SNC000024

Feasibility of Air-Cooled Condenser Cooling System for the Standardized AP1000 Nuclear Plant

(January 9, 2009)

(the "Revised Report")

Westinghouse AP 1000 Nuclear Plant
Air Cooled Condenser - Design Review

Feasibility of Air-Cooled Condenser Cooling System

for the

Standardized AP1000 Nuclear Plant

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Southern Company Generation
Engineering & Construction Services
Revision 4 – January 9, 2009

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Introduction

The Nuclear Regulatory Commission (NRC) approved the design of the AP1000 Nuclear Plant as part of its efforts to standardize plant designs for the nuclear power industry. Standardization would increase the viability of nuclear power as an energy source by reducing time of construction, time of licensing, and total plant cost. The standard AP1000 plant, as defined in DCD Rev. 17, the latest version currently pending before the NRC, includes a triple exhaust steam turbine cooled by a closed loop wet cooling system. This cooling system is composed of a traditional steam surface condenser to condense steam from the turbine, circulating water pumps to pump cooing water through the system, and a wet, evaporative cooling tower. In this system, cooling water is re-circulated from the tower to the condenser (where heat is transferred to the water from condensed steam coming out of the turbine) and back to the tower, where that heat is transferred to the air via evaporation.[1]

Southern Nuclear was questioned as to whether it had considered an alternate type of system -- a dry cooling system (also known as an air-cooled condenser (ACC)) -- to condense steam from the turbines for the proposed Units 3 & 4 at the Vogtle Electric Generating Plant. This type of system uses air instead of water as the main heat transfer medium for the steam coming out of the turbine. As such, dry cooling is perceived to have less impact on aquatic resources than the traditional closed loop wet cooling system currently included with the AP1000 Nuclear Plant design for the Vogtle site.

Scope

The scope of this study is to review the design of the current AP1000 Nuclear Plant proposed for the Vogtle 3 and 4 units (as described in DCD Rev. 17) and investigate the feasibility and impacts of replacing the wet cooling system with an ACC. To do so, this study examines capital cost differentials and O&M cost differentials between the two systems over the life of the plant. It also addresses impacts on the performance of the unit, differences in consumptive power (station service) requirements, and changes to the plant design and layout that would be necessitated by replacing the wet cooling system with an ACC.

AP1000 Cooling System Conceptual Design

The primary initiative of the NRC in approving the AP1000 Nuclear Plant was to promote generic standardized designs for use at all potential sites and for all potential clients. The standardized plant design for AP1000 would facilitate and expedite licensing, procurement, construction, and make more efficient the commercial operation of the standardized units. The NRC has repeatedly expressed its desire that

[1] There is a small amount of sensible heat transfer (heat transfer taking place due to the temperature difference between the hot water and relatively colder air) occurring in the cooling tower, but it is very small compared to the evaporative heat transfer taking place.

standardized design include the balance of plant beyond the nuclear island.[2] Based on this policy, Westinghouse conceptualized the design of the turbine island and cooling system components as described in the following sections.

Turbine Generator Design for AP1000 w/Steam Surface Condenser

A nuclear power plant operates on the basic principle that released energy from the reactor heats water, creating steam that flows across a turbine, and the turbine turns a generator, generating electricity. In the standard configuration of the AP1000 Nuclear Plant as defined in DCD Rev. 17, the steam leaves the turbine and passes directly over a steam surface condenser, a large heat exchanger filled with tubes that have cold water flowing through them. The cold water in the tubes absorbs the heat from the steam, causing it to condense back into liquid form; it is then pumped back to the steam generator and the process begins again. The cold water circulating through the condenser tubes is pumped out to a wet cooling tower where it is cooled off by dumping its heat to the surrounding air largely by evaporation. Once cooled, the water is pumped back through the condenser tubes. Both circuits operate in a continuous process loop (hence the name – “closed loop cooling system”).

The steam turbine on the AP1000 nuclear plant is a triple exhaust, six flow turbine.[3] This simply means that steam from the Low Pressure (LP) Turbine will exhaust at three distinct points (with two exhaust flows at each point, hence the six flow designation) into three separate steam surface condenser shells. For optimum plant efficiency, the condenser shells are interwoven with pipes so that they receive cooling water in series, meaning that the first shell gets inlet water directly from the cooling tower, the second shell gets its inlet water from the outlet of the first shell, and the third shell gets its inlet water from the outlet of the second. As such, while the first shell receives water at whatever temperature the cooling tower produces, the second shell receives water at that temperature *plus* whatever heat has been added by the steam condensing in the first condenser shell, and the third shell receives water at that temperature plus whatever heat has been added from the steam condensing in both of the first two shells. Because the water in the tubes of each of the condenser shells is at a different temperature, each section will actually condense the steam at a slightly different pressure, with the first shell pressure being lowest due to it having the coldest water, followed by the second shell and then the third. Similar in nomenclature, though not to be confused with corresponding sections of the turbine, these are generally referred to the high pressure (HP), intermediate pressure (IP), and the low pressure (LP) shells.

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[2] *See* Draft Statement of Policy on Conduct on New Reactor Licensing Proceedings, 72 Fed. Reg. 32,139, 32,142 (June 11, 2007) (“the Commission encourages applicants to standardize the balance of their plants insofar as is practicable”).

[3] Note that as with most standard power plant designs, the steam turbine has distinct sections, each generally referred to by the relative pressure of the steam as it passes through it. In the case of the AP1000 standard turbine as describe in DCD Rev. 17, there is the High Pressure (HP) turbine and the Low Pressure (LP) turbine. Only the LP turbine actually exhausts its steam into the condenser; the HP turbine exhausts to the LP turbine as well as other equipment (feedwater heaters, reheaters, etc.) within the plant.

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For the standard AP1000 unit[4], the three condenser shells are designed to operate at the following backpressures at design conditions[5] (from DCP/NUS0302):

HP Shell backpressure	3.57" HgA
IP Shell backpressure	2.82" HgA
LP Shell backpressure	2.37" HgA
Average backpressure	2.92" HgA

The average pressure of the three condenser shells (HP+IP+LP)/3 is the key determinant for unit performance of and operating limitations on the turbine generator.

Figure 1 shows a schematic of the turbine and steam surface condenser configuration for a standard AP1000 unit. The unit is depicted with a natural draft cooling tower, though the standard design per DCD Rev. 17 and DCP/NUS0302 allows for either a natural or mechanical draft wet tower.

[4] Here and henceforth, the term "standard AP1000 unit" is used to refer to the standard AP1000 unit, as specified in DCD Rev 17, proposed for the Vogtle 3 and 4 units.

[5] Design conditions are defined as the unit operating at full thermal load with an ambient air temperature of 95ºF (dry bulb) and 80ºF (wetbulb).

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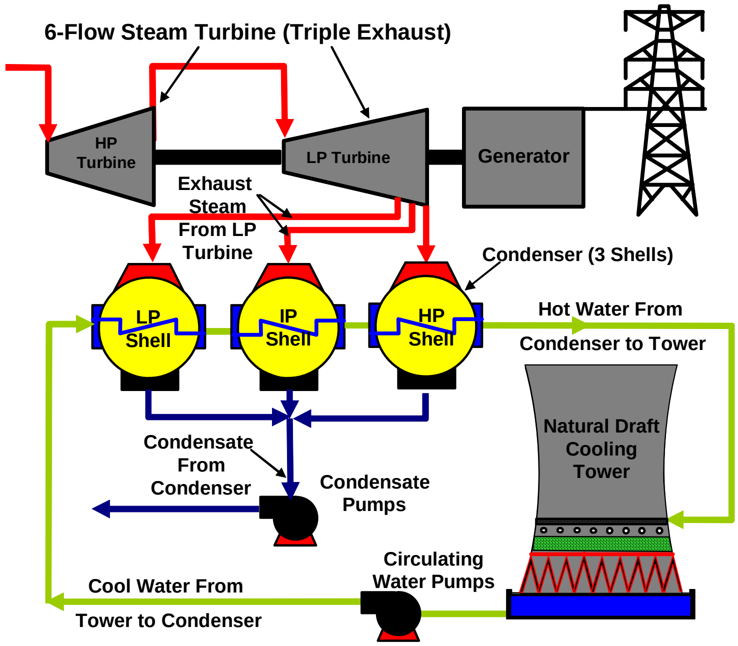

Steam Surface Condenser (Triple Pressure/3 Shell) Configuration
(3 shells = High Pressure, Intermediate Pressure, Low Pressure)

Figure 1 – Standard AP1000 Cooling Cycle

Normal operation of the steam turbine was assumed to be within an average exhaust pressure (backpressure) range of ~ 1.0" to 5.0" HgA. Since an AP1000 unit, or any nuclear unit for that matter, operates with a fixed reactor heat load (*e.g.*, a constant heat rate), the higher the backpressure on the turbine, the less electricity the generator is able to produce, while the lower the backpressure on the turbine, the more electricity the generator is able to produce (down to choke flow backpressure @ ~ 1.0" HgA).
Steam turbines are designed to trip off line to prevent damage to the turbine if the exhaust backpressure rises above a certain set point. The turbine trip point for the AP1000 design was assumed to be at a backpressure of 6.0" HgA with an alarm set point, above which continuous unit operation is not permissible, at 5.0" HgA.

