MEMORANDUM

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FROM: John Sunda, SAIC and Kelly Meadows
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SUBJECT: Cooling Tower Noise, Plume and Drift Abatement Costs

EPA tasked SAIC and Tetra Tech with evaluating how costs for noise, plume and drift abatement technologies may be developed for a universe of facilities potentially subject to closed-cycle cooling under the proposed existing facility rulemaking. This memo presents a brief overview of abatement technologies and associated costs and presents possible approaches for incorporating these costs into the proposed rule.

Noise Abatement

Background

When installing cooling towers at power plants close to residential and commercial areas, consideration must be given to noise impacts. For plants close to residential areas, local noise ordinances may be as low as 50 dBA, especially at night.[1] For a conventional mechanical draft cooling tower, sound levels of about 60 dBA can be expected at a distance of 500 ft (SPX 2010a). Distance to the nearest receptor is an important factor, as the noise dissipates as the distance increases. The general rule-of-thumb is that at distances of less than half the length of the tower, the noise level will dissipate roughly 3 dBA for each doubling of the distance, and at distances greater than half the tower length, the noise level will dissipate roughly 6 dBA for each doubling of the distance. Based on this rule-of-thumb, the nearest receptor would need to be at least 1,600 ft from the

[1] As an example, a study conducted for the Manchester Street Station (CH2MHill 2009) indicated that the noise regulations in Sections 16-91 through 16-109 of the City of Providence, Rhode Island Municipal Code required the following:

- In the absence of specific maximum noise levels, a noise level that exceeds the ambient noise by 5 dBA or more at the nearest property line or a noise audible at 200 feet is defined as unnecessary, excessive, or offensive noise.
- It is unlawful to operate equipment in any residential neighborhood that would exceed 50 dBA between 8 p.m. and 7 a.m. or exceed 55 dBA between 7 a.m. and 8 p.m.

unmodified conventional tower described above (60 dBA at 500 ft) to meet a noise limit of 50 dBA.

Cooling tower noise consists of two components: one is the sound of the fans and fan drives, and the other is the sound of the water splashing down through the tower. Noise abatement technologies used primarily for reducing fan noise may include:

- Low noise fans and gear boxes
- Fan deck barriers
- Inlet and outlet attenuation
- Building a larger tower to allow use of smaller Hp fans and/or reduced fan tip speed[2]
- Cooling tower designs that do not use fans (e.g., natural draft towers).

Noise abatement technologies used primarily for reducing water splashing noise include:

- Sound walls
- Splash attenuation
- Inlet attenuation.

Various combinations of these technologies may be selected, depending on the site conditions, equipment design, noise reduction requirements, and economic considerations.

Table 1 presents estimates using the rule-of-thumb for distances of 150, 350, and 500 ft, and 1,000 ft for a conventional mechanical draft cooling tower, a moderate reduction design (-10 dBA) and an aggressive noise abatement design (-16 dBA).

Table 1. Rough Estimate of Noise Levels at Varying Distances For Cooling Towers With and Without Noise Abatement Technology

Receptor Distance	Conventional Design	Moderate Noise Abatement (- 10 dBA)	Aggressive Noise Abatement Design (–16 dBA)
Ft	dBA	dBA	dBA
1,600 [a]	50	40	34
1,000 [a]	54	44	38
500	60	50	44
350 [a]	65	55	49
150 [a]	71	61	55

[a] Estimated values based on rule-of-thumb.

[2] Reducing the fan tip speed is a simple way to reduce fan noise. Fan tip speeds "over 61m/s are considered high by most people. 51-61 is considered typical and expected. 41-51 would be considered low noise. Below 41 is difficult to hear above the water noise." (Marley 2010)

The data in Table 1 estimating the noise reduction attainable and distances are intended for illustrative purposes only. The determination of the degree of noise reduction required, if any, must be based on site-specific data and may vary greatly from site to site. In practice, noise abatement requires a sophisticated analysis by a specialist. A more detailed analysis using the octave band analysis and the proposed tower design, location, noise receptor locations, and consideration of nearby buildings and topography would need to be performed to obtain a more definitive answer regarding necessary tower design requirements.

Estimated Costs

EPRI's cost estimation tool for cooling towers does not include costs for noise abatement. An example design provided by a cooling tower vendor indicated that reducing the noise level by 10 dBA from 60 to 50 dBA at 500 ft could increase the tower costs by approximately 60% (SPX 2010b). In this case, the design included a reduction in the fan speed requiring a physically larger tower, an added fan deck, perimeter barrier walls, and splash attenuation. If greater reduction is required, the cooling tower vendor cited a design that reduced noise by 16.3 dBA at a distance of 500 ft that would increase costs of the cooling tower by nearly 100% (SPX 2010a).

