Comments on September 2013 Bechtel Phase 2 Final Technologies Assessment for Alternative Cooling Technologies at Diablo Canyon Power Plant

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I. Executive Summary

Bechtel's September 20, 2013 *Final Technologies Assessment for the Alternative Cooling Technologies or Modifications to the Existing Once-Through Cooling System for Diablo Canyon Power Plant (DCPP)*, is an evaluation of a range of possible methods for attempting to reduce the impingement and entrainment occurring in the cooling water system of the plant. Three methods of reduction were selected for evaluation in the final Bechtel screening assessment: onshore fine-mesh screens, or offshore passive wedge-wire screens, and closed-cycle cooling (several types).

All methods considered in the Bechtel study and based on wedge-wire screens and fine mesh travelling screens for filtering out planktonic life forms to reduce entrainment at large once-through cooled power plant are likely to be ineffective and unreliable at this site. Plankton comprises the small organisms living freely in the water column and includes the early stages of many fish. The most abundant larval fish in the waters used by Diablo Canyon are very small, requiring a mesh size or slot width of less than 1 mm to exclude an appreciable proportion of the eggs and larvae.

The Bechtel report claims levels of entrainment reduction using 1 mm traveling mesh and 2 mm wedge-wire screens which cannot be achieved in practice because of the size range of the larvae present. Due to the generally smaller size of the larvae entrained at Diablo Canyon, the estimated reductions in entrainment for any mesh or wedge-wire slot openings larger than about 1 mm is very limited.

In the case of onshore traveling mesh screens there is a further problem, as larger larvae retained by the screens and not entrained become impinged. Converting entrained fish into impinged fish does not reduce the impact of the plant, as mortality amongst small impinged fish can be very high.

The Bechtel cost estimate is not credible due in substantial part to the selection of a steep and cost-prohibitive site chosen for the cooling towers. Bechtel would level a mountain at a cost of over $3 billion to prepare the site for cooling towers. The PG&E cost estimate lacks credibility because it includes demonstrably exaggerated costs compared to publicly verifiable costs for the same equipment. PG&E adds approximately $2 billion for essentially the same cooling tower design and layout as used in the TetraTech estimate. The PG&E cost estimates are consistently 3 to 4 times the TetraTech cost for the same equipment or activity.

For example, TetraTech proposes a 52-cell back-to-back conventional mechanical draft cooling tower for each unit while PG&E proposes a 40-cell back-to-back conventional mechanical draft tower design for each unit. TetraTech estimates the total cooling tower equipment cost at $61 million and is consistent with publicly available cooling tower manufacturer cost estimates. PG&E estimates a total cooling tower equipment cost of $242 million, four times greater than TetraTech, with no supporting documentation to justify the otherwise inexplicably high cost.

The 13-year construction schedule proposed by Bechtel is not credible when compared to the actual 3-year construction schedules achieved on multiple large cooling tower retrofits at nuclear and non-nuclear power plants around the country.

Bechtel's presumption that salt water cooling towers would be ineligible for air permits, and that salt deposition from the towers on insulators could compromise high voltage switchyard reliability, are unsupported and incorrect. It is reasonable to expect that air permits can be obtained for salt water cooling towers at Diablo Canyon based on prior EPA approval of the use of road paving in California and Arizona to offset particulate emissions from new major sources. Salt deposition on high voltage insulators has been effectively mitigated at operational power plants using salt water cooling towers and can be effectively addressed at Diablo Canyon.

The only reliable method to reduce entrainment is to reduce the amount of water taken in by the plant. The best method for volume reduction is closed-cycle cooling. Using saltwater cooling towers will reduce the volume of cooling water extracted by approximately 96 percent. Of the three cooling tower cost estimates prepared by Bechtel, PG&E, and TetraTech evaluated in this report, the $1.62 billion estimate by TetraTech is the most credible.

II. Travelling Fine Mesh and Wedge-Wire Screens

A. *Terminology*

1. Traveling Fine Mesh Screens

Travelling screens are used to remove debris and organisms from the cooling water entering a power plant. The basic scheme is to have a rotating screen in front of the intake onto which the debris is impinged. The impinged material is lifted by the moving screen to a set of water sprays which wash off the impinged material and clear the screen. This impinged material includes fish and other marine life.

2. Cylindrical Wedge-Wire Screens

Wedge-wire screens are a fine mesh screen placed in the sea at the mouth of the cooling water intake. They work to reduce impingement and entrainment by restricting the entry of organisms into the intake. The degree of restriction is determined by the slot width. Cylindrical wedge-wire screens have a "V" or wedge-shaped, cross-section wire welded to a framing system that forms a slotted screening element. For these passive screens to work there must be a low flow velocity across the screen slots and they must avoid becoming fouled by debris and marine life.

3. Definition of Entrainment

Entrainment is a term used here to describe the fate of organisms that are drawn via the water intake structure into the system. The size of the animals entrained depends on the mesh size of the screens used to filter the water. The organisms pass through filter screens, travel along the

plant's pipe-work, and are often discharged back to the environment with the effluent water. Of the wide range of planktonic organisms and early life stages that are entrained, the animals that are usually studied are small crustaceans and fish eggs, larvae and young. Of particular concern is the entrainment of fish eggs and larvae, which may be killed in very large numbers during passage through a plant. Recent studies show that mortality rates of entrained organisms can be as high as 97 percent, depending on the species and life stage entrained. It is often assumed that 100 percent mortality occurs.

Even when water use is not consumptive the passage through the plant can be damaging. Organisms undergo a range of stresses that often lead to injury or mortality. The principle causes of harm can be classified into (1) mechanical (abrasion, pressure, shear stress), (2) thermal (elevated water temperature and rapid changes in temperature) and (3) chemical (addition of biocides, low oxygen).

Factors that affect entrainment rates include:

- Cooling water (CW) intake location in relation to spawning grounds
- Life history of species
- Habitat preferences of species
- Swimming ability
- Growth rates and morphology

4. Definition of Impingement

Impingement is used here to describe the capture of fish and other organisms that are retained on the filter screens of a water intake system. These organisms are washed off the screens, and either collected in a trash basket for subsequent disposal, or are sluiced along a channel and returned to the environment. Even when a return system is installed, it will not ensure that fish and other organisms survive. Survival depends on the vulnerability of the organism to damage when it comes into contact with a hard surface, as well as upon other factors such as the presence of debris or predators in the release area and the temperature at the time of capture. Open-water fish, such as members of the herring family such as sardines, are found along the California coast and generally have low or negligible survival following impingement, because their skins are easily damaged.

The rate of impingement in all habitats increases with the volume of water extracted and the speed at which the water is travelling as it enters the intake system. Further, for a variety of reasons linked in part to fish behaviour, larger intakes catch considerably more fish than would be predicted by using the catch per unit volume observed at smaller intakes – in other words, if the volume of water abstracted is doubled, the number of fish caught increases by much more than a factor of two.

B. Cylindrical Wedge-Wire Screens

Wedge-wire screens have a proven ability to reduce entrainment mortality at low-volume intakes. For wedge-wire screens to work efficiently for the protection of larval fish, they need a range of conditions to be met. The key factors that are important in determining the performance of wedge-wire screens are as follows:

1. The slot width relative to the size of aquatic organisms that need to be protected
2. Through-slot velocity
3. Velocity of water currents sweeping across the face of the screen
4. The amount of bio-fouling
5. The amount of ambient debris, and
6. The species present in the water at the site.

Tests have shown that there needs to be velocity water current sweeping past the screen. This is to allow the larvae and eggs to be swept off the screens if they should become impinged, and also to remove debris that might block the mesh. For wedge-wire screens to be effective, there must be a sweep velocity greater than the through-screen velocity along the surface in order to carry debris and animals past the screen. The need for a sufficiently high sweep velocity is made clear in the EPRI (1999) report on Fish Protection at Cooling Water Intakes TR-114013:

> *Another factor that may limit application of wedge-wire screens in some environments is the lack of ambient currents to sweep organisms past the screen and carry backwashed debris away. This is an important requirement of this technology. Therefore, it may not be practicable to consider in water bodies without at least a low velocity cross-current.*

This requirement is often problematic in the marine environment because water currents vary with the tide and other conditions. Not all areas of the coast have strong currents, and even in areas with suitable currents, local topography can have very large effects on the current at any point. The tidal flows in the sea also mean that there are often periods of slack water, with little flow. The frequency and duration of these slack water periods are highly site-specific. There are no data given in the Bechtel report as to the velocities around the site to allow an assessment of these issues.

Another factor that determines the suitability of wedge-wire screens is the expected debris loading at the site. If the area has large amounts of debris (seaweed, kelp, leaves, etc.) then blocking can occur. There are clearing methods, such as air-burst cleaning, that can be used. But even with these, installed screens can become partially blocked, resulting in velocity “hot spots” of flow through the screens. High through-screen velocities must be avoided as they can result in soft-bodied eggs and larvae becoming extruded through the screen. The removal of debris from wedge-wire screens is not considered in detail with the Bechtel report (p. 104) although the risk is recognized:

> *Operation of the deepwater intake, intake relocation, and offshore wedge wire system may include self-cleaning capability. These offshore intake systems and the substrate filtering system are likely to demand physical inspection and cleaning of offshore*

components and they all have the potential to generate additional biological wastes (vegetative debris). Assuming no significant kelp debris issues, collection and disposal of these marine wastes could represent a moderate operational negative impact.

Note here that there has been no detailed analysis by Bechtel of screen cleaning issues.

In the Bechtel report, the use of a 2 mm wedge-wire screen array is suggested, with a through-screen velocity of 0.5 feet per second (fps).[1] Copper-nickel alloy screens are proposed to resist bio-fouling. To achieve the filtering area required would need a large screen array. It is suggested for the 2mm slot size option that 48 eight-foot diameter tee screens would be needed. This will take up a large area of seabed, and as the screens will leach copper, will add a measurable pollutant to the waters and sediments of the region. The bio-fouling resistance of the copper-nickel alloy is related to the leaching of copper.

Generally, smaller slot widths, lower through-slot velocities, and higher sweep velocities will result in better screen performance. However the smaller the slot size, the more screens are needed to produce the flow required for the power plant. In areas with weak currents or large arrays of screens, the probability that a larva or egg will have multiple encounters with the screen surfaces as it passes the array should be taken into account.

It really feels that we could use a conclusion here that sums up our critique/conclusions in regard to the wedge wire screens.