The steam turbine is located on a concrete pedestal above the steam surface condenser which allows steam to be routed directly from the turbine to the condenser below. The exhaust duct carrying the steam to the condenser is called the turbine hood which is simply a distribution/transition piece from the turbine to the surface condenser below. The powerhouse building design is dependent on the turbine and condenser arrangement, size, and configuration. The turbine pedestal supports the turbine with the steam surface condenser located directly under the turbine and pedestal. The design of the turbine extraction piping, location of feed-water heaters, and condensate pumps is also largely dependent on turbine and condenser design and location.

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Cooling Tower Design

The cooling tower was designed based on operating parameters provided by Westinghouse/Toshiba. Because the AP1000 design can include mechanical draft or natural draft wet cooling towers and a final decision has not been made as to which type will be utilized at the Vogtle site, this study investigated both designs. Each tower design uses air to cool the circulating water coming from the condenser; they differ only in the means of moving the air through the tower. A mechanical draft cooling tower uses large fans to force the air through, while a natural draft tower uses the differential air density between hot and cold air to create a draft effect similar to that of a chimney on a fireplace to pull air through. Both are considered viable design options for an AP1000 Nuclear Plant at the Vogtle site.

Current cooling tower design conditions:

Design cooling water flow:	600,000 GPM (gallons per minute)
Design hot water temperature:	116.2°F
Design tower range:	25.2°F
Design dry bulb temperature (natural draft):	96.1°F
Design wet bulb temperature:	80°F
Design tower approach:	11°F
Design cold water temperature:	91°F

A mechanical draft tower usually accommodates an average flow of ~ 12,500 GPM to 13,000 GPM per tower cell. As such, a mechanical draft tower is anticipated to be sized as follows:

Design cooling tower flow:	600,000 GPM
Number of tower cells	48 Cells
Number of towers	2 Towers w/ 24 Cells Per Tower (2x12)
	3 Towers w/ 16 Cells Per Tower (2x8)
	4 Towers w/ 12 Cells Per Tower (2x6)
Fan Hp/Cell	200 HP / 175 kW
Total Tower Fan Power	9,600 HP / 7,162 kW

As a demonstration of the scale of these towers, Figure 2 shows a typical natural draft cooling tower installation and Figure 3 shows a 40-cell (2 x 20) mechanical draft tower installation.

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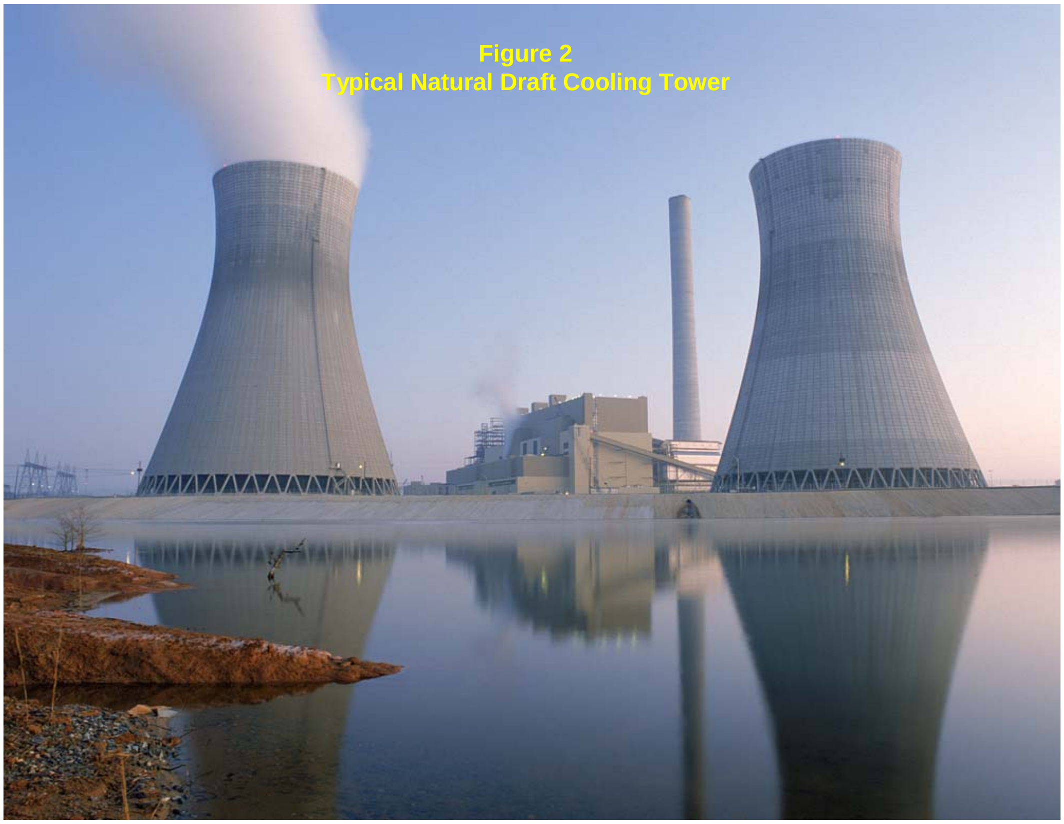

Figure 2
Typical Natural Draft Cooling Tower

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Figure 3
Mechanical Draft Cooling Tower

Steam Surface Condenser Design

Figure 4 shows a typical steam surface condenser similar to the one designed for a standard AP1000 unit by Westinghouse/Toshiba with the following design parameters:

Type Condenser:		Multi-pressure, Single Pass, Three Shell
Design Tube Material		Titanium
Design Tube O.D. / Tube Gage		1.0” O.D / 22 BWG
Design Tube Velocity		8.2 FPS
Design Flow		600,000 GPM
Design Heat Load (MBtu/Hr)		7,565.2 Btu/Hr x 10^6
Design Inlet Cold Water Temperature		91.0 °F
Design Range (Delta T - ° F)		25.2 °F
Design Surface Area		1,235,737 Sq. Ft.
Design TTD - ° F		5.33 °F
Design Pressures	High Pressure (HP) Shell	3.57” HgA
	Intermediate Pressure (IP) Shell	2.82” HgA
	Low Pressure (LP) Shell	2.37” HgA
	Average (Avg.) Shell Pressure	2.92” HgA

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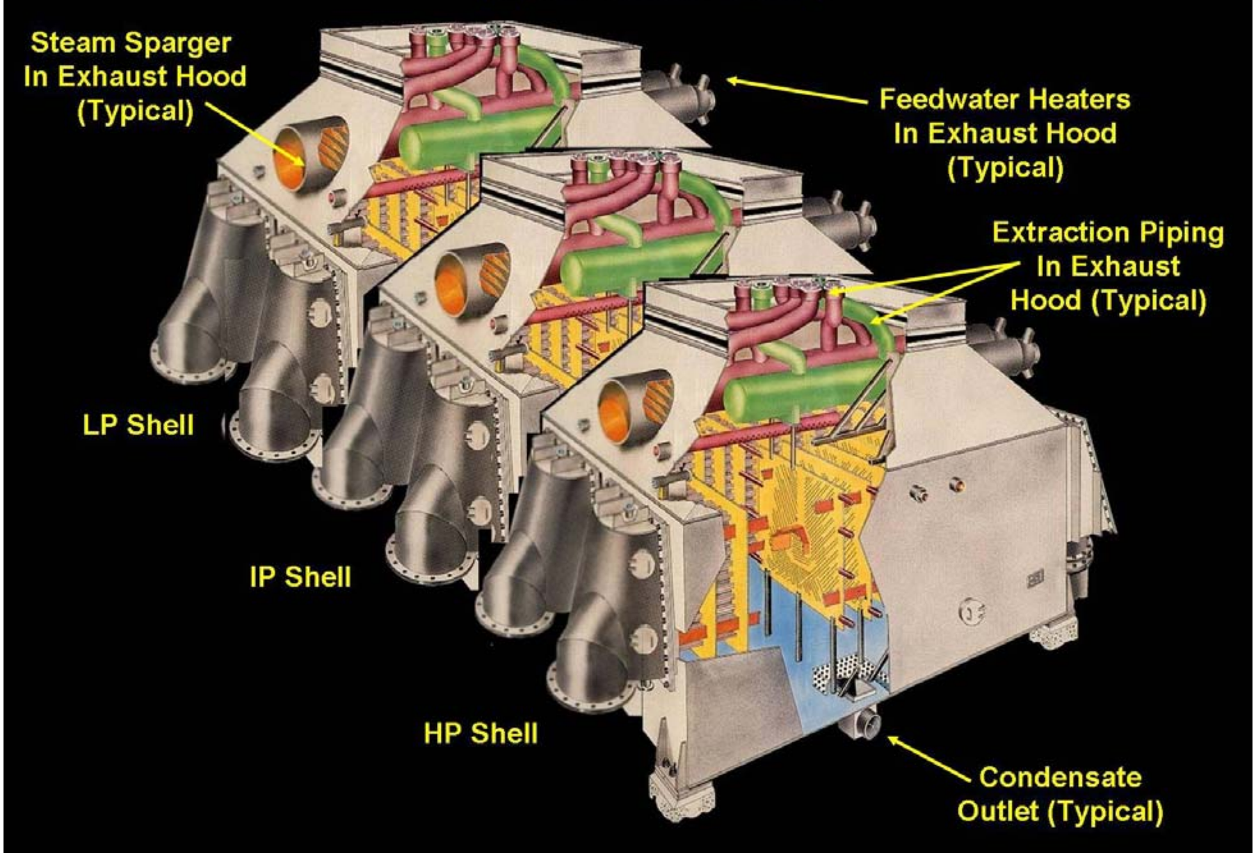
Figure 4 shows the exhaust hood(s) from the three exhaust sections of the LP turbine to the steam surface condenser. Figure 4 also shows the steam surface condenser with feed-water heaters (FWH) installed in the exhaust hoods, which saves on piping and building cost/space. Such an arrangement, which enables proficient use of space in the exhaust hoods rather than requiring additional building space and is common on nuclear plants with large condensers, is part of the AP1000 standard plant layout.[6]