By comparison, the 2001 316(b) Phase I technical documentation ("Economic and Engineering Analyses of the Proposed §316(b) New Facility Rule" Table A-4) provided relative cost factors for various cooling tower types and indicated that the addition of 10 dBA noise abatement should increase cooling tower capital costs by a factor of 30% and O&M costs by a factor of 7% when compared to a standard mechanical draft cooling tower. Using these data points as bounding estimates, the noise abatement tower capital cost factors can range from 30% to 60% to 100% represent a range of noise reduction and abatement technology combinations.

The amount of noise abatement required is a function of both the local community noise code and the distance from the tower to the nearest sound receptor that must meet the specified noise code. Noise abatement costs will be highest if a tower must be located near areas with highly restrictive noise codes, such as residential areas. The location and orientation of the receptors surrounding the tower are also important, as some noise abatement technology components may be needed only on one side of the tower, which can help reduce costs.

As noted above, noise abatement costs may range from 30-100% of cooling tower capital costs. The median tower component cost (including the basins) of a closed-cycle system retrofit is estimated by EPA to be approximately $80/gpm of recirculating cooling water flow (SAIC 2010). Based on the 30% and 60% factors, the added costs for a 10 dBA noise abatement design can range from $24/gpm to $48/gpm. These differences represent different noise abatement strategies, with the higher cost example relying on larger towers and lower fan speeds, which should reduce the operating costs when compared to the lower cost approach which cited a 7% increase in O&M including the fan energy component. Since these costs are based on well-known design principles, the higher capital, lower O&M cost example has been selected as the best choice for estimating noise abatement costs in the proposed approach outlined below. While the larger tower may require a minor increase in the cost of materials maintenance, the reduced air velocities and reduce fan tip speed in the larger tower should reduce fan energy and fan maintenance requirements. Thus, the net effect of this noise abatement technology design on cooling tower O&M costs is expected to be minimal.

Plume Abatement

Background

Cooling towers dissipate heat via evaporation, resulting in warm, humid air being discharged from the towers. Under certain conditions, the plume is visible and may persist for some time or distance. In some cases, this may be a concern for visibility on roads or at airports, icing of roadways or other structures (as the plume condenses), or for aesthetics.

Plume abatement can be accomplished by various means and is often accomplished using a hybrid wet/dry cooling tower that combines air from both dry cooling and wet cooling to produce a less saturated tower exhaust air stream.

Estimated Costs

EPRI's cost estimation tool for cooling towers does not include costs for plume abatement. For plume abatement technology, the total cost of the tower component is estimated to increase by a factor of 2.0-3.5.[3] For this discussion of proposed changes to the cost methodology, a factor of 2.5 was selected for estimating the cost of conventional cooling towers with plume abatement, resulting in an additional cost of 1.5 times $80/gpm which is equal to $120/gpm.

Hybrid cooling towers will have higher O&M costs for the energy requirements and equipment maintenance compared to conventional mechanical draft cooling towers. A cooling tower vendor estimated that the pumping head would increases by 8 ft and the fan energy requirement would increase by 10% (SPX 2010a). This results in an increase in the EPA estimate for cooling tower energy requirement of 0.0000031 MW/gpm. It was also estimated that the non-energy O&M cost would increase by 50% to 100% due to the larger tower and maintenance of coils and dampers (SPX 2010a). A factor of 80%, which is close to the midpoint of the range cited and equal to an increase of $1.00/gpm, was assumed for the increase in non-energy O&M for plume abatement towers.

[3] A cooling tower vendor cited 2.5 to 3.5 (SPX 2010a) as cost factors. The 316(b) Phase I support document (Table A-4) indicates that typical hybrid towers have capital cost factors of 2.5 to 3.0 when compared to standard cooling towers made of Douglas fir. Similarly, the EPRI Cooing Tower Calculation documentation states that plume abatement capital costs will be 2 to 3 times those of conventional mechanical draft towers.