C. Fine Mesh Travelling Screens

Fine-mesh screens, with mesh sizes of less than 5mm, have been installed on conventional traveling screens to reduce entrainment. Fouling and clogging are major issues with this screening technology, and the increased size of the screens needed to maintain a low speed through the mesh makes retrofitting difficult.

The main problem with fine-mesh traveling screens is that they convert entrainment into impingement, and can simply transfer the mortality from one category to another. The survival of impinged small fish can be very low, with the larval stages often having greater than 80 percent mortality. This is because most larval fish are planktonic and simply not adapted to come into contact with hard surfaces or powerful jets of water.

Survival following impingement on such screens is highly species-specific, with clupeid (herring family) and other pelagic fish such as anchovy species having low survival, and depends on several factors:

1. Water velocity through the screen
2. The duration of impingement on the screen
3. Exposure to air during the removal from the screen

[1] Bechtel, September 2013, Section 1.2.2.2.

4. The amount of debris retained by the screen.

Bechtel proposes that the through-mesh velocity of screens will reduce from 1.95 fps to 1 fps, which is still above the 0.5 fps California once-through cooling policy rules.[2] This does not take into account any debris loading which can increase the flow through open areas of the screens.

Bechtel states that the design requires a 1 mm by 6 mm mesh on fine screens.[3] This will not protect small fish eggs and larvae from entrainment, and will convert the larger post-larvae presently entrained into impinged animals. The survival of the impinged larvae is not known, but mortality is likely to be high.

In conclusion, fine mesh travelling screens transfer some of the entrainment impact into impingement impact. Small organisms which would have passed through the cooling water system are now impinged on the screens. Delicate planktonic stages of fish are killed by impingement so fine mesh screens offer these species no protection. In addition, the size of mesh under consideration will not stop many of the early egg and larval stages of the fish found in the vicinity of Diablo Canyon from passing into the plant.

D. Suggested Entrainment Reductions

The Bechtel report considers the efficiencies of fine-mesh travelling screens to protect marine life. It suggests that there are large reductions in entrainment possible using fine-mesh screens. To support this they present the data given in Table 1.

Table 1: The suggested reduction in entrainment mortality (*Final technologies assessment for existing once-through cooling systems* (Bechtel Power Corporation report - Sept 20, 2013, page 28))

Out of 15 species evaluated, Tenera reported that average percentage reductions in mortality by slot/screen width are as follows:

Slot Size	0.75 mm	1 mm	2 mm	3 mm	4 mm	5 mm
Average percentage reduction in mortality	77.1%	67.6%	34.6%	15.8%	7.8%	1.8%

These data originate from a Tenera report which is presented as Table 2 below.[4] Table 1 is not representative of the actual results presented in the Tenera report, because of the size of the eggs and larvae entrained at Diablo Canyon. We therefore conclude that Bechtel is misrepresenting the underlying data by relying on average figures statewide rather than the Diablo-specific

[2] Ibid, Section 1.2.2.3.
[3] Ibid, Section 4.1.2.
[4] Tenera, *Length-Specific Probabilities of Screen Entrainment of Larval Fishes Based on Head Capsule Measurements*, July 31, 2013.

figures from the Tenera report. The true figure is only 39.7 percent with a 1 mm mesh at Diablo Canyon, and for a 2 mm mesh it is only 8.4 percent.

We will demonstrate that this is the case by a detailed examination of the tables within the Tenera report. The Tenera report states:[5]

> *The estimated population-level reductions in entrainment mortality in Table 4 assume that the screen is effective across all length classes up to the maximum lengths of 20 or 25 mm (0.79 or 0.98 in) used in the analysis.*

Table 2: The table from the Tenera report from which the summary originates (originally Table 4, *Length-Specific Probabilities of Screen Entrainment of Larval Fishes Based on Head Capsule Measurements, July 31, 2013*).

Table 4. Estimated percentage reductions (two standard errors in parentheses) in mortality (relative to an open intake) to the population surviving past the size where they would be subject to entrainment,[1] based on probabilities of screen entrainment for larvae from 15 taxonomic categories of fishes for six WWS slot widths.

Taxon	Size Range	Percentage Reduction in Mortality by Slot Opening Width [1]					
		0.75 mm	1 mm	2 mm	3 mm	4 mm	6 mm
kelpfishes	2–25 mm	73.3 (2.4)	64.6 (2.4)	24.9 (2.4)	1.4 (0.5)	0.0 (0.0)	0.0 (0.0)
sculpins	2–25 mm	85.9 (2.5)	81.1 (2.4)	64.4 (2.4)	49.7 (2.4)	36.0 (2.4)	14.1 (1.7)
flatfishes	1–25 mm	78.8 (2.3)	72.8 (2.3)	51.5 (2.3)	33.0 (2.2)	18.8 (1.8)	4.6 (0.8)
monkeyface prickleback	3–25 mm	75.7 (2.6)	62.1 (2.5)	12.8 (1.6)	0.5 (0.2)	0.0 (0.0)	0.0 (0.0)
combtooth blenny	2–20 mm	81.9 (3.1)	72.1 (3.1)	32.4 (2.8)	8.4 (1.4)	1.5 (0.4)	0.0 (0.0)
clingfishes	2–20 mm	83.0 (3.1)	75.8 (3.1)	48.8 (3.0)	26.9 (2.5)	13.1 (1.7)	2.6 (0.6)
anchovies	2–25 mm	55.4 (2.3)	45.1 (2.3)	5.5 (1.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
croakers	1–20 mm	81.9 (3.0)	74.9 (3.0)	46.1 (2.9)	17.6 (2.7)	1.7 (0.7)	0.0 (0.0)
gobies	1–25 mm	74.6 (2.3)	66.5 (2.3)	35.7 (2.3)	8.3 (1.7)	0.2 (0.1)	0.0 (0.0)
silversides	2–25 mm	76.0 (2.5)	68.5 (2.5)	34.8 (2.4)	3.0 (1.5)	0.0 (0.0)	0.0 (0.0)
Pacific barracuda	1–20 mm	68.2 (2.9)	53.1 (2.8)	15.8 (1.5)	4.4 (0.6)	1.3 (0.2)	0.1 (0.0)
rockfishes	2–25 mm	77.7 (2.5)	69.7 (2.5)	43.4 (2.2)	22.3 (1.7)	10.6 (1.0)	2.4 (0.4)
cabezon	2–25 mm	79.1 (2.5)	70.1 (2.5)	39.3 (2.1)	20.6 (1.5)	10.6 (1.0)	2.9 (0.4)
sea basses	1–25 mm	84.8 (2.4)	79.6 (2.2)	59.9 (2.4)	41.0 (2.3)	22.7 (2.3)	0.1 (0.1)
pricklebacks	3–25 mm	80.4 (2.6)	58.2 (2.5)	3.9 (0.5)	0.1 (0.0)	0.0 (0.0)	0.0 (0.0)
Average % Reduction		77.1	67.6	34.6	15.8	7.8	1.8

[1] - Extrapolated to the size at which the larvae are no longer susceptible to entrainment (estimated to be 20–25 mm [0.98 in] for this analysis). Not the reduction in adult equivalents.

[5] Ibid.

The entrained fish at Diablo Canyon are small, with the majority less than 6 mm long. Table 3 presents data for the most common species. Table 4 gives abundance data and shows that these species represent about 50 percent of the total fish numbers entrained. As can be seen in Table 3, the two most abundant groups entrained at Diablo Canyon are sculpins and rockfish. For both of these species over 80 percent of the larvae entrained were 4 mm or less long. **Such small sizes of larvae result in fine-mesh screens producing low levels of exclusion and therefore not appreciably reducing entrainment.**

Table 3: The length of fish at Diablo Canyon (originally Table 7 of *Length-Specific Probabilities of Screen Entrainment of Larval Fishes Based on Head Capsule Measurements, July 31, 2013*)

Table 7. Distribution of length measurements by number and percentage (in parentheses) for seven taxa of larval fishes collected during entrainment sampling at DCPP from October 1996 through June 1999. Only fishes up to 25 mm (0.98 in) length included in analysis.

Length (mm)	sculpins	rockfishes	kelpfishes	monkeyface prickleback	anchovies	cabezon	flatfishes
1	-	-	-	-	-	-	4 (1.0%)
2	128 (1.3%)	13 (0.1%)	1 (0.0%)	-	97 (3.8%)	1 (0.1%)	124 (31.5%)
3	6,134 (60.3%)	1,085 (8.3%)	7 (0.1%)	3 (0.1%)	914 (36.2%)	5 (0.3%)	204 (51.8%)
4	2,993 (29.4%)	10,101 (77.1%)	285 (3.9%)	5 (0.1%)	665 (26.3%)	394 (25.6%)	26 (6.6%)
5	692 (6.8%)	1,791 (13.7%)	1,938 (26.4%)	27 (0.5%)	162 (6.4%)	946 (61.5%)	6 (1.5%)
6	164 (1.6%)	91 (0.7%)	2,332 (31.8%)	591 (10.0%)	53 (2.1%)	188 (12.2%)	6 (1.5%)
7	40 (0.4%)	21 (0.2%)	1,499 (20.4%)	3,560 (60.2%)	38 (1.5%)	2 (0.1%)	17 (4.3%)
8	16 (0.2%)	1 (0.0%)	664 (9.1%)	1,056 (17.9%)	56 (2.2%)	1 (0.1%)	7 (1.8%)
9	5 (0.0%)	1 (0.0%)	307 (4.2%)	352 (6.0%)	73 (2.9%)	-	-
10	-	1 (0.0%)	125 (1.7%)	150 (2.5%)	69 (2.7%)	-	-
11	-	-	72 (1.0%)	76 (1.3%)	66 (2.6%)	-	-
12	1 (0.0%)	-	40 (0.5%)	48 (0.8%)	53 (2.1%)	-	-
13	-	-	13 (0.2%)	20 (0.3%)	37 (1.5%)	-	-
14	-	-	17 (0.2%)	10 (0.2%)	29 (1.1%)	-	-
15	-	-	2 (0.0%)	5 (0.1%)	27 (1.1%)	-	-
16	-	-	2 (0.0%)	4 (0.1%)	31 (1.2%)	-	-
17	-	-	4 (0.1%)	1 (0.0%)	27 (1.1%)	-	-
18	-	-	-	-	21 (0.8%)	-	-
19	-	-	5 (0.1%)	-	19 (0.8%)	-	-
20	-	-	6 (0.1%)	-	23 (0.9%)	-	-
21	-	-	5 (0.1%)	-	18 (0.7%)	-	-
22	-	-	6 (0.1%)	-	12 (0.5%)	-	-
23	-	-	1 (0.0%)	-	12 (0.5%)	-	-
24	-	-	-	-	12 (0.5%)	-	-
25	-	-	-	1 (0.0%)	13 (0.5%)	-	-
Totals	**10,173 (100%)**	**13,105 (100%)**	**7,331 (100%)**	**5,909 (100%)**	**2,527 (100%)**	**1,537 (100%)**	**394 (100%)**

Table 4: The abundance of different species at Diablo Canyon (originally Table 5, *Length-Specific Probabilities of Screen Entrainment of Larval Fishes Based on Head Capsule Measurements, July 31, 2013*).