Figure 4
Typical Steam Surface Condenser Illustration
(Triple Pressure - 3 Shell)



To facilitate analysis of unit performance, the steam surface condenser design was modeled and verified for performance based on the Heat Exchange Institute (HEI) Standards (9^{th} edition). Figure 5 shows a turbine backpressure curve versus unit generation (kW). Figure 5 also shows the condenser average design pressure of 2.92" HgA superimposed on the turbine exhaust backpressure curve. Figure 5 shows the gross unit generation of the unit to be ~ 1,193 MW at the turbine/condenser backpressure of 2.92" HgA.

[6] As shown on Westinghouse preliminary drawings APP-2000-P2-901, -903, and -905.

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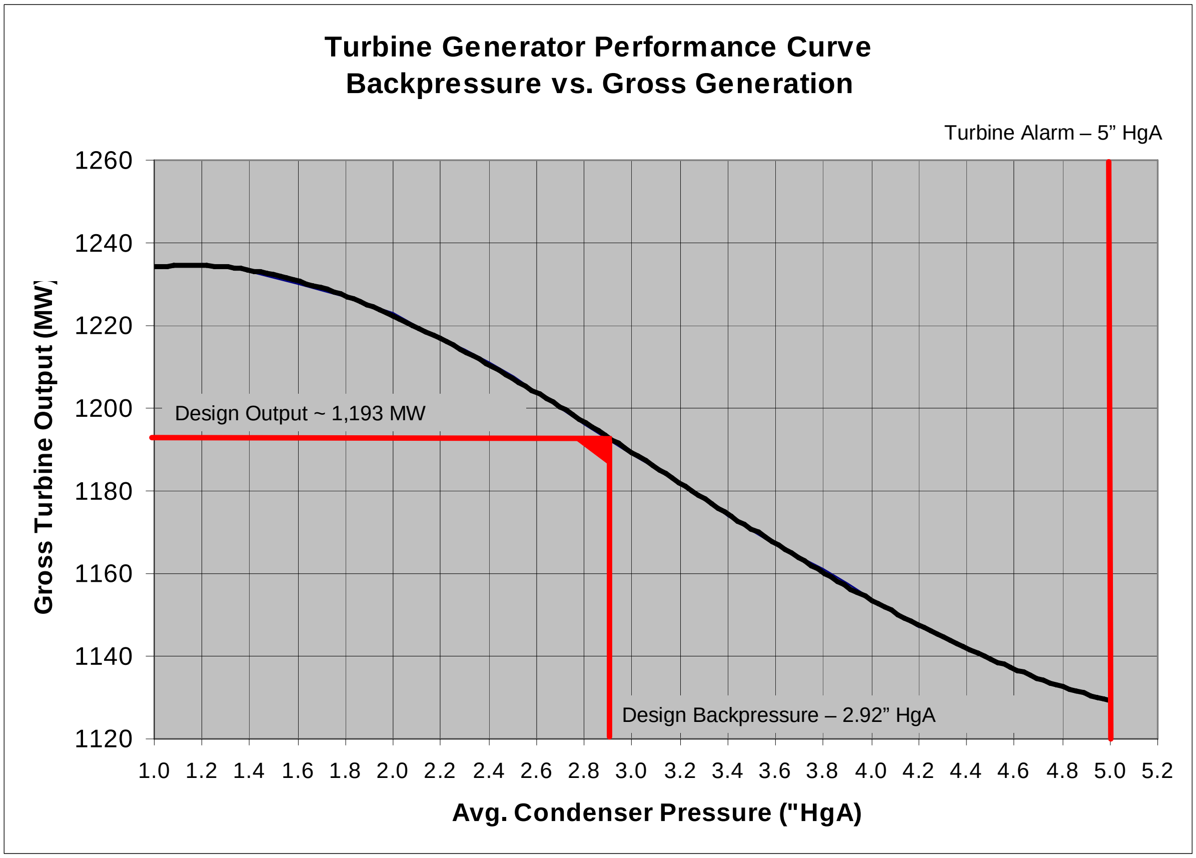
Figure 5 – Turbine Exhaust Pressure Curve



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Current Air Cooled Condenser Technology Is Not Compatible With the Standard AP1000 Turbine

With an air-cooled condensing system, the steam leaving the turbine is piped through large ducts outside of the turbine building to an ACC, where it is condensed into water inside large, metal-finned tubes that have air drawn across their outside surface. The heat is rejected directly to the air and atmosphere. The water is drained into a large tank from which it is pumped back into the plant to create steam. Similar to a mechanical draft wet tower, an ACC uses fans to force air across the finned tubes to achieve optimum heat transfer. Each set of a fan and bank of finned tubes is typically referred to as a module. Figure 6 shows a schematic of what the turbine exhaust and ACC configuration for an AP1000 unit might look like (as none has ever been designed or built).

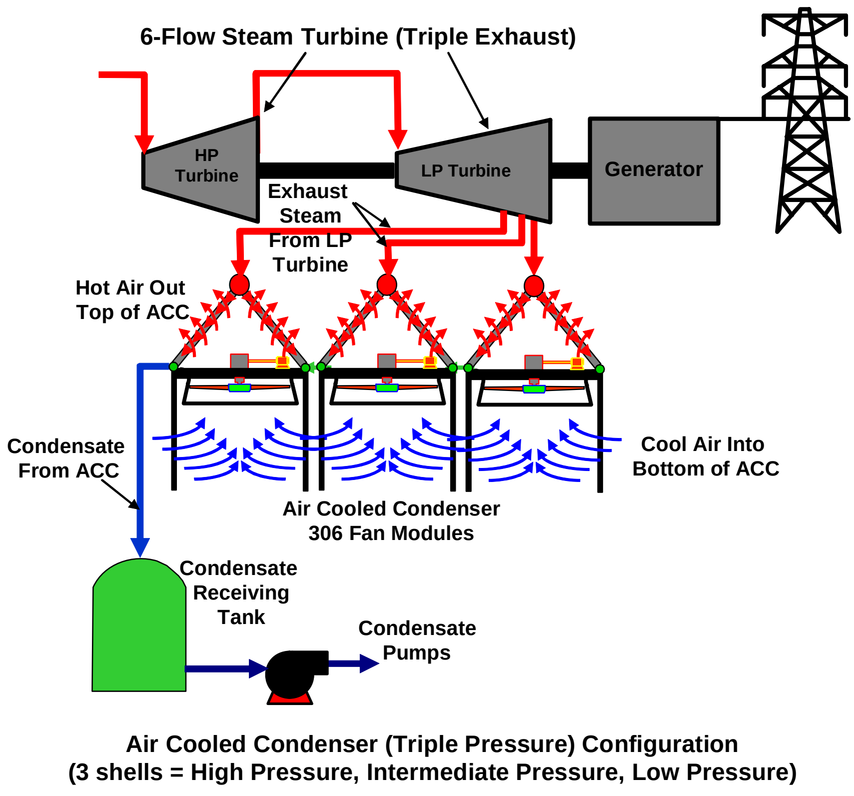


Figure 6- AP1000 Flow Steam Turbine (Triple Exhaust)

Though thermodynamically simpler than a wet system, an ACC is not as thermally efficient. The wet system can utilize water as a cooling medium and capitalize on the comparatively greater quantity of heat that can be removed via evaporation, something the dry system, which relies on convective heat transfer (*i.e.*, the difference in temperature between the steam and the air alone), cannot do. Due to this degradation in efficiency, an air-cooled system must be significantly larger than a comparable wet system to maintain the same unit performance. Because of these limitations, air-cooled systems have typically been built in the United States on smaller units with much lower heat loads than an AP1000 unit. As discussed in more detail below, no one has any experience with such systems on large facilities such as the AP1000 Nuclear Plant. Therefore, the following discussion of dry cooling for the Vogtle units must remain in the realm of the hypothetical.