Space Requirements

Conventional mechanical draft hybrid wet/dry plume abatement towers must be configured in an in-line configuration. For large volumes of cooling water, this requires a series of long towers that require an area that is long enough for the towers and wide enough to allow for spacing if two towers are set side by side. If the towers are placed too close together, plume recirculation can occur and significantly reduce tower performance. Potential solutions include a new design by SPX called ClearSky Air2Air, which provides plume abatement and can be configured in the back-to-back configuration, and round towers which are described in more detail below.

In a recent cooling tower retrofit study for Units 2 and 3 at the Indian Point Nuclear Power Plant, a more compact round tower configuration was the selected technology. The tower design included a round counterflow forced draft configuration, hybrid wet/dry plume abatement with low noise fans, and sound attenuation baffles. These more expensive round hybrid towers were selected over conventional mechanical draft towers due to space limitations at the site which required a more compact design. The vendor's design-and-construct estimate[4] for these round hybrid cooling towers was $205 Million (2009 dollars) for a 702,000 gpm tower (Enercon 2010). This is equal to a tower unit cost of $292/gpm or roughly 3.65 times the estimated conventional tower cost of $80/gpm. These higher cost towers are representative of the cost of plume abatement, noise abatement, and compact size requirements combined, and are within the range cited above for plume abated towers considering they include noise abatement as well.

Application to Proposed Rule Costing Methodology

Table 2 provides a summary of the increase in cooling tower costs for the options described above and the estimated total costs when they are applied to the "average" retrofit cost estimation factors used by EPA for conventional mechanical draft cooling towers. The "difficult" retrofit costs are also shown for comparison. EPA has selected the "average" difficulty retrofit cost factors as ones that take into consideration the range of variations in site-specific conditions that affect the degree of difficulty in retrofitting to closed-cycle cooling. Some facility retrofits will cost more and some less, but on a national basis these costs should balance out.

The EPRI costs are based on a cooling tower retrofit cost analysis prepared by Maulbetsch Consulting for approximately 50 facilities, which categorized cooling tower retrofits into "easy," "average," and "difficult" cost categories. Data presented by Maulbetsch indicates that noise and plume abatement technologies are used for some of the plant costs (Maulbetsch 2003, Maulbetsch 2008). Thus, it is reasonable to assume that some noise and plume abatement technologies may be included as part of the technology mix associated with the Maulbetsch cost estimates used to derive these costs, particularly those that fall toward the "difficult" end of the range of costs. However, if requirements for cooling tower retrofits are more widely and strictly applied (i.e., noise or

[4] Enercon's analysis is based on a recent estimate for the Calvert Cliffs Nuclear Plant, which also uses brackish water

plume abatement is more prevalent), particularly in high density population areas, the proportion of retrofits near the “difficult” end of the cost range may be greater than the mix in the Maulbetsch study cost database.

Table 2. Summary of EPA Cooling Tower Costs Plus the Added Costs of Noise and Plume Abatement

	Capital Cost (2009 Dollars)	Fixed O&M (2009 Dollars)	Variable O&M – Chemicals[1] (2009 Dollars)	Variable O&M - Pump & Fan Power
	Dollars/gpm (% Increase[2])	Dollars/gpm	Dollars/gpm	MW/gpm
Average Retrofit[3]	**$263 (0%)**	**$1.265**	**$1.25**	**0.0000237**
Difficult Retrofit[3]	**$411 (56%)**	**$1.265**	**$1.25**	**0.0000237**
Add for Noise Abatement	$48	$0	0.0	0.0
Add for Plume Abatement	$120	$1.0	0.0	0.0000031
Add for Round Plume and Noise Abatement[4]	$212	$1.0	0.0	0.0000031
Average with Noise Abatement	**$311 (18%)**	**$1.265**	**$1.25**	**0.0000237**
Average with Plume Abatement	**$383 (47%)**	**$2.265**	**$1.25**	**0.0000268**
Average with Both Plume and Noise Abatement	**$431 (64%)**	**$2.265**	**$1.25**	**0.0000268**
Average with Plume and Noise Abatement with Space Limitations – Round[4]	**$475 (81%)**	**$2.265**	**$1.25**	**0.0000268**

[1] Non-power variable O&M costs are for additional treatment chemical for optimized tower operation at higher cycles of concentration.
[2] Percent increase compared to “average” difficulty retrofit.
[3] Values shown are same as used in previous cost estimates except that the previous fixed O&M total is now split into variable O&M for Chemicals and Fixed O&M.
[4] Based on round tower with plume and noise abatement.