Table 5. Abundances of fish larvae collected during entrainment sampling annual entrainment estimates at DCPP for two year long time periods: **July 1997–June 1998** and **July 1998–June 1999** for the fishes analyzed for this report. The annual entrainment estimates were based on actual plant cooling water flow volumes during those periods.

	1997–1998			1998–1999		
Common Name	Average Concentration (# / 1,000 m³)	Percent of Total Concentration	Total Annual Entrainment Estimate	Average Concentration (# / 1,000 m³)	Percent of Total Concentration	Total Annual Entrainment Estimate
sculpins	80.57	18.3%	281,090,063	55.17	18.9%	276,345,912
rockfishes	65.27	14.8%	216,878,458	66.06	22.6%	374,596,029
kelpfishes	36.88	8.4%	121,977,076	23.36	8.0%	90,774,143
monkeyface prickleback	32.61	7.4%	118,960,221	24.30	8.3%	127,721,405
northern anchovy	31.02	7.0%	106,375,289	1.27	0.4%	3,209,133
gobies	22.45	5.1%	77,134,182	6.77	2.3%	22,413,173
croakers	18.03	4.1%	67,033,233	4.89	1.7%	21,431,357
flatfishes	12.11	2.8%	45,128,059	5.22	1.8%	19,245,735
pricklebacks	9.52	2.2%	35,579,099	5.76	2.0%	33,382,111
cabezon	3.90	0.9%	14,707,340	1.83	0.6%	9,189,686
clingfishes	0.28	0.1%	989,753	1.13	0.4%	4,728,863
combtooth blennies	2.03	0.5%	7,154,897	4.43	1.5%	10,673,514
silversides	0.18	0.0%	482,917	0.08	0.0%	97,072
sea basses	0.02	0.0%	64,552	0.00	0.0%	-
Subtotal	**314.87**	**71.6%**	**1,093,555,139**	**200.24**	**68.6%**	**993,808,134**
Other Taxa (54 and 40)	125.19		422,730,243	91.86		292,431,756
Total	**440.06**		**1,516,285,382**	**292.10**		**1,286,239,890**

Tenera went on to adjust the level of entrainment based on the actual sizes of the fish present. These results are presented in Table 5. From this table it is clear appears that none of the slot sizes under consideration will produce an appreciable reduction in entrainment. **Even the 0.75 mm slot size, which has been excluded from the technology options for engineering reasons, would only be predicted to reduce entrainment by 18 percent. The smallest slot size under consideration of 1 mm only produced a reduction of 5 percent. Any slot size above this did not reduce entrainment by more than 0.2 percent.**

Table 5: Estimated entrainment reduction taking the size of entrained fish into account (originally Table 8, *Length-Specific Probabilities of Screen Entrainment of Larval Fishes Based on Head Capsule Measurements, July 31, 2013*).

Table 8. Estimated total entrainment for seven taxonomic categories of fishes at DCPP for two year-long time periods: **July 1997–June 1998** and **July 1998–June 1999**, and estimated entrainment and percentage reductions in entrainment for six WWS slot widths.

Taxon	Year	Annual Entrainment Estimate	Entrainment with 0.75 mm Slot	Entrainment with 1.0 mm Slot	Entrainment with 2.0 mm Slot	Entrainment with 3.0 mm Slot	Entrainment with 4.0 mm Slot	Entrainment with 6.0 mm Slot
sculpins	97-98	281,090,063	250,963,525	272,928,200	280,905,488	281,077,740	281,088,820	281,090,063
	98-99	276,345,912	246,727,840	268,321,802	276,164,452	276,333,797	276,344,690	276,345,912
		Percent Reduction	**10.7**	**2.9**	**0.1**	**<0.1**	**<0.1**	**0.0**
rockfishes	97-98	216,878,458	184,049,464	207,640,578	216,852,906	216,877,448	216,878,392	216,878,458
	98-99	374,596,029	317,893,252	358,640,210	374,551,895	374,594,285	374,595,915	374,596,029
		Percent Reduction	**15.1**	**4.3**	**<0.1**	**<0.1**	**<0.1**	**0.1**
kelpfishes	97-98	121,977,076	99,498,869	116,388,842	121,704,903	121,972,683	121,977,076	121,977,076
	98-99	90,774,143	74,046,082	86,615,434	90,571,594	90,770,874	90,774,143	90,774,143
		Percent Reduction	**18.4**	**4.6**	**0.2**	**<0.1**	**0.0**	**0.0**
monkeyface prickleback	97-98	118,960,221	75,512,079	112,810,990	118,940,270	118,959,255	118,960,201	118,960,221
	98-99	127,721,405	81,073,394	121,119,296	127,699,985	127,720,367	127,721,383	127,721,405
		Percent Reduction	**36.5**	**5.2**	**<0.1**	**<0.1**	**<0.1**	**0.0**
anchovies	97-98	106,375,289	92,329,457	96,839,651	105,639,334	106,375,289	106,375,289	106,375,289
	98-99	3,209,133	2,785,398	2,921,462	3,186,931	3,209,133	3,209,133	3,209,133
		Percent Reduction	**13.2**	**9.0**	**0.7**	**0.0**	**0.0**	**0.0**
cabezon	97-98	14,707,340	10,576,147	13,674,113	14,705,082	14,707,330	14,707,340	14,707,340
	98-99	9,189,686	6,608,365	8,544,088	9,188,275	9,189,680	9,189,686	9,189,686
		Percent Reduction	**28.1**	**7.0**	**<0.1**	**<0.1**	**0.0**	**0.0**
flatfishes	97-98	45,128,059	42,009,412	43,464,849	45,114,887	45,128,059	45,128,059	45,128,059
	98-99	19,245,735	17,915,728	18,536,427	19,240,118	19,245,735	19,245,735	19,245,735
		Percent Reduction	**6.9**	**3.7**	**<0.1**	**0.0**	**0.0**	**0.0**
Average Percent Reduction in Entrainment			**18.4**	**5.2**	**0.2**	**<0.1**	**<0.1**	**0.0**

Tenera went on to do a further analysis with the results presented in Table 6 below (their Table 9). For these calculations they adjusted the number of larvae entrained by the likelihood of survival to an age at which they would not be vulnerable to entrainment. As we understand their argument, it is that some of the larvae killed by entrainment would die anyway and so can be discounted. The actual method of adjustment is not explained, but even with the adjustment, a 1 mm gap mesh was only calculated to reduce the entrainment by about 40 percent and a 2 mm gap mesh by about 8 percent.

Table 6: Estimated entrainment reduction with population weighting (originally Table 9, *Length-Specific Probabilities of Screen Entrainment of Larval Fishes Based on Head Capsule Measurements, July 31, 2013*).

Table 9. Estimated percentage reductions (standard errors in parentheses) in mortality (relative to an open intake) to the population surviving past the size where they would be subject to entrainment,[1] based on probabilities of screen entrainment for larvae from seven taxonomic categories of fishes measured during DCPP entrainment studies conducted October 1996 through June 1999. Mortality adjusted from estimates in **Table 4** based on length range of larvae measured from the studies, except for anchovies.

	Percentage Reduction in Mortality by Slot Opening Width [1]					
Taxon	0.75 mm	1 mm	2 mm	3 mm	4 mm	6 mm
sculpins	69.2 (5.4)	58.7 (5.3)	24.3 (4.6)	5.5 (2.2)	0.5 (0.4)	0.0 (0.0)
rockfishes	46.2 (5.7)	32.0 (5.0)	5.2 (1.7)	0.5 (0.2)	0.0 (0.0)	0.0 (0.0)
kelpfishes	72.1 (2.5)	63.0 (2.5)	21.8 (2.4)	0.8 (0.3)	0.0 (0.0)	0.0 (0.0)
monkeyface prickleback [2]	62.8 (3.9)	42.2 (3.8)	0.9 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
anchovies *	55.4 (2.3)	45.1 (2.3)	5.5 (1.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
cabezon	36.3 (7.2)	19.0 (5.5)	0.6 (0.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
flatfishes	34.1 (7.1)	17.7 (6.0)	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Average % Reduction	**53.7**	**39.7**	**8.4**	**1.0**	**0.1**	**0.0**

[1] - Extrapolated to the size at which the larvae are no longer susceptible to entrainment (estimated to be 20–25 mm [0.98 in] for this analysis). Not the reduction in adult equivalents.

[2] - 25 mm monkeyface prickleback in Table 7 not included as the length distribution shows the data point as an outlier.

* - percentage reductions are the same as the values in Table 4.

E. Conversion of Entrained to Impinged Animals

When converting from a coarse-mesh to a fine-mesh screening system, fish that would have passed through the original screens are now impinged on the fine screen. To quantify the reduction in mortality achieved two factors need to be considered. First, the proportion of animals that will be stopped by the new screen – this is discussed in the section above. Second, and equally important, is the fate of the "converts". If, for example, all the converts die due to impingement stresses, impact of the station has not been reduced at all.

Another Tenara document addresses the issues of converts and their survival.[6] They reviewed the available literature and noted that generally there was a relationship between the size of a larvae and its likelihood of survival. For most of the very small larvae there was negligible survival. For some species such as the Northern anchovy, the report noted that even large larvae are very vulnerable to the stresses of impingement and would not survive. In the conclusion of this document they state:[7]

"The purpose of installing fine-mesh screens at DCPP is largely to reduce the effects of entrainment as the existing levels of impingement at the plant are very low. Based on the available information from entrainment studies at DCPP and studies of fine-mesh performance,

[6] Tenera, *Evaluation of Fine-mesh Intake Screen System for the Diablo Canyon Power Plant*, August 5, 2013.
[7] Ibid, p. 10.

the expected benefits from the screens would be minimal. ***The entrainment studies at DCPP show that the vast majority of the fishes entrained were very small and based on other studies, the probability of these larvae surviving impingement, screen-wash systems, and fish return would be very low****. Northern anchovy was the only fish taxa entrained with large numbers of larvae greater than 10 mm, and the expected survival of the larvae for this species would be very low based on the results of the LMS (1981) studies at Redondo Beach."*

F. Fine Mesh Travelling Screens and Wedge-Wire Screens Conclusion

All methods based on filtering out planktonic life-forms from once-through cooling water flows to reduce entrainment at large power plants are problematical and unreliable.