The chief governing design characteristic of an ACC is the Initial Temperature Difference (ITD), which is the difference between the temperature of the outside air and the saturation temperature of the steam condensing within the tube bundles. Because this saturation temperature bears a direct relationship with the backpressure of the steam condensing within the tubes, the ITD directly impacts the backpressure on the steam turbine. Current “state-of-the art” air-cooled condensers for the utility industry are designed with an ITD of around 40^{o}F, although there have been a few ACCs built in the United States with an ITD of 35^{o}F. No manufacturer of air-cooled condensers has successfully built an air-cooled condenser with a lower ITD than this. The minimum ITD is a material limitation on the technical feasibility of an ACC system in conjunction with the AP1000 steam turbine, especially when the peak ambient temperatures in the vicinity of Plant Vogtle and the maximum backpressures at which the standard AP1000 turbine can operate are taken into account.

As mentioned, steam turbines are designed to trip off-line to prevent damage to the turbine if the exhaust backpressure rises above a certain set point, and the turbine trip point for the AP1000 design was assumed to be at a backpressure of ~ 6.0” HgA. The turbine also has an alarm set point at 5.0” HgA, meaning that if the turbine backpressure exceeds this figure then the unit operators have to decrease the thermal load (and thus electrical output) of the unit so that the backpressure drops back below 5.0” HgA. These design features effectively limit plant operation to conditions which will keep the turbine at a pressure below 5.0” HgA, which corresponds to a steam saturation temperature of approximately 133.5^{o}F. Adding a 35ºF ITD (the current limit of technology) to the 95°F design ambient air temperature for the AP1000 shows that the best ACC that could theoretically be constructed at the Vogtle site would have a design steam saturation temperature of 130ºF (95ºF air + 35ºF ITD = 130ºF saturation temperature). A 130°F saturation temperature would correspond to a backpressure of over 4.5” HgA. While this is technically not in excess of the upper end of turbine’s operational limit, it is close enough to allow no margin for error or variability in other factors which influence performance and reliability of a unit operating with an ACC. This poses several potential problems for a standard AP1000 unit operating with such an ACC.

To begin, an ACC designed at the current limit of technology would result in the operation of thermal cycle significantly deviating from what the AP1000 turbine’s design envisions. As described, the turbine currently exhausts at three distinct pressures. Because an ACC uses ambient air as its cooling mechanism, which is at a constant temperature and not able to be routed in series, in order to operate at three distinct backpressures an ACC would have to be divided into three distinct sections of different sizes.[7] If the lowest backpressure that any of these sections could achieve at design conditions was around 4.5” HgA, the other two sections would have to operate at higher design pressures to correspond to the two higher pressure exhaust sections of the turbine. Certainly one, and most likely both of these sections, would have design pressures higher than the turbine alarm point of 5.0” HgA, rendering the turbine inoperable for large portions of the year.[8] For a “real world” application, one would just make all three sections of the ACC the same size and operate them at the same design backpressure. This would not cause physical harm to the AP1000 turbine; it would still be able to operate safely and reliably if all three exhaust sections were exhausting against the same backpressure. It would, however, cause a substantial performance detriment when compared to the AP1000 standard design because that average backpressure would be much greater than the 2.92” HgA average backpressure of the current wet cooling system and multi-pressure surface condenser. As mentioned earlier, higher backpressure results in less electricity generated.

From an operational standpoint, if wind speed and direction caused any of the hot air being discharged from the ACC’s exhaust to recirculate back to its air inlet, then the higher air inlet temperature would cause a corresponding rise in condensing pressure and the unit might threaten its backpressure limitations. In an extreme case, such a transient condition could theoretically cause the unit backpressure to quickly spike above the turbine’s trip point and the entire unit would be forced off-line. Additionally, as mentioned, air-cooled condensers operate in correlation with the dry-bulb temperature of the air, which can vary as much as 20-30 degrees in a day. This variation, especially when coupled with air inlet recirculation as mentioned above, can cause the inlet air temperature of the ACC to fluctuate dramatically. These wide variances would cause difficulties operationally, as the condenser backpressure will then also fluctuate widely throughout the day. Working with an ACC designed to operate so near the turbine alarm point, the unit operators would have to effectively “chase the weather”, that is to lower the unit’s thermal load (and thus electrical output) in an effort to keep the unit from exceeding backpressure limits when the temperature warms or the wind blows in a particular manner and then increasing it back to ensure maximum generation as the temperature cools or the wind dies. During certain times of the year, this could become an almost constant situation. Such swings could cause unit instability, which is not desirable on any generating unit, but especially on a nuclear unit, which typically would be a baseload unit with a high capacity factor. Such limitations on

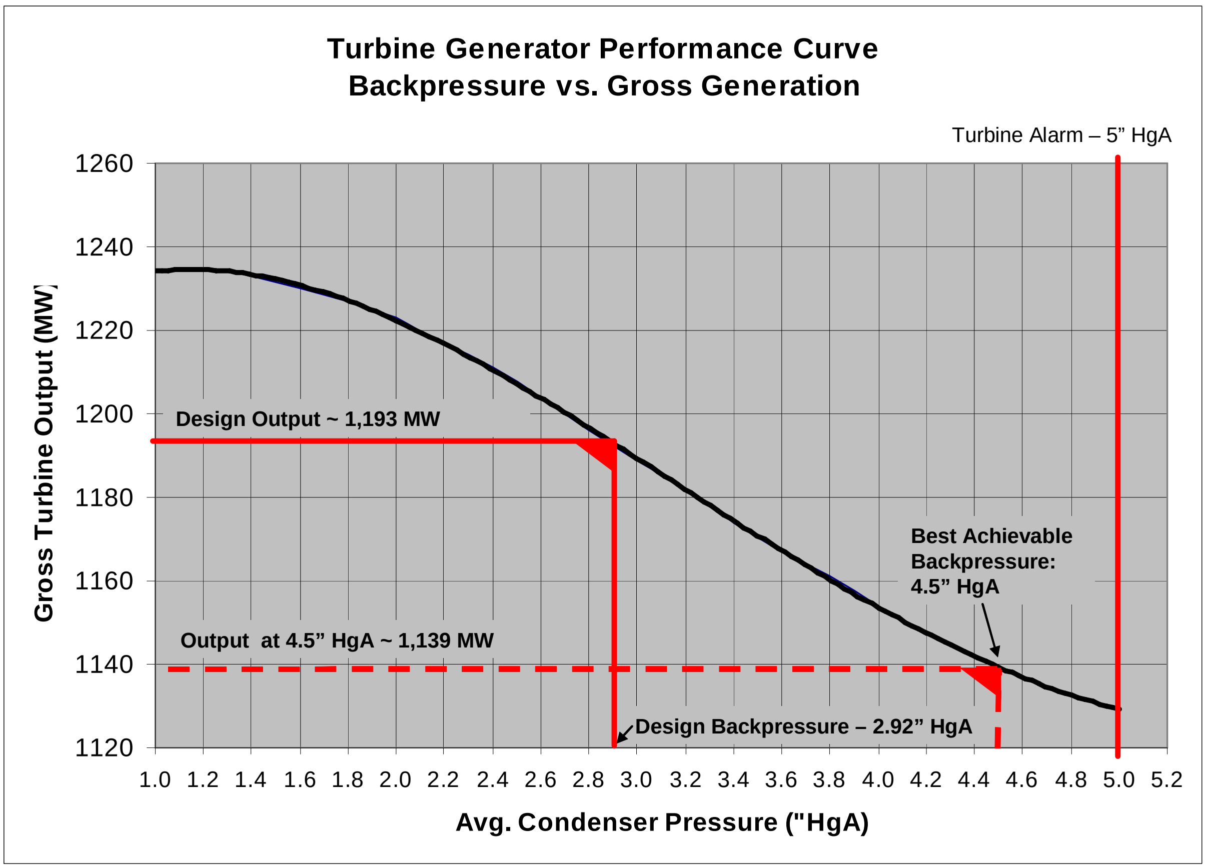
[7] Since the design backpressure of an ACC is in general indirectly proportional to the ACC’s size, a large section would be needed to achieve a certain backpressure (corresponding to the HP shell of a surface condenser), a slightly larger section would be needed to achieve a slightly lower backpressure (corresponding to the IP shell of a surface condenser), and an even larger section would be needed to achieve a still lower backpressure (corresponding to the LP section of a surface condenser).