Noise abatement may be necessary at locations near residential, urban, or other areas. However, it is difficult to determine (on a national scale) which facilities would incur noise abatement costs using the current set of information. Noise ordinances are typically administered at the state or even local level and would require a site-specific analysis to determine if they would be applicable at a given facility.

Plume abatement will primarily be a concern in locations where the plume may create safety problems such as reduced visibility on nearby roadways or icing on roads and bridges. Thus, facilities located near major roadways and bridges will be candidates for this requirement. As with noise abatement, it is difficult to determine (on a national scale) which facilities meet this criterion using the current set of information.

The availability of space and whether conventional or round towers would be feasible will be very site-specific and must take into consideration property size, shape, adjacent development, and topography. Requirements for the demolition and/or moving of existing structures and infrastructure may be more likely to be a requirement at sites with space constraints. Facilities that are located close to areas of higher population density are more likely to have limitations on availability of space, since available space not currently used by the plant and adjacent property will tend to be developed.

A detailed evaluation of each site would be required to determine which requirements would apply to that site. One possible source of data that may be used to identify facilities that may be candidates for some combination of these requirements would be to use census data to identify facilities that are located within areas of higher population density.

As can be seen in Table 2, the selected retrofits for noise abatement, plume abatement, and both noise and plume abatement increase the estimated costs of an "average" retrofit by 18%, 46%, and 64%, respectively. If space constraints require a round tower that includes plume and noise abatement, the increase may be up to 81% using the assumptions in this analysis. By comparison, the "difficult" retrofit represents an increase of 56% and falls in the middle of this range of options.

There are two basic approaches that could be used to identify facilities that would be assigned higher costs for the proposed rulemaking, using surrogate data or using an alternative wet cooling tower design; these are described below.

Using Surrogate Data

Facility data necessary to determine specific tower requirements is not readily available and it may not be practical to apply the noise abatement, plume abatement, or round tower costs shown in Table 2 to plants individually. A simpler solution would be to identify candidate facilities that may be more likely to require some mix of these technology modifications using a surrogate measure such as local population density data.[5] Aggregate cost factors representing one or combinations of these requirements could then be applied.

[5] The U.S. Census Bureau defines an urban area as: "Core census block groups or blocks that have a population density of at least 1,000 people per square mile (386 per square kilometer or 1.6 per acre) and surrounding census blocks that have an overall density of at least 500 people per square mile (193 per square kilometer or 0.8 per acre)" (US Census Bureau 2000). A review of the population density and aerial views of several sample facilities may help in establishing reasonable threshold values for high and low density areas.

One approach would be to assume that the “difficult” retrofit capital costs ($411/gpm) or the combined plume/noise abatement costs ($431/gpm) would be representative of the costs of requiring some combination of noise and plume abatement at facilities that would otherwise require an “average” difficulty retrofit. For all of these facilities, the increased O&M costs associated with plume abatement in Table 2 should also apply.

Alternative Wet Cooling Tower Design

A second approach would be to assume that facilities would install an alternative wet cooling tower design. The model wet cooling tower technology that forms the basis for the EPA compliance technology is the rectangular mechanical draft cooling tower configured either in an in-line or back-to-back configuration. For these types of cooling towers, the most common type of plume abatement technology involves use of separate dry (coils) and wet cooling sections with the exhaust of each being mixed prior to discharge.

Back-to-back configuration is not advised due to poor mixing that occurs because the dry section air is introduced on only one side. This limits the use of this technology to locations where the available space is compatible with in-line mechanical draft towers. Other wet cooling tower technologies that provide plume abatement but have different space requirements are described below.

<u>SPX ClearSky</u>

A new design by SPX called ClearSky Air2Air provides plume abatement and can be configured in the back-to-back configuration. This design places the dry cooling component directly above the wet component of the tower rather than along the side, thus allowing for a back-to-back configuration. This technology re-condenses a portion of the evaporated water and was designed to provide for water conservation, but was found to reduce plume visibility as well. It is a promising technology, especially with respect to reducing water consumption. The technology has only been demonstrated on a full-scale basis at a single location in New Mexico and remains a somewhat unproven technology and may require time to develop acceptance within the industry.

<u>Natural Draft Cooling Towers</u>

Natural draft cooling towers (NDCTs) have higher capital costs and lower O&M costs than conventional mechanical draft towers. The lower O&M costs are due to the elimination of fan energy costs. At locations where there are no noise or plume abatement requirements, NDCTs are more economical than conventional mechanical draft cooling towers only for large base-load plants with a service life of 40 or more years (SPX 2010b).