Wedge-wire screens with a slot width of 2 mm and 6 mm as selected by Bechtel for pilot testing would not appreciably reduce entrainment at Diablo Canyon, because of the small size of the dominant larval fish at this location. Using data on the sizes of eggs and larval fish vulnerable to entrainment at Diablo Canyon shows that a 2mm mesh would reduce entrainment by only 8.4%.

The use of fine-mesh travelling screens is equally ineffective. The small, delicate, early stages are converted from being entrained into being impinged on the screens. They then need to be washed off and returned to the sea via some form of return system. Impingement and any form of handling is almost inevitably fatal to delicate planktonic fish larvae. Fine-mesh screens will therefore be ineffective in reducing larval mortality.

The only assured method to reduce entrainment is to reduce the amount of water taken in by the plant. The best method for volume reduction is the use of closed-cycle cooling.

III. Closed Cycle Cooling

A. Closed Cycle Cooling Introduction

Diablo consists of two reactors with a total capacity of 2,200 MW that came online in the mid-1980s using once through seawater cooling. Closed-cycle cooling would reduce cooling water demand at Diablo Canyon, relative to once through cooling, by approximately 96 percent or about 2.4 billion gallons of water per day.

Three different entities have evaluated cooling tower options and associated costs for Diablo Canyon: Bechtel, PG&E, and TetraTech. Bechtel (September 2013) evaluated five cooling tower designs at a site located to the north of the developed plant site on steep terrain and identified 590-foot tall hyperbolic natural draft cooling towers as the preferred alternative. Bechtel budgets $3.3 billion primarily to excavate 317 million cubic yards of material to level the chosen site. The total mid-range project cost estimated by Bechtel for construction of the cooling towers, and replacement power during the construction outage, is approximately $9.9 billion, or $4,500 per kilowatt (kW) of installed capacity.

Bechtel has an ongoing relationship with PG&E. Bechtel provided start-up engineering and construction support for the completion and commercial operation of Diablo Canyon, and has done hundreds of projects for PG&E over the years.

PG&E (March 2011) evaluated back-to-back conventional mechanical draft cooling towers in the active parking and warehouse areas adjacent to the Diablo Canyon reactors. This site eliminates the multi-billion dollar cost of removing a mountain to make space for the cooling towers. PG&E estimated a retrofit cost of $4.49 billion (~$2,040/kW).

TetraTech (February 2008) also evaluated back-to-back conventional mechanical draft cooling towers in the active parking and warehouse areas under contract to the State Water Resources Control Board. TetraTech estimated a retrofit cost of $1.62 billion (~$740/kW). TetraTech is a major nuclear industry contractor.

TetraTech provides the most detail in terms of equipment and cost assumptions. Although the TetraTech cooling tower cost estimate for Diablo Canyon is much higher on a unit basis than TetraTech cost estimates for non-nuclear once through cooled power plants in California, which are in the $90/kW to $200/kW range, it is at least a credible initial estimate. Bechtel on the other hand chooses a cooling tower site that requires over $2 billion in excavation costs to be usable for cooling towers. No justification is provided by Bechtel for selecting such a site, despite the fact that both the PG&E and TetraTech cooling tower layouts were available to Bechtel before it initiated its evaluation.

The Bechtel cost estimate is not credible due in substantial part to the selection of a steep and cost-prohibitive site chosen for the cooling towers. Bechtel would level a mountain at a cost of over $3 billion to prepare the site for cooling towers. The PG&E cost estimate lacks credibility because it includes demonstrably exaggerated costs compared to publicly verifiable costs for the

same equipment. PG&E adds approximately $2 billion for essentially the same cooling tower design and layout as used in the TetraTech estimate. The PG&E cost estimates are consistently 3 to 4 times the TetraTech cost for the same equipment or activity.

For example, TetraTech proposes a 52-cell back-to-back conventional mechanical draft cooling tower for each unit while PG&E proposes a 40-cell back-to-back conventional mechanical draft tower design for each unit. TetraTech estimates the total cooling tower equipment cost at $61 million and is consistent with publicly available cooling tower manufacturer cost estimates. PG&E estimates a total cooling tower equipment cost of $242 million, four times greater than TetraTech, with no supporting documentation to justify the otherwise inexplicably high cost.

Numerous U.S. power plants have been retrofitted from once through cooling to cooling towers. All three cooling tower retrofit cost estimates for Diablo Canyon are far above the unit cost, in $/kW, of costs incurred on actual cooling tower retrofits at nuclear and non-nuclear plants. Of the three estimates, the TetraTech estimate is the most credible in terms of the cooling tower design chosen, cost, and outage time necessary for cooling tower piping interconnection.

However, the TetraTech estimate of lost efficiency due to the cooling tower retrofit is unrealistically high at 5 percent relative to Bechtel (2.3 percent) and the EPA (1.5 percent), and appears to be based on an incorrect assumption about the performance capabilities of existing steam turbine surface condensers at Diablo Canyon. For that reason, the cooling tower performance penalty calculated by Bechtel, though still conservative, is a more realistic estimate.

The cost of replacement power assumed for the cooling tower construction outage(s) is directly related to the length of the outage. Both Bechtel and PG&E assume 17-month outages. TetraTech assumes 8 months per unit. In reality, no additional cost should be assumed at the initial study level for replacement power during a forced outage for hook-up of cooling tower piping to the existing circulating water piping system at Diablo Canyon.

Very invasive projects have been conducted at Diablo Canyon, specifically the replacement of steam generators within the nuclear containment dome(s), with outages of as little as seven weeks (58 days). These outages were timed with scheduled refueling outages to minimize or eliminate forced outage time.

In the same study TetraTech conducted on a cooling tower conversion at Diablo Canyon, TetraTech estimated the hook-up time for non-nuclear California coastal plants at four weeks, less than the duration of a typical four- to six-week nuclear plant refueling outage. No convincing rationale is offered by Bechtel, PG&E, or TetraTech for the very long outage time presumed for cooling tower tie-in at Diablo Canyon. Several actual U.S. non-nuclear plant cooling tower conversions required four weeks or less of outage time to tie-in the cooling tower piping.

B. Use of Cooling Towers at U.S. Nuclear Plants

The U.S. EPA has documented the distribution closed-cycle, once-through cooling, and combination (can operate as closed-cycle or once-through) systems at U.S. nuclear plants. There are 31 nuclear plants in the U.S. that exclusively use once through cooling, and 31 nuclear plants

that exclusively use closed cycle cooling or a combination of closed cycle and once through cooling.[8] In other words, half of U.S. nuclear plants have the capability to operate using closed cycle cooling.

Combination cooling systems can operate as closed-cycle or once-through cooling systems depending on the position of the isolation valves and sluice gates. Examples of U.S. nuclear power plants utilizing a combination cooling system are Xcel Energy's 1,100 MW Prairie Island Nuclear Generating Station (MN) and Entergy's 605 MW Vermont Yankee Nuclear Power Plant (VT).[9] The cooling towers at these two nuclear plants are shown in Figure 1.

Figure 1. Cooling Towers at Prairie Island Nuclear and Vermont Yankee

a. Prairie Island Nuclear Generating Plant[10]

b. Vermont Yankee Nuclear Power Plant[11]

[8] U.S. EPA, *Technical Development Document for the Proposed Section 316(b) Phase II Existing Facilities Rule*, March 2011, Exhibit 4-10, p. 4-9.
[9] ASA, Inc., *Hydrothermal Modeling of the Cooling Water Discharge from the Vermont Yankee Power Plant to the Connecticut River – Final Report*, ASA Report 02-088, prepared for Normandeau Associates, Inc., April 2004 (revision), p. 1.
[10] Xcel Energy – Prairie Island Nuclear Generating Plant webpage: http://www.xcelenergy.com/Safety_&_Education/Nuclear_Safety/About_Nuclear_Energy/Prairie_Island_Nuclear_Generating_Plant.
[11] Google Earth photograph of Vernon, VT and Vermont Yankee Nuclear.

The installed cost of the only cooling tower retrofit conducted to date on a U.S. nuclear unit, the 800 MW Palisades Nuclear in Michigan, was $68/kW in 1999 U.S. dollars. This is equivalent to approximately $95/kW in 2011 dollars, a small fraction of Bechtel's cooling tower conversion cost estimate.[12] This retrofit project included the installation of higher head pumps to overcome the hydraulic resistance of the cooling tower(s).[13] The two inline mechanical draft cooling towers at Palisades Nuclear are shown in Figure 2.

Figure 2. Mechanical Draft Inline Cooling Towers at Palisades Nuclear[14]

In addition to PG&E's ownership of Diablo Canyon, California utilities also own 18 percent of the 3,700 MW Palo Verde Nuclear Power Plant in Arizona.[15] Palo Verde is the largest nuclear plant in the U.S. and began operation about the same time as Diablo Canyon, in the mid-1980s.[16] Palo Verde employs round mechanical draft cooling towers in a closed cycle cooling system in one of the hottest climates in the U.S. Palo Verde utilizes treated wastewater from nearby

[12] Chemical Engineering, *Marshall & Swift Equipment Cost Index*, April 2012 and November 2008 editions. Annual index in 2000 = 1,089.0; annual index in 2011 = 1,518.1. Therefore, unit cooling tower retrofit price, adjusted from 2000 to 2011 = (1,518.1 ÷ 1,089.0) × $68/kW = $95/kW.

[13] U.S. EPA, 2002 Phase II TDD, p. 4-5 ("The final installed cost of the project was $18.8 million (in 1973-1974 dollars), as paid by Consumers Energy. The key items for this project capital cost included the following: two wood cooling towers (including splash fill, drift eliminators, and 36-200 hp fans with 28 ft blades); two circulating water pumps; two dilution water pumps; startup transformers; yard piping for extension of the plant's fire protection system; modifications to the plant screenhouse to eliminate travelling screens and prepare for installation of the dilution pumps; a new discharge pump structure with pump pits; a new pumphouse to enclose the new cooling tower pumps; yard piping for the circulating water system to connect the new pumphouse and towers; switchgear cubicles for the fans; roads, parking lots, drains, fencing, and landscaping; and a chemical additive and control system.").