[8] If a true multi-pressure ACC were ever constructed, then the highest backpressure (*e.g.*, that of the HP section) would be the limiting factor for steam turbine operation. That section would likely exceed 5.0” HgA even if the LP section was operating at considerably less than the 4.5” HgA design temperature.

the reliability and operability of an ACC system are not acceptable for a baseload generating facility in southern Georgia.

Even if the unit could be maintained in a stable condition below the trip point for the current turbine, the increase in backpressure associated with using an ACC as compared to a wet system would result in a substantial reduction in output. Assuming an average turbine backpressure 4.5" HgA could be achieved using an ACC in conjunction with the standard AP1000 turbine, the result would be a loss of close to 55 MW out of the generator as compared to operation at the current design backpressure of 2.92" HgA.

Figure 7 – Turbine Exhaust Pressure Curve

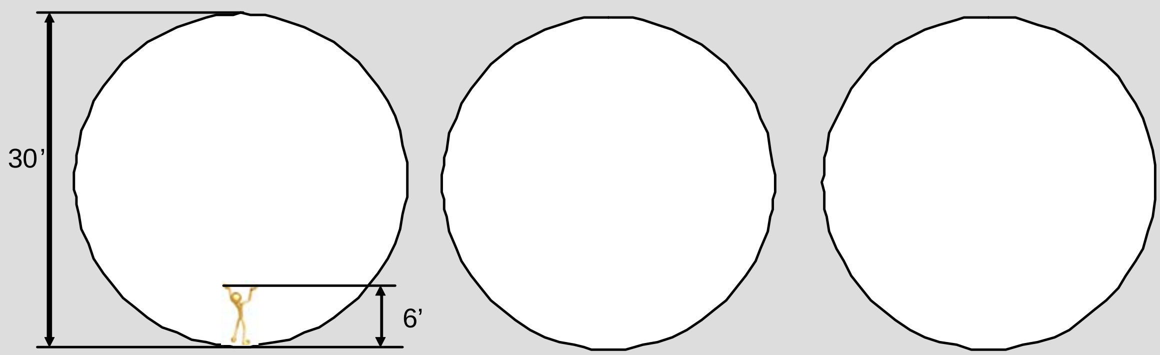


In addition to its negative impact on performance, this ACC would require additional time and money be spent revising the entire turbine building arrangement and overall plant layout, potentially quite dramatically. In place of the current steam surface condenser, three very large ducts similar to those shown in Figure 8 would have to be constructed beneath the turbine.

FIGURE 8 –

Required Size for ACC Steam Ducts for an AP1000 Unit

(Average Height Man Shown for Scale)



These ducts would then have to be run through the walls of the turbine building and outside to a distance a minimum of 100 feet away prior to routing the ducts to individual sections of the ACC up to 2000 feet away. This would necessitate changes to the wall of the turbine building and probably the turbine pedestal. Because the AP1000 turbine pedestal design is an integral part of the turbine building structural design[9], this would effectively mean redesigning the entire structure of the turbine building. Removing the steam service condenser would also cause layout changes to other equipment, most notably the six feedwater heaters currently located in the exhaust hoods of the condenser shells. It is beyond the scope of this report to suggest a cost or the time required to redesign and lay out the revised equipment; it suffices to say, though, that when complete such a unit would not bear significant resemblance to a standard AP1000 unit.

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[9] *See* Section 10.2.2.1 of DCD Rev. 17.

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Using a Steam Turbine Designed to Operate with a Higher Backpressure Limit is Not Feasible for an AP1000 Unit as Described in DCD Rev. 17

In theory, another option for using an ACC would be to replace the steam turbine currently employed in an AP1000 standard unit with a different turbine designed to allow for operation at higher backpressure limits than those of the current turbine design. Obviously such a change would be a dramatic departure from the Toshiba turbine incorporated in the standard AP1000 unit as specified in DCD Rev. 17 and would require revisiting the portions of the DCD performance and safety analyses that are based upon the currently proposed steam turbine design. Such issues aside, use of a higher backpressure turbine faces an incontrovertible technical limitation. While it is true that “high backpressure” turbines are common on air-cooled installations across the United States, all of those units are usually 200-300 MW steam turbines (though some are a bit larger), considerably smaller than an AP1000 unit, and none has a triple exhaust, six flow LP turbine. Regardless of its cooling system design or exhaust pressure, an AP1000 unit must use a multi-exhaust turbine in order to physically be able to pass the steam flow specified in the AP1000 thermal cycle. To our knowledge, a large, multi-exhaust turbine capable of safely operating at elevated backpressures has never been designed or manufactured anywhere in the world, nor are we aware of any current plans to design or build such a machine.

A Theoretical Air-Cooled System That Would Be Compatible with the Current Standard AP1000 Unit is Not Feasible From A Reliability, Cost, or Environmental Standpoint

The current reality is that an air-cooled system is not technically feasible for an AP1000 unit constructed at the Vogtle site. However, in an effort to provide a suitable comparison to show the effects of replacing the current wet cooled system with an ACC, two theoretical designs were studied.

The first was an ACC that would duplicate the performance of the current wet cooled system and thus have a condensing steam temperature of just over 114^{o}F (the saturation temperature of steam at the pressure of 2.92” HgA used in the current Westinghouse wet cooling system design). Since the design ambient temperature for the Vogtle site is 95^{o}F, the design ITD of the ACC is would be *less than 20^{o}F; i.e., more than 40% less than the minimum ITD using current technology!* It cannot be overstated that this is a purely academic design and that it is not now, nor would it seem to be in the foreseeable future, technologically feasible to construct an air-cooled condenser that could replicate this performance.

The second design was an ACC designed at the current “state-of-the-art” limit of technology, a 35ºF ITD. As mentioned earlier, this design would cause a change in the way the thermal cycle operated by virtue of mandating that all three turbine sections exhausted at the same backpressure. It would also press the operating limits of the steam turbine at design conditions, to say nothing of operation during times when ambient temperatures exceeded the design temperature of 95ºF or transient weather conditions caused air inlet recirculation, when it would certainly exceed them.

Analysis of an ACC Designed to Replicate the AP1000 Wet Cooling System

If an ACC system sized to replicate the performance of the AP1000's wet cooling system could actually be constructed and designed, its design parameters would be as follows:

ACC Design Steam Flows (Lb/Hr)	Exhaust 1	2,781,543 Lbs/Hr
	Exhaust 2	2,781,543 Lbs/Hr
	Exhaust 3	2,781,543 Lbs/Hr
	Total Steam Flow	8,344,629 Lbs/Hr
Total Number of Modules		324
Number of Rows of Modules		54
Modules Per Row		6
Fan Power Per Module		190 HP / 141.7 kW
Total ACC Fan Power		61,390 HP / 45,923 kW
Design Heat Load (MBtu/Hr)		7,565.2 Btu/Hr x 10^6
Design Ambient Temperature		95.0 °F
Design Pressure		2.92" HgA

As an example of potential size, Figure 9 shows an ACC designed for 10.0" HgA with 30 modules for a ***220 MW steam turbine***.

