generator to produce power. The cycle continues through the condenser for cooling by the circulating water cycle.

turbine shaft steam seals - uses low pressure steam (4 psi) to seal the turbine openings where the rotor penetrates the housing. Necessary to keep air leakage to a minimum.

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Appendix A: Description of the Reactor and Turbine Water Cycles

Reactor Water Cycle:

The reactor water cycle consists of a reactor and four closed reactor coolant loops connected in parallel to the *reactor vessel*, each loop containing a reactor coolant pump and a *steam generator*. The reactor water cycle also contains an *electric heated pressurizer* and other auxiliary equipment. The reactor core at Plant Vogtle is capable of producing 3565 MWt (Megawatts thermal).

High pressure reactor coolant (highly purified water) circulates through the reactor core to remove the heat generated by the nuclear chain reaction. The heated water exits from the reactor vessel and passes via the coolant loop piping to the steam generators. Here it gives up its heat to the *feedwater* to generate steam for the turbine generator. The cycle is completed when the water is pumped back to the reactor vessel. The entire Reactor Coolant System is composed of leaktight components to ensure that all radioactivity is confined to the system.

Turbine Water Cycle:

The Westinghouse PWR system (used at Plant Vogtle) utilizes saturated steam for transporting thermal energy from the steam generators to the turbine, where it is converted to mechanical and then electrical energy. Energy is conserved as the steam expands through the nozzles and blades of the turbine on its way to the condenser.

The main steam system transports the steam from the outlet of the steam generators to the various system components throughout the turbine building. The steam is used for operational auxiliaries such as *turbine shaft steam seals*, driving *main and auxiliary feedpumps* and *steam jet air ejectors*. The principal purpose of the steam is to drive the main turbine and provide *reheat steam*.

Steam admission to the double flow, high pressure turbine is controlled by *governor valves* and can be quickly isolated by quick acting stop valves in an emergency. These valves are not an integral part of the turbine. Four separate pipes direct the steam from the governor valves to the nozzle chambers. Thermal energy is converted to mechanical energy by expansion through a *control stage* and a number of *reaction blade stages* within the turbine. On leaving the last row of high pressure blades, the steam has a moisture content of approximately 10 percent. The steam is passed through a moisture separator and reheater to improve the turbine efficiency, reduce the low pressure turbine exhaust moisture, and reduce maintenance on the low pressure blades of the turbine rotor.

The moisture separator and reheater are housed in one pressure vessel. Wet steam enters the vessel and passes through the moisture separator where the moisture is removed and drained to a heater drain tank. The steam rises above the moisture separator, passes over the tube bundle and is reheated by high pressure and high temperature steam. The hot reheat steam is conveyed to the double flow, low pressure turbines. The steam expands across the turbine blades and is exhausted into the condenser.

The condenser is a large heat exchanger that has steam exhaust on the shell side and circulating water on the tube side. As the steam hits the cool tubes it is condensed into water. The condensed water (condensate) is collected in the bottom of the condenser *hotwell*. The condensate and feedwater system returns the condensed steam from the turbine condenser and drains from the *regenerative feedwater heating cycle* to the steam generators, while maintaining the water inventories throughout the cycle.

TT 1-16-98

Procedure 50016-C Rev 11	Minor Design Change (MDC)	Page 1 of 24

MDC NO.: 97-V2M047 REV. 0 Outage/POD 2R6

MDC TITLE: **Cooling Tower Water Distribution Improvement**

SAFETY RELATED [ ] YES [**X**] NO PROJ. CLASS **626** UNIT **2**

SYSTEM NO,: COMPONENT TAG NO.; SYSTEM DESCRIPTION:
1401, 2-1401-W4-001, Circulating Water System

DESIGN OBJECTIVE:
To improve water distribution over the cooling tower fill system, thereby reducing the volume of cold air bypass flow into the exit airstream which will enhance the thermal performance efficiency of the cooling tower.

SUGGESTED CHANGE (attach sketches, mark-up dwgs, etc.) - if known:
Nozzle locations, orifice sizes and lengths will be optimized. Flow diverters will be installed at the entrances of eight manifold pipe assemblies adjacent to risers 2 & 3. PVC fill will be installed adjacent to the flumes.

JUSTIFICATION AND DETAILED EXPLANATION (Include estimate of installation labor and material cost):
Exit air temperature and velocity mappings prepared by John Cooper & Associates in 1995 identified air/water distribution problems. To improve water distribution in the vicinity of the flumes and risers, 828 new nozzle locations will be added. To improve water distribution near the cooling tower shell, the orifice size of 536 existing perimeter nozzles will be will be increased. To properly redistribute the flow of hot water droplets over the plan area of the cooling tower system, 9024 nozzle orifice insert sizes will be optimized. To eliminate areas of high velocity, cool, airflow in the central portion of the cooling tower along the sides of the water distribution flumes, high efficiency film-type PVC fill will be installed adjacent to the flume walls. To more evenly distribute water, 8 additional stainless steel flow diverters are required at the entrances of each of the 8 manifold pipe assemblies adjacent to risers 2 and 3.

The material cost of this modification will be approximately $116,000. The installation cost is expected to be approximately $ 50,000. The improvement in thermal performance efficiency of the cooling tower is expected to be approximately 2 °F resulting in a 1.54 MW increase during June, July and August or a $3,011,526 savings over the remaining life of the plant.