[14] Palisades Nuclear webpage: http://palisadespowerplant.com/.

[15] U.S. Energy Information Administration. *San Onofre nuclear outage contributes to Southern California's changing generation profile*, November 14, 2012: http://www.eia.gov/todayinenergy/detail.cfm?id=8770

[16] J. Maulbetsch, M. DiFilippo, *Performance, Cost, and Environmental Effects of Saltwater Cooling Towers – PIER Final Consultant Report*, prepared for California Energy Commission, January 2010, Table 4-1, Salt Water Tower Installations, pp. 20-21. Palo Verde I, 1985; Palo Verde II, 1986; Palo Verde III, 1987.

Phoenix as water supply for the cooling towers. The total dissolved solids content, also known as "salt" content, in the cooling tower circulating water is about 70 percent that of seawater at 24,000 parts per million.[17] The Palo Verde cooling towers are shown in Figure 3.

Figure 3. Palo Verde Nuclear Plant with Round Mechanical Draft Cooling Towers[18]

Back-to-back cooling towers, both conventional wet and plume-abated, are in commercial use in the U.S. SPX recently commercialized a plume-abated back-to-back cooling tower design known as ClearSky™ capable of operating on salt water or fresh water. See **Attachment A** for a description of the ClearSky™ cooling tower. Figure 4 provides examples of operational back-to-back cooling towers and a ClearSky™ cell in operation in New Mexico.

Figure 4. Examples of Operational U.S. Back-to-Back Cooling Towers and ClearSky Cell

Plant Yates, Georgia

Plant Branch, Georgia

[17] Ibid, p. 40. "The (Palo Verde) cooling towers are operated (on average) at 24 cycles of concentration—at times, as high as 30 cycles. Average feedwater TDS is approximately 1,000 mg/l. Therefore, circulating water TDS is approximately 24,000 mg/l, about 70 percent of normal seawater."
[18] Ibid, p. 39.

Bergen Generating Station, New Jersey	ClearSky cell, New Mexico (far left)

C. *Design and Siting of Cooling Towers at Diablo Canyon*

The use of saltwater cooling towers at Diablo Canyon would reduce seawater withdrawals for cooling by 96 percent.[19] This a reduction from the current once through cooling withdrawal rate of approximately 2.5 billion gallons per day to about 100 million gallons per day.

Cooling tower alternatives examined by TetraTech and PG&E assume use of seawater in the cooling towers. In contrast, the Bechtel report presumes that salt water cooling towers could not be used at Diablo Canyon due to the mist or "drift" escaping the cooling tower and the resulting particulate emissions as the mist dries. Bechtel presumes these particulate emissions represent and insurmountable compliance challenge with respect to local air pollution control district and EPA requirements.[20] No analysis is included in the Bechtel report, such as summaries of meetings or discussions with air pollution control authorities, to support this position. Instead Bechtel assumes the need for a large and costly seawater desalination plant to provide fresh makeup water to the cooling towers to minimize particulate emissions from the towers. This issue is addressed in more detail in Section J, "Closed-Cycle Cooling Particulate Emissions Can Be Mitigated."

It is important to remember the context of a cooling tower retrofit at Diablo Canyon. Cooling towers are being evaluated for Diablo Canyon to meet Clean Water Act Section 316(b). Section 316(b) of the Clean Water Act requires that the location, design, construction and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact.[21]

EPA is the federal government entity charged with assuring power plant operators comply with Section 316(b). It is not credible to assume, as Bechtel has done, that either the local San Luis Obispo County Air Pollution Control District (SLO APCD) or the EPA would seek to derail a

[19] TetraTech, *California's Coastal Power Plants: Alternative Cooling System Analysis*, February 2008, Chapter C – Diablo Canyon Power Plant, p. C-1.
[20] Bechtel report, Table 1-2, p. 13.
[21] EPA webpage, Cooling Water Intake Structures—CWA §316(b): http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/

Section (b) compliance project at Diablo Canyon by impeding the development of effective mitigation measures, known as "emission reduction credits," for particulate emissions from the new cooling towers.

As noted in the 2010 salt water cooling tower report commissioned by the California Energy Commission, Bechtel has commissioned the construction of two salt water cooling towers in the U.S. in the past 15 years.[22] Salt water is a viable alternative for cooling towers at Diablo Canyon.

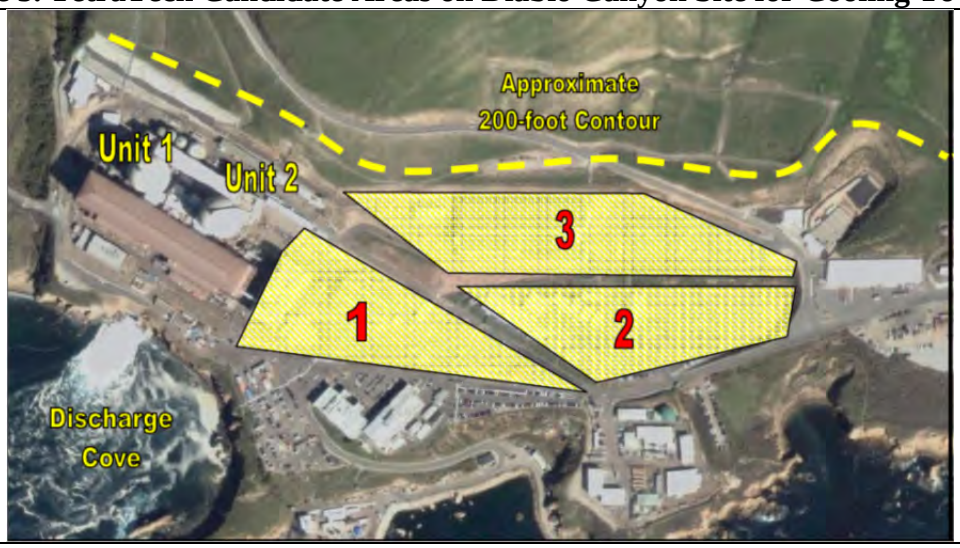
The TetraTech, PG&E, and Bechtel cooling tower assessments are summarized in the following sub-sections.

1. TetraTech Design

TetraTech identified three viable areas for siting cooling towers on developed land to the immediate east of Diablo Canyon Units 1 and 2 as shown in Figure 5. Some removal or relocation of existing structures would be necessary with the proposed TetraTech cooling tower design as shown in Figure 5. TetraTech states that:

> *Area 1 is occupied by the administration building, security offices, and cold machine shop, and that the cumulative size of this area (approximately 200,000 square feet) could accommodate the cooling tower for either Unit 1 or Unit 2.*
>
> *Area 2 is occupied by parking lots and temporary buildings.*
>
> *Area 3 is occupied by employee parking lots and the main warehouse, which is approximately 100,000 square feet. To install wet cooling towers in this area, suitable relocation spots for the main warehouse and parking areas must be identified.*

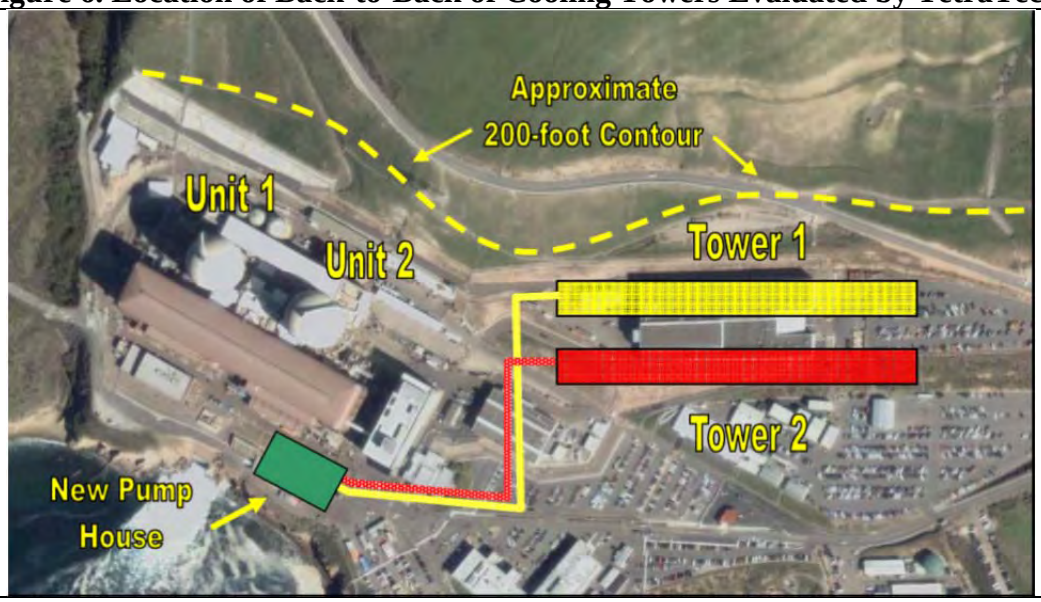
Figure 5. TetraTech Candidate Areas on Diablo Canyon Site for Cooling Towers[23]



[22] J. Maulbetsch, M. DiFilippo, *Performance, Cost, and Environmental Effects of Saltwater Cooling Towers – PIER Final Consultant Report*, prepared for California Energy Commission, January 2010, Table 4-1, p. 19.
[23] Ibid, p. C-13.

TetraTech evaluated two 52-cell back-to-back conventional mechanical draft cooling for Units 1 and 2 at Diablo Canyon as shown in Figure 6. Each cooling tower would be 1,404 feet long by 108 feet wide by 59 feet tall. TetraTech assumed that each cooling tower would be one continuous 1,404 feet long unit. This assumption overly limited cooling tower siting possibilities.

Figure 6. Location of Back-to-Back of Cooling Towers Evaluated by TetraTech



There is sufficient space to site back-to-back cooling towers with minimum impact on the existing main warehouse (Area 3) and temporary buildings (Area 2) if the cooling towers are each split into two equivalent 22-cell sections, or two sections that sum to 44-cells per cooling tower. PG&E, in its conceptual cooling tower plan for Diablo Canyon, split the back-to-back cooling towers into two equivalent sections (see discussion of PG&E cooling tower conceptual plan in this section).