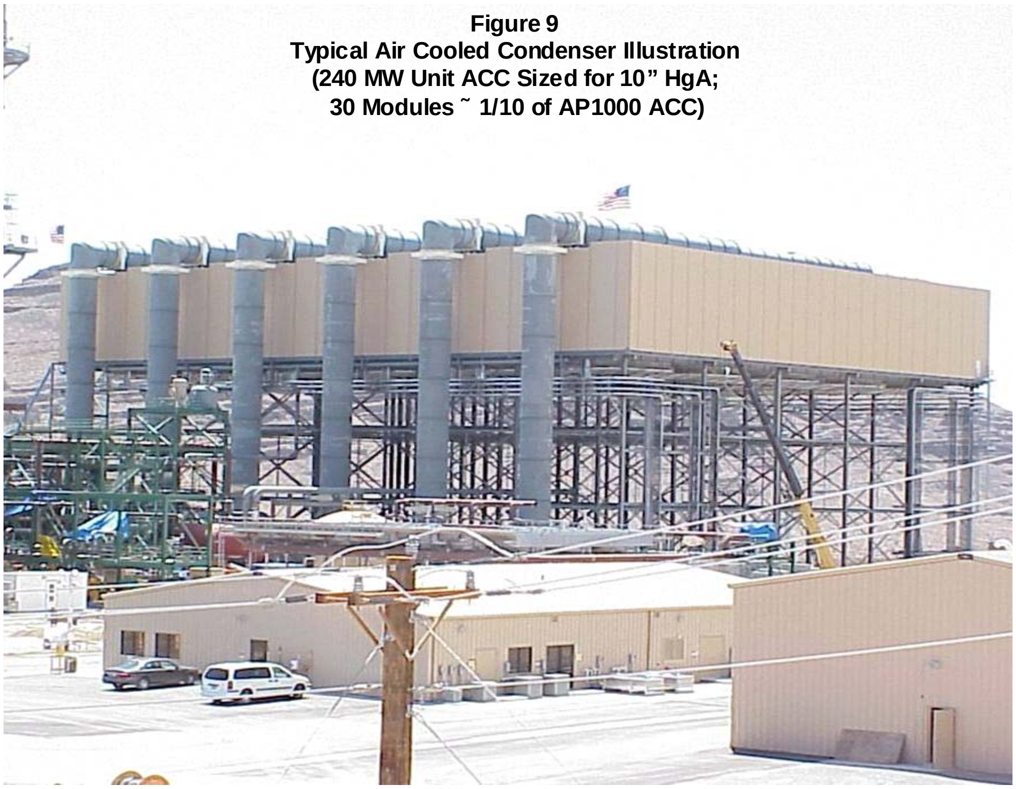
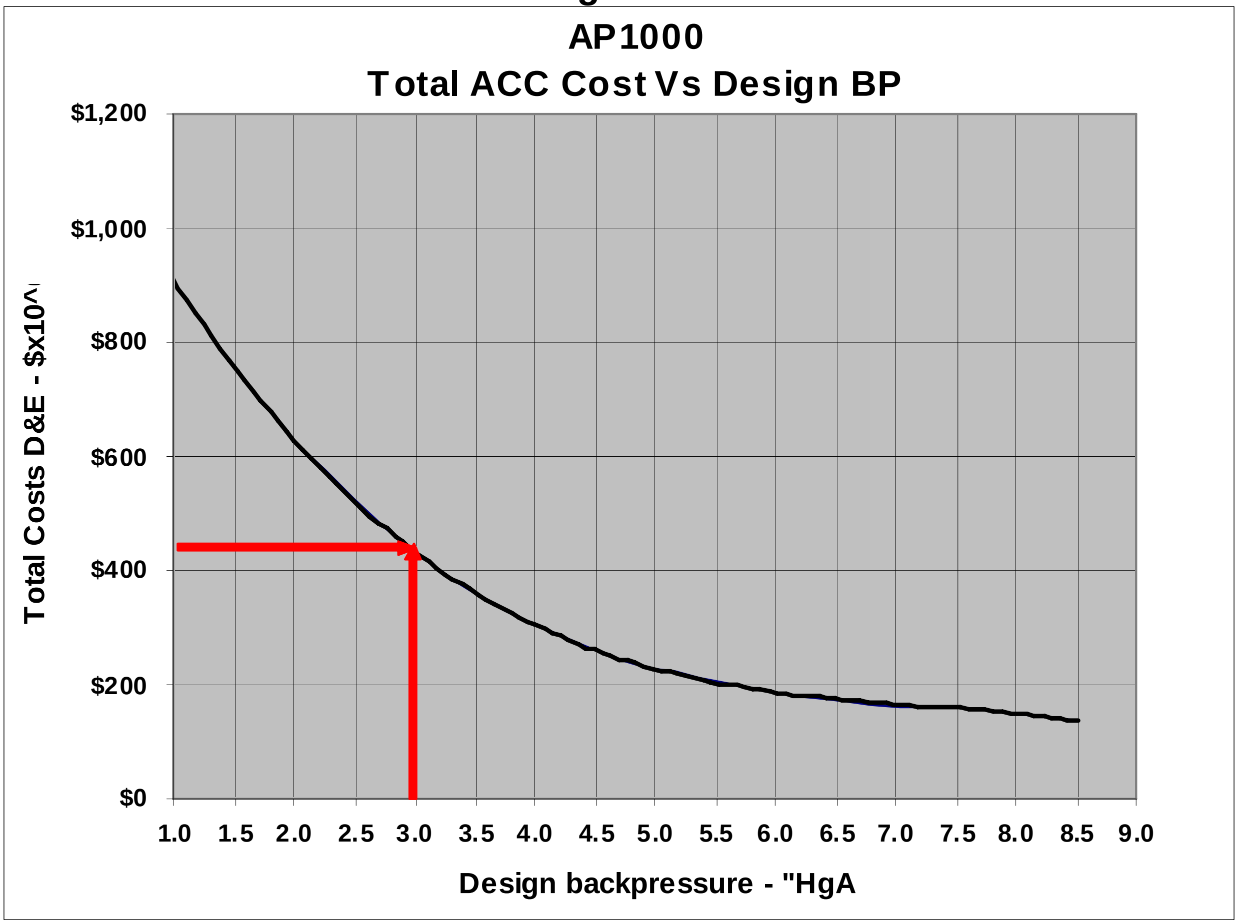


Figure 9
Typical Air Cooled Condenser Illustration
(240 MW Unit ACC Sized for 10" HgA;
30 Modules ˜ 1/10 of AP1000 ACC)

Designing an ACC for 2.92" HgA for the same 220 MW turbine would require 66+ modules. By comparison, based on recent vendor supplied data, an ACC designed for an AP1000 plant at the Vogtle site with a 2.92" HgA condenser backpressure would require ~ 324 modules with a fan power of ~ 190 BHP per module. The consumptive power (station service) requirement for the 324 modules of the ACC would be ~ 45,923 kW (~ 46 MW).

The capital cost of such an ACC for the AP1000 plant, as shown on Figure 10 depicting cost as a function of ACC design backpressure, would be ~ $445,000,000 per unit.

Figure 10 -



Layout and real estate requirements for this ACC design are very large. Figure 11 shows the number of modules required per turbine exhaust section for this theoretical ACC. The maximum depth of bays (parallel to air inlet) was limited to 6 modules deep in keeping with standard design practice by manufacturers of ACCs. ACC orientation with regard to predominant wind direction is critical to minimize potential recirculation, meaning that all of the individual sections of the ACC would need to be arranged next to each other in a parallel configuration and oriented (if possible) parallel to the prevailing wind direction at the site. Figure 12 shows the layout and size requirements for the complete ACC installation which is approximately ½ mile in total length. This obviously requires a substantial and expensive steam duct routed from the powerhouse to the ACC, to say nothing of substantial acreage.

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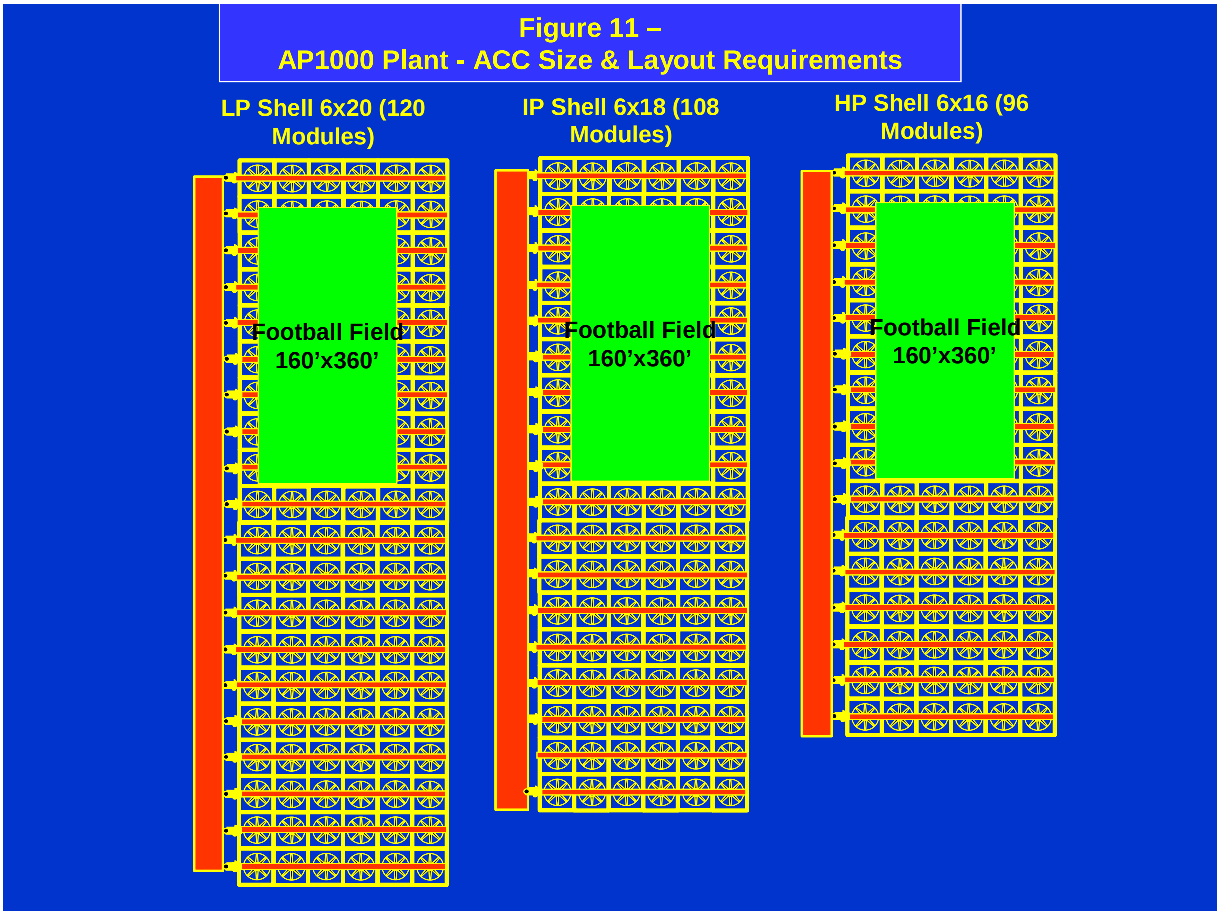