NDCTs are suitable alternatives for plume abatement because the high air outlet location and large size of the plume reduces the possibility that the plume will approach the ground or be recirculated. When equipped with sound barrier walls, NDCTs also serve as an effective noise abatement technology option. At locations where both plume and noise abatement is required, the economic benefits of NDCTs become more favorable—even more so if the cost of constructing a new flue gas stack associated with new air pollution control equipment is avoided by disposing treated flue gas through the tower.[6] However, as noted above, noise and plume abatement requirements are often the result of proximity to urban or residential areas where there may be building height restrictions and/or substantial public resistance to the installation of such large structures, potentially limiting the applicability of this technology.

Hybrid Round Forced Draft Cooling Towers

Round mechanical draft cooling towers function in a similar way to conventional towers, with the air entering radially from all sides. Fans may be clustered around the center point of the tower (induced draft) or at the perimeter openings (forced draft). The latter is commonly used for hybrid round plume abatement towers. These towers have the following advantages:

- Useful where available space is compact and site does not allow for the long narrow configuration of mechanical draft towers.
- While the air outlet is closer to the ground than natural draft towers, the large diameter and compact nature of the combined plume increases plume height over conventional mechanical draft towers, reducing plume recirculation and eliminating spacing concerns associated with conventional towers.
- Increased plume height improves the distribution of drift, making this technology useful where better dispersion of saltwater drift is desired.

In one example cited above, the estimated cost of round plume and noise abatement towers was about $44/gpm higher than the estimated cost for combined plume and noise abatement rectangular mechanical draft towers.

Fan Assisted Natural Draft Cooling Towers

Fan assisted natural draft cooling towers are a hybrid of mechanical draft and natural draft towers and are similar in design to NDCTs but have a much lower height and use fans during periods when conditions require them. These towers have the following advantages:

- Useful where space requirement is compact and site does not allow for the long narrow configuration of mechanical draft towers.
- Tower height is limited.
- Lower fan energy requirement than mechanical draft towers.

[6] See detailed discussion in DCN 10-6681.

- Suitable for locations where climatic conditions would result in insufficient buoyant forces in an NDCT, requiring fan assist to provide sufficient airflow. In this case, the cost of the added height of NDCT is not justified.

These towers do not provide for plume abatement, but like NDCTs, they have a higher discharge location and the plume is larger and more buoyant, making it less prone to approach the ground or recirculate compared to conventional mechanical draft towers.

Drift Abatement

Background

The cooling tower engineering cost estimates use the EPRI cost spreadsheet methodology for the capital costs for "average" or "difficult" installation. The Spreadsheet Instructions accompanying the EPRI Tower Calculation Worksheet state: "Most modern cooling towers are equipped with drift eliminators which are specified to limit drift to 0.0005% of the circulating water flow." Since the EPRI costs are for modern cooling towers and the default drift rate in the spreadsheet is 0.0005%, EPA can reasonably assume that the compliance cost estimates include costs for drift eliminators.

For comparison, cooling towers that do not employ drift eliminators emit significantly more water droplets. Table 3 below illustrates typical drift rates for towers with and without drift abatement.

Table 3. Cooling Tower Drift Factors

Tower Type	Drift Estimation Factor*
Natural Draft	0.3 to 1.0%
Mechanical Draft	0.1 to 0.3%
Tower with Drift Eliminator	0.005%
Tower with High Efficiency Drift Eliminator	0.0005%

* Drift (gpm) = Recirculation (gpm) x Drift Estimation Factor / 100

Note that while the EPRI methodology assumes high efficiency drift eliminators, no data has been collected on the prevalence of standard drift eliminators versus high efficiency drift eliminators in use at existing facilities or at recently constructed towers. However, in addition to the EPRI documentation, BPJ suggests that new towers would likely use the high efficiency eliminators, as the additional costs of installing and operating them can be included in the initial cooling system design and the incremental costs over standard efficiency would be small. Additionally, air quality requirements at a given site may require high efficiency eliminators as part of Best Available Technology.

Estimated Costs

As noted above, costs for high-efficiency drift abatement are already included in the costs calculated by the EPRI cost tool. No further action is required.

Conclusion

Noise, plume and drift abatement technologies can add significant costs to a cooling tower retrofit design. A number of site-specific factors come into play to determine the selection of technology, but appropriate assumptions for estimating national-level compliance costs can be made regarding the impacts of these abatement technologies to the overall cost of the retrofit.

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