Plume-abated back-to-back mechanical draft cooling towers are also a feasible option at the Diablo Canyon site. TetraTech, in a June 2013 study, evaluated back-to-back plume abated cooling towers as a feasible alternative for the two-unit 2,050 MW Indian Point (NY) nuclear power plant.[24] TetraTech utilized a cooling tower design, the SPX ClearSky™ technology, that was not commercially available at the time TetraTech issued its closed cycle cooling evaluation of Diablo Canyon in early 2008.[25]

Use of plume-abatement would minimize any issues with visible plumes from the cooling towers. Back-to-back plume-abated mechanical draft cooling towers are a low profile design

[24] TetraTech, *Indian Point Closed-Cycle Cooling System Retrofit Evaluation*, prepared for the New York Department of Environmental Conservation, June 2013.
[25] Ibid, p. 12.

with a height of 80 to 90 feet,[26] would avoid generating highly visible vapor plumes, and would also not alter the general appearance of the plant site as seen from the ocean.

Figure 6 shows the existing seawater supply piping (solid blue lines) to Units 1 and 2 and the warm water discharge infrastructure (solid tan lines).[27] The new closed cycle cooling circulating water pump house identified by TetraTech and associated piping is shown as dashed tan lines in Figure 6. TetraTech identifies the pump house location as the same pump house location identified in the 1982 Terra Corp study.[28]

Figure 6. Existing Cooling Water Piping and New Pump House Identified by TetraTech

At the time TetraTech developed its cooling tower retrofit alternative for Diablo Canyon in early 2008, back-to-back mechanical draft plume-abated cooling towers capable of operating on salt water were not commercially available. Since that time SPX has commercialized the ClearSky™ plume-abated mechanical draft cooling tower. SPX provided Powers Engineering with a generic sizing and cost estimate for the back-to-back ClearSky cooling tower using salt water in nuclear applications. The SPX estimate is provided in **Attachment B**.

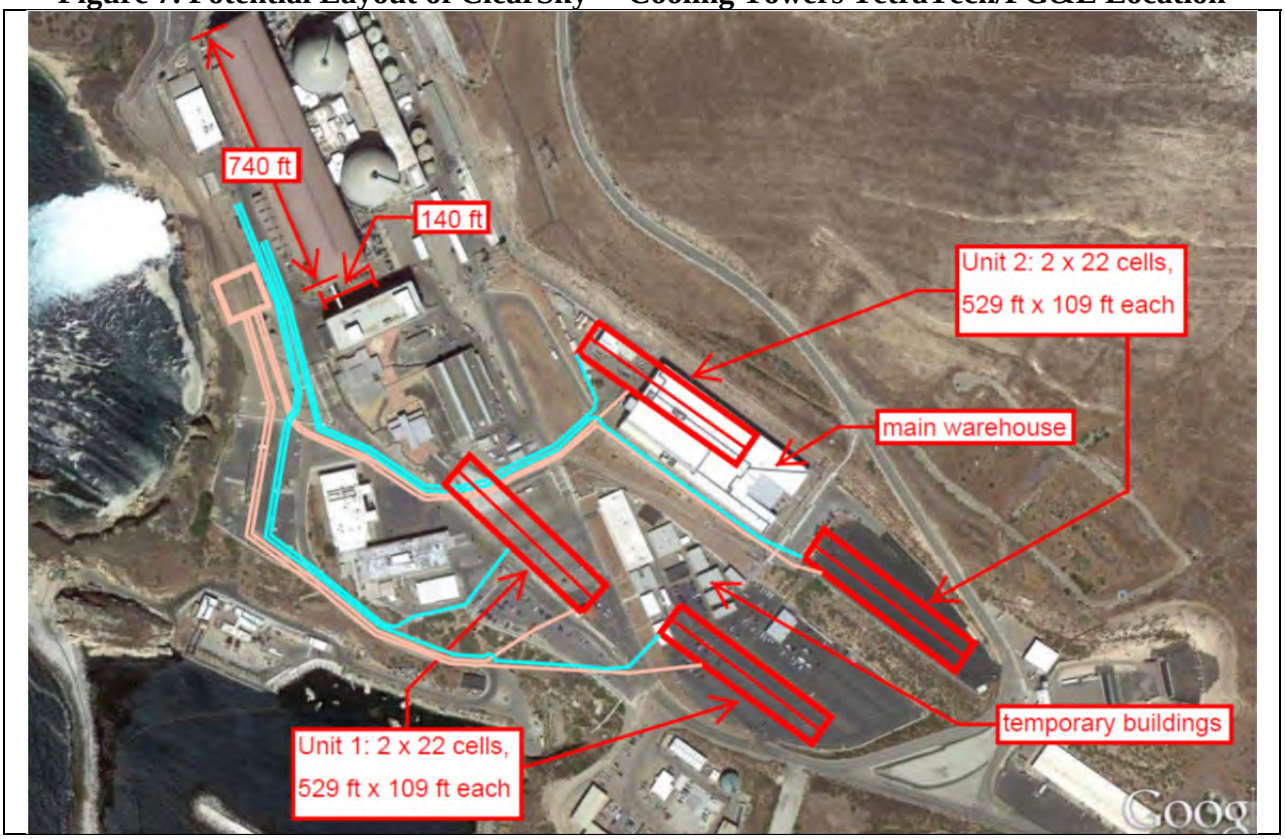
The SPX estimate assumes a design cooling tower approach temperature of 12 ^{o}F. To meet a 12 ^{o}F approach temperature at design conditions, two 62-cell salt water cooling towers would be required at Diablo Canyon. Approach temperature is a measure of how close the circulating

[26] E-mail from Paul Lindahl, Director, Market Development, SPX Thermal Equipment & Services, to B. Powers, Powers Engineering, August 16, 2012.
[27] Bechtel report, Figure 4.3-5. Circulating Water System, p. 81.
[28] Tetratech, p. C-14.

cooling water temperature "approaches" the ambient wet bulb temperature at design conditions. TetraTech assumed a design cooling tower approach temperature of 17 ^{o}F for the Diablo Canyon cooling towers. All other design parameters being equal, as the approach temperature increases the cooling tower size decreases in a nearly linear pattern. This characteristic is shown in **Attachment C**.

Adjusting the 62-cell, 12 ^{o}F design approach temperature SPX salt water cooling tower to a 17 ^{o}F design approach temperature results in 44-cell salt water cooling towers for Unit 1 and Unit 2. These cooling towers would be constructed in two sections each as shown in Figure 6. Splitting the cooling towers into two sections allows much more effective use of available space at Diablo Canyon. It also minimizes the potential for recirculation of warm air exiting the cooling towers by increasing the spacing between tower sections. A potential layout at Diablo Canyon for the two 44-cell cooling towers configured in two 22-cell sections each is shown in Figure 7.

Figure 7. Potential Layout of ClearSky™ Cooling Towers TetraTech/PG&E Location

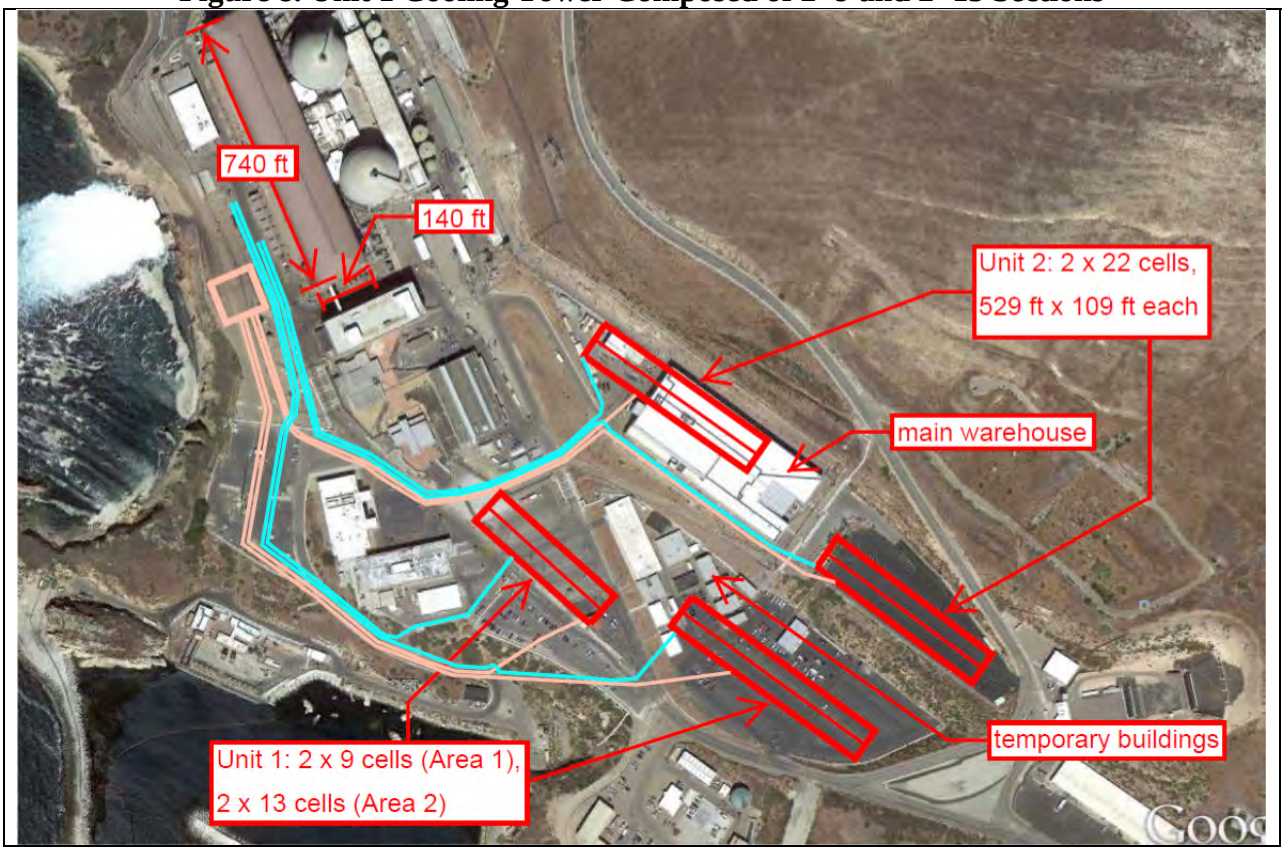


tan lines = warm water from Units 1 and 2 to cooling towers; blue lines = cold return water to plant

The potential arrangement for the Unit 1 cooling tower sections shown in Figure 7 above could also be modified to take advantage of the greater amount of space available in Area 2 than Area 1 for the cooling tower sections. Only temporary buildings would be displaced in Area 2 by the Unit 1 cooling tower section. A 9×2 cooling tower section in Area 1 would provide an additional buffer between buildings in Area 1 and the Unit 1 cooling tower section. A 2×13 cell Unit 1 cooling tower section would be located in Area 2. See the Unit 1 cooling tower configuration in Figure 8. The Unit 1 cooling tower would remain a 44-cell back-to-back plume abated tower. The capacity of the dedicated circulating water pumps and associated pipelines serving each of

the two Unit 1 cooling tower sections would be adjusted to meet the flowrate and hydraulic head requirements specific to each section of the Unit 1 cooling tower.