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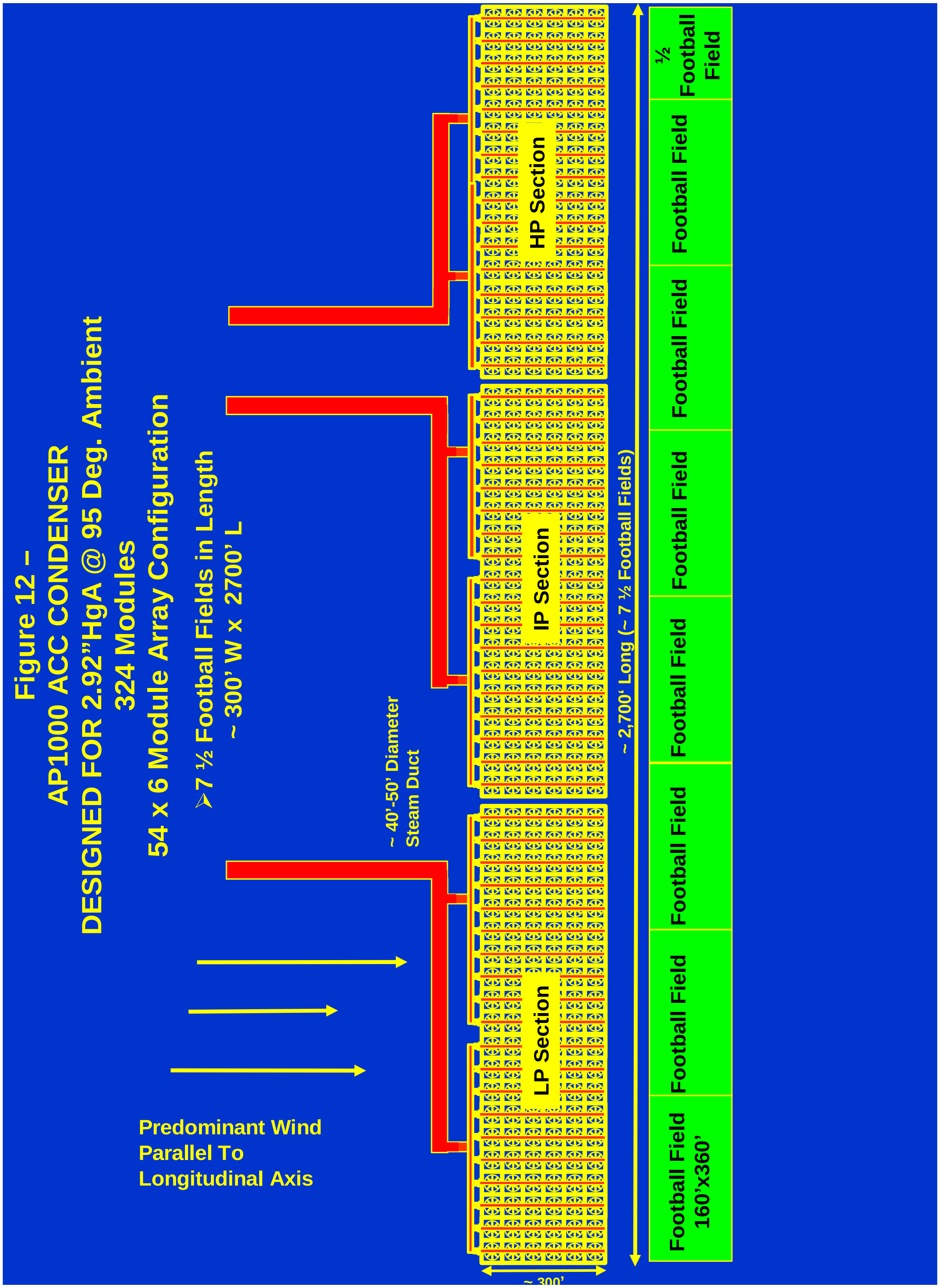
Air Cooled Condenser - Design Review



Analysis of an ACC Designed for a 35ºF ITD at Design Conditions

If an ACC sized to successfully maintain the AP1000 turbine at or below its operating limits at design conditions based on the current limits of technology could be constructed,[10] its theoretical design parameters would be as follows:

ACC Design Steam Flows (Lb/Hr)	Exhaust 1	2,781,543 Lbs./Hr
	Exhaust 2	2,781,543 Lbs./Hr
	Exhaust 3	2,781,543 Lbs./Hr
	Total Steam Flow	8,344,629 Lbs./Hr

Total Number of Modules	204
Number of Rows of Modules	34
Modules Per Row	6
Fan Power Per Module	190 HP / 141.7 kW
Total ACC Fan Power	38,658 HP / 28,915 kW
Design Heat Load (MBtu/Hr)	7,565.2 Btu/Hr x 10^6
Design Ambient Temperature	95.0 °F
Design Pressure	4.5" HgA

The consumptive power (station service) requirement for the 204 modules of the ACC was estimated to be ~ 28,915 kW (~ 30 MW). Such a unit would also cost an estimated $285,000,000. It would also have the same potential impacts to the turbine building design and layout as well as the entire plant layout. Though significantly smaller than an ACC that would replicate the current AP1000 wet cooling system's performance, as shown in Figure 13, such an ACC would still be immense in size.

[10] As mentioned previously, such a unit presents enough potential for operational uncertainty and problems that it is considered unfeasible even though it is theoretically possible.

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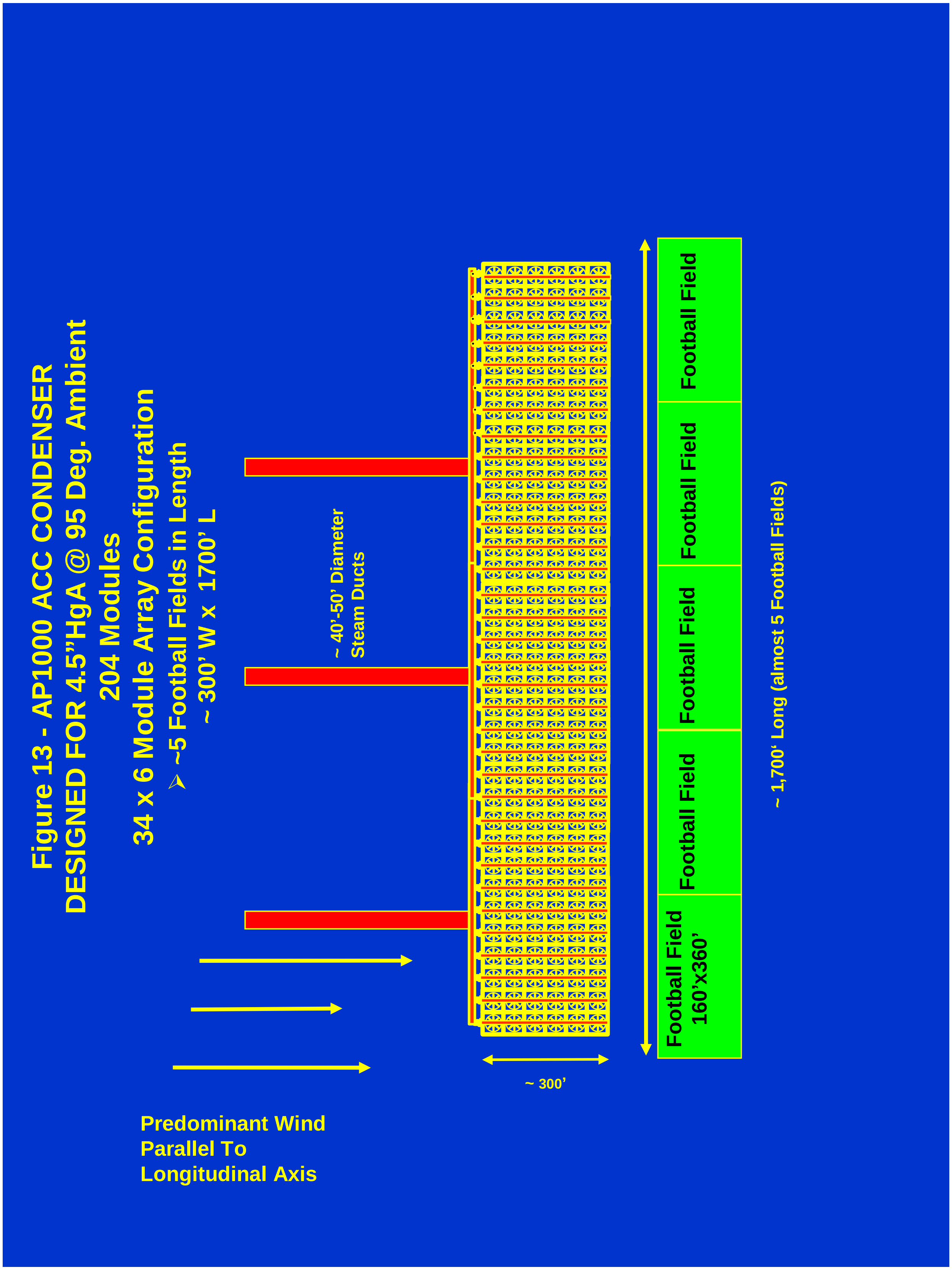