REFERENCES: (Origination Doc,. Commitment, AFR, RER, REA, etc.) **None**

CONCURRENCE FOR INSTALLATION Melvin Griffin
Maint Manager or PMMS Manager

Tracy Thompson 8-25-97 Paul H Bell 8-29-97
RE DATE ES DATE

W Brumenter 8-29-97 97-V1M0009
MES DATE OPPOSITE UNIT MDC NO

Printed August 25, 1997 Plant Vogtle F:\HOME\TATHOMPS\1401\MDC\TOWER2.DOC

ORIGINAL

Approved By W.L. Burmeister	Vogtle Electric Generating Plant	Procedure Number 50010-C	Rev 12
Date Approved 06/03/98	FIELD CHANGE REQUESTS	Page Number 9 of 12	

FIELD CHANGE REQUEST

☐ MINOR
☒ SIGNIFICANT

FCR NO. 97-V2M047-0-F001 SHEET 1 OF 10

APPLICABLE PAGE/SKETCH/DRAWING NO. 2X4AD01-20015/20016 REV. 2

REASON FOR CHANGE: The resizing of flow nozzle orifices during 2R6 per 97-V2M047 resulted in inadequate flow to the perimeter of the tower. Investigation has shown that the water level in the tower risers dropped at least 1 foot further than projected resulting in too low a head pressure on perimeter nozzles for sufficient flow. The resulting "dry" fill areas at the perimeter allows a significant flow of air to effectively bypass any wetted fill area. This air bypass is the reason for the higher than expected Unit 2 circulating water temperature .

John Cooper, tower consultant, has reanalyzed the Vogtle tower hydraulic model that was the basis for orifice sizing and concluded that the resulting low riser water levels and flow deficiency are due to flume entrance pressure losses being higher than initially assumed in the flow model. The changes described below have been recommended by Cooper to correct the flow problem.

DESCRIPTION OF CHANGE: John Cooper has determined that the flow deficiency at the perimeter of the tower can be corrected by reducing the orifice size of 2908 interior nozzles to 1.01" diameter. This change will raise the riser levels by approximately 1 foot and restore proper head pressure to the perimeter nozzles. The particular orifices to resize are those which may be isolated by closing the central deicing valves. See attached sketches.

DOES THIS CHANGE IMPACT OTHER DEPARTMENTS' PROCEDURES OR PROGRAMS?

☒ NO ☐ YES If yes, list the impact, notify the affected department by memo, and add impacts to RTS Checklist.

RESPONSIBLE ENGINEER: Kerry Walton *K W Walton* 9-30-98 DATE

DESIGN ENGINEERING VERBAL APPROVAL: N/A N/A DATE
(DCPs ONLY)

for Kenneth Walker 10/5/98 *[signature]* 10/7/98
Independent Review DATE ENGRG SUPV DATE

SITE APPROVAL: *[signature]* 10-7-98
MES/MPMMS DATE

DESIGN ENGINEERING APPROVAL: N/A N/A
(DCPs ONLY) DESIGN TEAM LEADER DATE

Printed September 29, 1998 at 14:32

Procedure Rev 50010-C 12	FIELD CHANGE REQUEST	Page 1 of 29

[ ] MINOR
[X] SIGNIFICANT

FCR NO. 97-V2M047-0-F002 SHEET 1 OF ___

APPLICABLE PAGE / SKETCH / DRAWING NO. 2X4AD01-20015/20016 REV. 2

REASON FOR CHANGE: **The resizing of flow nozzle orifices under FCR 97-V2M047-0-F001 resulted in inadequate flow to the perimeter and center of the tower. Recent cooling tower performance test indicated that the tower efficiency was reduced from approximately 90% to 78%. John Cooper and Associates verified the tower problems with a recent thermal mapping and hydraulic modeling. This hydraulic model has indicated that the nozzle orifice sizes changed under the previous FCR were incorrect due to not modeling the tower using the original Research Cottrell effective flume height (EFH). The previous FCR actually lowered the EFH below the original design and therefore starved the perimeter areas of cooling water distribution. To rectify this design John Cooper has reissued an altered design recommendation using the new hydraulic model information that was modeled to retain the same flow rate of water and EFH.**

DESCRIPTION OF CHANGE: **John Cooper has determined that the flow distribution of the entire tower can be restored to better than original design by changing the nozzle orifices to a uniform size of 1.25" throughout the tower. The only additional nozzle size in the tower will be approximately 900 nozzle orifices of 1.05" directly adjacent to the flume distribution pipes. This modification will be much easier to implement since for the most part there will only be one major nozzle size and color (black) along with a minor number of the 1.05" nozzle orifices (white). This design will maintain the same flow rate and raise the EFH to approximately 51.69".**

This FCR will also change the list of affected documents in the MDC on page 6 of 29, drawings 2X4AD01-027, 028, 029, 030, 031 and 032. These documents show quadrants 2, 3 and 4 of the cooling tower distribution piping and nozzle arrangements. Because the new nozzle arrangement in the tower will be uniform throughout, drawings 2X4AD01-027, 028, 029, 030 will be deactivated to make the cooling tower drawings easier to maintain. Drawings 2X4AD01-031 and 032 are already deactivated.

This FCR will also revise the materials list of the MDC (page 26 of 29) to reflect the materials needed to modify the tower design.

DOES THIS CHANGE IMPACT OTHER DEPARTMENTS' PROCEDURES OR PROGRAMS?

[x] NO [ ] YES If yes, list the impact, and notify the affected departments by memo, and add impacts to RTS Checklist.

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