Figure 8. Unit 1 Cooling Tower Composed of 2×9 and 2×13 Sections

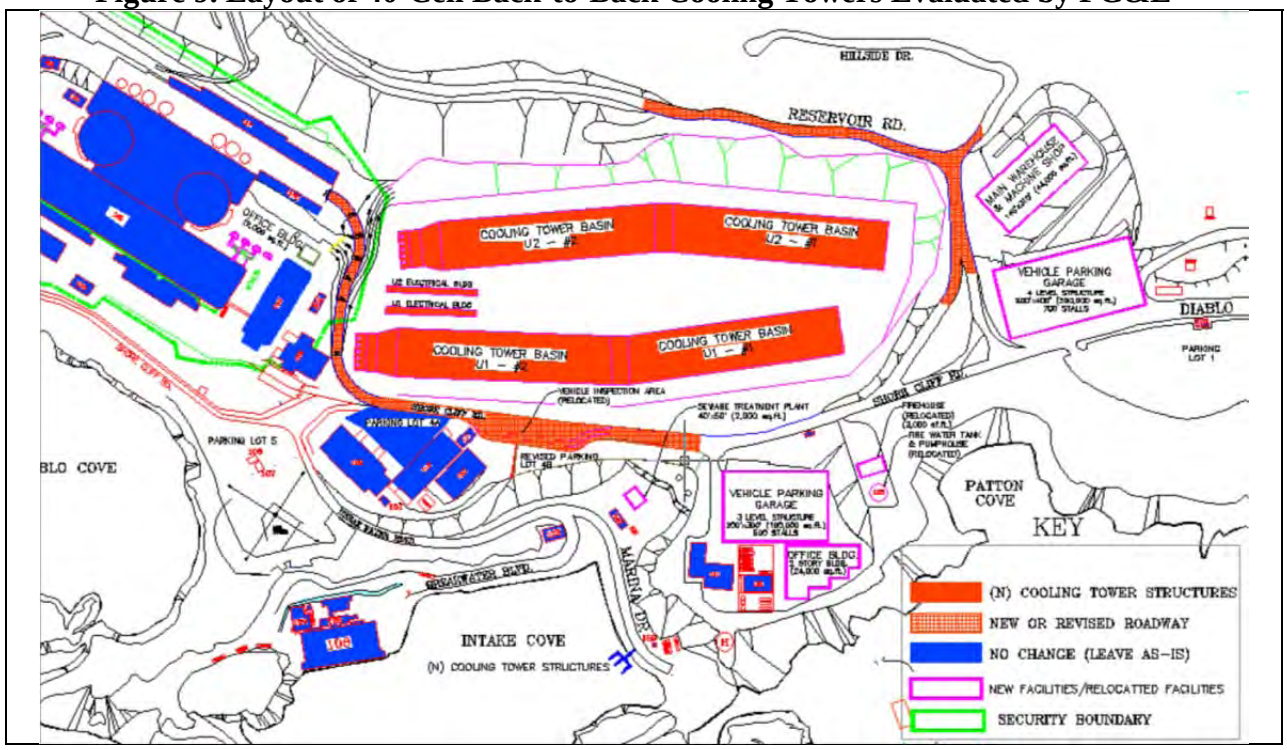


2. PG&E Design

PG&E evaluated back-to-back mechanical draft cooling towers for Diablo Canyon in 2011, using cooling towers similar to those assumed by TetraTech in its 2008 study.[29] The PG&E cooling towers consist of 40-cells for each unit, in two sections of 20 cells each, located in the existing warehouse and parking areas to the east of the reactors. This is the same area where TetraTech located the cooling towers in its 2008 study. The layout of the cooling towers evaluated by PG&E is shown in Figure 9.

[29] PG&E, *Diablo Canyon Once Through Cooling*, PowerPoint presentation, March 28, 2011.

Figure 9. Layout of 40-Cell Back-to-Back Cooling Towers Evaluated by PG&E[30]

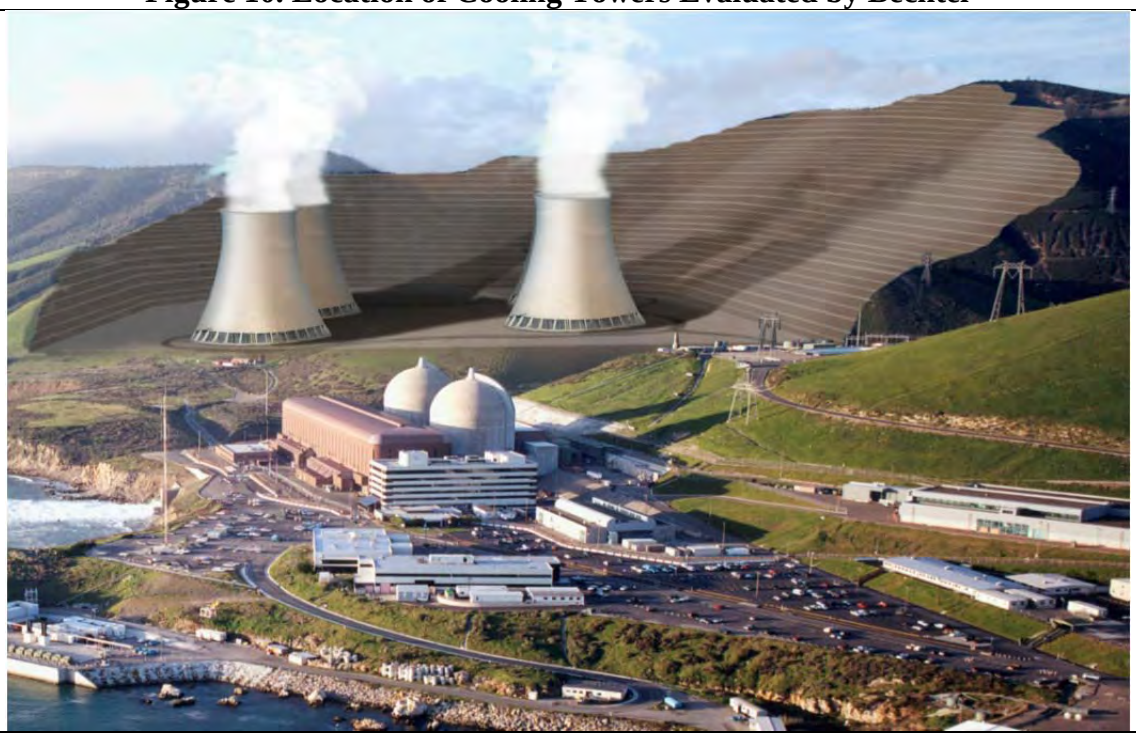


3. Bechtel Design

In contrast, Bechtel evaluated several different cooling tower designs away from the main plant site on (currently) steep terrain east of a 47-acre archaeological site.[31] Bechtel provides no explanation in its report as to why it selected this site instead of other possible sites on the property. Bechtel identified the preferred design as natural draft hyperbolic cooling towers on a mountainous site requiring the removal of over 317 million cubic yards of rock and overburden.[32] Bechtel makes no mention in its report of prior Diablo Canyon closed cycle cooling studies, such as those prepared by TetraTech and PG&E, that selected salt water back-to-back mechanical draft cooling towers and located these towers in the developed area to the east of the reactors. The proposed cooling towers and their location are shown in Figure 10.

[30] Ibid, p. 6.
[31] PG&E Letter DCL-12-080 to U.S. Nuclear Regulatory Commission, *Non-Routine Report of Planned Disturbance of Archaeological Site SLO-2*, August 21, 2012. "Of specific concern is archaeological site SLO-2, which covers approximately 47 acres adjacent to DCPP."
[32] Bechtel, September 20, 2013, p. 186.

Figure 10. Location of Cooling Towers Evaluated by Bechtel[33]



D. Cooling Tower Capital Cost

Table 1 is a comparison of the cost estimates prepared by Bechtel, PG&E, and TetraTech for cooling towers at Diablo Canyon.

Table 1. Comparison of Cooling Tower Cost Elements in Bechtel, PG&E, and TetraTech Estimates

Element	Bechtel ($ millions)	PG&E ($ millions)	TetraTech ($ millions)
1. Site work, excavation, retaining walls	3,632	325	213
2. Demolition, replacement of buildings, roads, parking		316	
3. Recirculating water/make-up water pumps, tunnels, piping	506	298	219
4. Permitting, engineering, project management, security	370	269	see (11)
5. Cooling towers	272	242	61
6. Electrical systems, process/instrumentation, utility relocation	133	199	16
7. Worker transportation, commute wages, parking	21	189	

[33] Ibid, p. 12.

8. Upgrades – condensers, sewage treatment, SCW	see (2)	131	26
9. Blowdown water treatment, mixing station, diffuser	see (2)	56	see (3)
10. Plant shutdown and start-up	NA	50	NA
11. Indirect costs and contingency	3,480	614	360
Total project construction cost	8,414	2,689	895
Replacement power cost during plant outage	1,493	1,800	727
TOTAL OVERALL PROJECT COST	9,907	4,489	1,622

The unit cooling tower retrofit cost for each estimate, including the cost of plant outage replacement power during construction, is: Bechtel, $4,500/kW; PG&E, $2,040/kW; and TetraTech, $740/kW. The principal reasons for Bechtel's very high cost are: 1) site selection requiring more than $3 billion in additional expense compared to the PG&E and TetraTech estimates to remove a mountain to make space available for the proposed cooling towers and to construct a desalination plant to provide cooling tower makeup water under the incorrect presumption that air permits could not be obtained for salt water cooling towers, and 2) huge indirect and contingency costs totaling nearly $3 billion more than comparable PG&E and TetraTech estimates.