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Results/Conclusions

For easy reference, the capital cost and consumptive power demands for an ACC versus a steam surface condenser on a closed loop cooling system are compared in the attached Appendix A. Equipment prices shown here are budgetary estimates based solely on the information provided by ACC Vendors and Southern Nuclear. The cost impact on redesigning the turbine building and/or changing the site layout was not assessed for either ACC design due to the magnitude and complexity of system changes (*e.g.*, redesigning building structure, relocating feedwater heater system, changing and relocating condensate system, etc.). Southern Nuclear also did not account for any additional equipment costs such as condensate storage tanks, larger air removal system requirements, piping and auxiliaries, that would be necessitated by utilizing an ACC. In the event an actual plant using dry cooling was to be designed and built, potential changes in building design, appropriating additional real estate, constructing the ACC ductwork, and associated subsystems would increase the cost substantially and cause an even greater differential from the cost for a conventional system designed with a steam surface condenser (existing closed cycle wet cooling design concept).

It is worth reiterating that designing an ACC to match the AP1000 steam surface condenser performance is purely academic, which by no means confirms that such an ACC could even be actually designed and/or built. The lack of any experience with an extremely large ACC on a multi-pressure turbine suggests caution in assuming the concept could be viable. Nonetheless, if such a unit were theoretically constructed, the capital cost for an ACC designed to replicate the performance of a comparable wet cooling tower and steam surface condenser on a closed loop cooling system would be approximately 4½ - 6½ times greater than the cost of the wet system. The consumptive power demand for such an ACC would be approximately 46 MW, a demand that is 27-33 MW greater than the demand for a wet cooled system.[11] Constructing such unit would in effect cause Southern Nuclear and the citizens of Georgia to spend almost $700,000,000 of additional money to build two generating units that produced 60 MW less electricity and were less reliable than comparable units utilizing wet cooling.

Designing an ACC to operate at a higher backpressure than the current design but still below the AP1000 turbine alarm point at design conditions might be theoretically achievable, but would still be pressing the limits of technology. Such a unit would also at best introduce significant operational risk during peak summer conditions. Nonetheless, for sake of comparison, the capital cost for an ACC designed to operate at a higher backpressure but still below the AP1000 steam turbine alarm point of 5" HgA at design conditions is approximately 3-4 times greater than the cost of the standard AP1000 wet system. The loss in output from the generator due to operating at a higher backpressure is approximately 55 MW. The consumptive power demand for even a

[11] Depending on what type of wet cooling tower was used (see Appendix A for details).

"smaller" ACC like this would be 9 -15 MW greater than the demand for a wet cooled system,[12] giving the system a net loss of anywhere from 64-70 MW compared to a standard AP1000 unit. Constructing a system such as this would in effect cause Southern Nuclear and the citizens of Georgia to spend over $420,000,000 of additional money to build two generating units that produced at best around 130 MW less electricity[13] and were less reliable than two standard AP1000 units utilizing wet cooling.

The design of either ACC requires substantial real estate above the standard plant design (site area > 0.5 miles wide per unit). Implementing an ACC would also require substantial changes to the standard AP1000 turbine pedestal (and thus the entire turbine building structure), steam piping, feedwater heater layout, as well as numerous other equipment and subsystems which further substantiates that utilization of an ACC (if technically viable) will require a site specific custom plant design. An ACC would also require increased maintenance costs versus a wet system over the life of the unit due to the higher number of fans, motors, and gearboxes that would have to be maintained.

In summary, utilization of an ACC in conjunction with the deployment of an AP1000 unit at the Vogtle site is not feasible from the standpoint of technical viability, unit reliability, unit performance, and/or cost. Utilizing dry cooling would require an order of magnitude increase in capital expenditure only to produce less net power in a less reliable manner. Construction of a standard AP1000 unit on the Vogtle site utilizing dry cooling simply does not make sense.

[12] Depending on what type of wet cooling tower was used (*see* Appendix A for details).
[13] That output would be further reduced when the temperature at the inlet to the ACC exceeded 95ºF, whether by ambient temperature increase, recirculation effects, or both, and the unit thermal load had to be decreased to avoid operation above the turbine alarm point.

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APPENDIX A – Data Comparisons

	80F Wetbulb 11F Approach Natural Draft	80F Wetbulb 11F Approach Mechanical Draft	95F Drybulb 2.92" HgA Design BP Air-Cooled Condenser	95F Drybulb 4.5" HgA Design BP Air-Cooled Condenser
Design Condenser Flow - GPM	600,000	600,000	N/A	N/A
Design Tower Wetbulb (Deg.F)	80	80	N/A	N/A
Design Tower Approach (Deg.F)	11	11	N/A	N/A
Condenser Design CWT (Deg.F)	91	91	N/A	N/A
Condenser Design BP ("HgA)	2.92	2.92	2.92	4.50
Design Range (Deg.F)	25.2	25.2	N/A	N/A
Condenser Design HWT (Deg.F)	116.2	116.2	N/A	N/A
Number of Tower Cells/ACC Modules	N/A	48	324	204
Number of Tower/ACC Fans	N/A	48	324	204
Tower Fan HP	N/A	9600	61,560	38,760
Tower Capital Cost	$48,000,000	$30,000,000	N/A	N/A
Tower Pumping head	50	38	0	0
Steam Surface Condenser Cost	$42,000,000	$42,000,000	N/A	N/A
Circulating Water Pump Cost	$5,000,000	$5,000,000	N/A	N/A
Air-Cooled Condenser Cost	N/A	N/A	$445,000,000	$285,000,000
Total Equipment Capital Costs (2008$)	*$95,000,000*	*$77,000,000*	*$445,000,000*	*$285,000,000*
Station Service Requirements				
Circulating Water Pump TDH (Ft. Water)	95	85	N/A	N/A
Circulating Water Pump SS (kW0	13,298	11,898	N/A	N/A
Cooling Tower Fan SS (kW)	N/A	7161.6	N/A	N/A
Air Cooled Condenser Fan SS (kW)	N/A	N/A	45,924	28,915
Total SS - (kW)	13,393	19,145	45,924	28,915
Worth of SS ($/kW) - Assumed	$6,000	$6,000	$6,000	$6,000
Total Station Service Cost	$80,356,096	$114,867,160	$275,542,560	$173,489,760
Differential In Station Service Cost	*$0*	*$34,511,064*	*$195,186,464*	*$58,622,600*
Unit Performance				
Turbine Exhaust BP - "HgA	2.92	2.92	2.92	4.50
Turbine Gross Generation @ BP (kW)	1,193,150	1,193,150	1,193,150	1,139,260
Worth of Generation ($/kW) - Assumed	$3,000	$3,000	$3,000	$3,000
Generation Loss vs. Base Case (kW)	0	0	0	53,890
Differential In Net Generation Losses	*$0*	*$0*	*$0*	*$161,670,000*
O&M Requirements				
Annual Fan/Gearbox repairs	N/A	$120,000	$810,000	$510,000
Fan Gearbox replacement	N/A	$600,000	$4,050,000	$2,550,000
Fan Motor Rewinding	N/A	$200,000	$1,350,000	$850,000
Freeze Protection Repairs	$50,000	$30,000	$202,500	$127,500
ACC Tube Cleaning	N/A	N/A	$500,000	$500,000
Maintenance Totals	*$50,000*	*$950,000*	*$6,912,500*	*$4,537,500*
GRAND TOTAL	***$95,050,000***	***$112,461,064***	***$647,098,964***	***$509,830,100***

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