Bechtel provided start-up engineering and construction support for the completion and commercial operation of Diablo Canyon for PG&E, and has done hundreds of projects for PG&E over the years.[34,35] TetraTech is a major nuclear industry contractor that has done projects for the majority of U.S. nuclear power plants.[36]

TetraTech recently completed a cooling tower conversion study for the two-unit 2,050 MW Indian Point nuclear plant. The estimated capital cost of the conversion, using SPX ClearSky™ back-to-back plume abated cooling tower technology, is $807 million without the 25 percent contingency and $1.01 billion with the contingency budget included.[37] Substantial excavation and bedding/backfill is assumed in the TetraTech study. The proposed Indian Point cooling tower configurations would require approximately 2.7 million cubic yards of excavation and 440,000 cubic yards of bedding and backfill.[38] The forced outage periods estimated by TetraTech

[34] Bechtel Corporation website, *Bechtel History 1980-1989: Surviving a Global Downturn*: http://www.bechtel.com/BAC-Chapter-6.html.
[35] San Francisco Chronicle, *Global Power Trip for PG&E, Bechtel*, February 27, 1995. "Bechtel and PG&E have done business together in the United States for more than 65 years. Bechtel has worked on more than 300 PG&E projects, mostly in California . . ."
[36] TetraTech wepage, Nuclear Facilities License Renewal: http://www.tetratech.com/projects/nuclear-facilities-license-renewal.html. "Tetra Tech's license renewal experience dates from 1991, with our participation in industry review and comment on draft NRC regulatory changes to its environmental requirements for license renewal. Our staff has supported or is currently supporting the majority of license renewal initiatives to-date for the 104 reactors at 65 operating commercial nuclear power sites."
[37] TetraTech, *Indian Point Closed-Cycle Cooling System Retrofit Evaluation*, prepared for the New York Department of Environmental Conservation, June 2013, p. 22.
[38] Ibid, Appendix A, p. 1.

for the cooling tower conversions at Indian Point under an aggressive work schedule are 30 weeks (Unit 2) to 35 weeks (Unit 3).[39] The overall TetraTech cost estimate for the cooling tower conversions at Indian Point, including capital cost, contingency, construction outage, efficiency losses, and maintenance costs, is $1.61 billion.[40]

E. Cooling Tower Energy Penalty

The preferred cooling tower alternative evaluated by Bechtel is a natural draft wet cooling tower. This design has lower operating costs than other alternatives as the fan power demand is eliminated. Use of a natural draft cooling tower introduces a small "energy penalty" consisting of: 1) extra pumping power needed to pump cooling water through the cooling tower, and 2) reduced power output due to the higher backpressure on the steam turbine caused by the incrementally higher cooling water temperature (relative to once-through cooling).

The U.S. EPA has studied these energy penalties as part of the process of establishing national regulations for cooling water intake structures. Both the EPA 316(b) 2001 Phase I Technical Development Document (TDD) for new plants and the 2002 Phase II TDD for existing plants included the average heat rate penalty, fan penalty, and pump penalty for cooling tower retrofits at nuclear plants. The average turbine efficiency penalty data is presented in Table 2 below.

Table 2. EPA Cost Model – Annual Average and Peak Turbine Efficiency Penalty for Cooling Towers on Nuclear Plants[41,42]

Plant type	Average turbine efficiency penalty (%)	Peak turbine efficiency penalty (%)
Nuclear	0.40	1.03

The 2002 Phase II TDD includes the average cooling tower fan energy penalty and pump energy penalty for nuclear plants. These energy penalties are shown in Table 3.

Table 3. EPA Estimates of Nuclear Plant Cooling Tower Pump and Fan Power Penalty[43]

Plant type	Pump power energy (%)	Fan power energy (%)	Total pump and fan power energy (%)
Nuclear	0.57	0.56	1.13

[39] Ibid, p. 24.
[40] Ibid, p. 26.
[41] EPA, *Technical Development Document for the Proposed Section 316(b) Phase I Existing Facilities Rule*, November 2001, Table 3-14, p. 3-20. See: http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase1/technical_index.cfm.
[42] EPA, *Technical Development Document for the Proposed Section 316(b) Phase II Existing Facilities Rule*, April 2002, Table 5-10, p. 5-20 ("2002 Phase II TDD"). See: http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase2/upload/2009_03_26_316b_phase2_devdoc_ph2toc.pdf
[43] Ibid, Table 5-12 and Table 5-15, p. 5-23 and p. 5-33. EPA model cooling tower costs are based on a cooling tower with a 10 ^{o}F approach temperature. EPA identifies representative fan power energy penalties in Table 5-12 of the 2002 TDD for four sample plants. The fan power energy penalties shown in Table 3 are for Plant #3 using a cooling tower with an approach temperature of 10 ^{o}F and a flowrate of 243,000 gpm. None of the other cooling towers in Table 5-12 have an approach temperature of 10 ^{o}F. Table 5-15 of the 2002 TDD, *Summary of Fan and Pumping Energy Requirements as a Percent of Power Output*, incorrectly uses the fan power energy penalty for a 5 ^{o}F approach cooling tower and not the design 10 ^{o}F approach cooling tower assumed in the EPA cost model.

A natural draft hyperbolic cooling tower would have no fan energy penalty, only a pump energy penalty. The cooling tower pump energy penalty estimated by the EPA for nuclear units is 0.57 percent. The total energy penalty for the natural draft hyperbolic cooling tower, including the 0.40 percent average steam turbine efficiency penalty, would be: 0.57 percent + 0.40 percent = 0.97 percent.

Mechanical draft cooling towers, either inline, back-to-back, or round, would have both booster pumps and fans, and associated pump and fan energy penalties. The average mechanical draft cooling tower pump and fan energy penalty would be 1.13 percent. The total energy penalty for the mechanical draft cooling tower, including the 0.40 percent average steam turbine efficiency penalty, would be: 1.13 percent + 0.40 percent = 1.53 percent.

Bechtel estimates a total energy penalty for plume-abated mechanical draft cooling towers at Diablo Canyon of 51 MW.[44] This represents a total energy penalty of 51 MW ÷ 2,200 MW = 0.0232 (2.32 percent). The Bechtel total energy penalty estimate for plume-abated mechanical draft cooling towers it evaluated at Diablo Canyon is conservative relative to the generic EPA estimate for retrofit cooling towers at nuclear plants, but in the same general range.

The 2.3 percent cooling tower performance penalty calculated by Bechtel is a realistic, though still conservative, estimate of the overall performance impact of cooling towers at Diablo Canyon. The TetraTech estimate of lost efficiency due to the cooling tower retrofit is unrealistically high at 5 percent relative to Bechtel (2.3 percent) and the EPA (1.5 percent).[45] This TetraTech efficiency penalty overestimate appears to be based on an incorrect assumption about the performance capabilities of the existing steam turbine surface condensers at Diablo Canyon.

F. Salt Water Cooling Towers and Insulator Arcing

The California Energy Commission (CEC) contracted for an analysis of the performance of salt water cooling towers in 2010. The report lists 58 power plants in the U.S. and other countries that utilize either salt water or brackish water cooling towers.[46] Two of the installations listed were commissioned by Bechtel. The fact that many plants have been operating successfully, in some cases for over three decade, with salt water cooling towers or with brackish water cooling towers where the circulating water in some cases approaches the total dissolved solids ("salt") concentration of seawater, is clear evidence that concerns regarding the potential for increased arcing across onsite high voltage insulators can be effectively managed.

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[44] Bechtel, September 2013, Table 4.3-4, p. 76. Bechtel also estimates the energy demand of a desalination plant to provide fresh water as cooling tower makeup water. This energy demand is not included in the 51 MW. The inclusion of the desalination plant is based on Bechtel's erroneous assumption that seawater cannot be used in the cooling tower due to San Luis Obispo County Air Pollution Control District particulate emission rate limits.

[45] TetraTech, *California's Coastal Power Plants: Alternative Cooling System Analysis*, February 2008, Chapter C – Diablo Canyon Power Plant, Table C-20, p. C-29.

[46] J. Maulbetsch, M. DiFilippo, *Performance, Cost, and Environmental Effects of Saltwater Cooling Towers – PIER Final Consultant Report*, prepared for California Energy Commission, January 2010, Table 4-1, Saltwater Tower Installations, pp. 18-21.

For example, the authors of the CEC-commissioned study of salt water cooling towers conducted site visits to selected plants to assess the performance and impacts of salt water cooling towers. The effect on insulator arcing of onsite salt water cooling towers was addressed during the visit to the St. John's River Park power plant in Jacksonville, Florida. Plant personnel stated that, "*Salt deposits on switchyard insulators have led to arcing problems. These are minimized through the use of larger insulators and insulators made of polymer-based material or silicone-coated porcelain.*"[47]

It is important to note also that the cooling tower location(s) selected by Bechtel is significantly closer to the Diablo Canyon switchyard than the alternative cooling tower location in the existing Diablo Canyon parking lots. This spatial relationship is shown in Figure 11. The closest Bechtel cooling tower is about 1,500 feet from the edge of the switchyard. The closest back-to-back cooling tower in the alternative parking lot location is about 2,200 feet from the edge of the switchyard. In addition, the Bechtel tower locations are at the entrance to the ravine where the switchyard is located. In contrast, there is a ridgeline separating the alternate parking lot cooling tower location from the switchyard.

Figure 11. Distance from Diablo Canyon Switchyard to Cooling Tower Locations

G. Closed-Cycle Cooling Retrofits Have Been Done

The U.S. EPA reviewed closed-cycle cooling retrofits performed at a number of U.S. power plants, both nuclear and non-nuclear, in the technical development document the agency prepared for the 316b existing facilities rule in 2002. Cooling tower conversions at Diablo

[47] Ibid, Appendix C - Site Visit and Telephone Interview Reports, p. APC-6.

Canyon will not be first-of-kind conversions. The results of the EPA review are summarized in Table 4.[48]

Table 4. U.S. Closed-Cycle Retrofits - Site, MW Rating, and Cooling Water Flowrate

Site	MW	Flowrate (gpm)
Palisades Nuclear	800	410,000
Brayton Point Station	1,500	800,000
Pittsburg Unit 7	751	352,000
Yates Units 1-5	550	460,000
Canadys Station	490	not reported
Jeffries Station	346	not reported

H. Closed Cycle Retrofits Have Encountered Space Limitations

Some of the completed cooling tower retrofits listed in Table 5 encountered space limitations and incorporated to a degree some components of the existing once-through cooling system. Space limitations must be taken into account at Diablo Canyon to develop an efficient cooling tower layout in the available Diablo Canyon parking and warehouse areas. There is also the potential to reuse much of the existing seawater supply piping if the Diablo Canyon Unit 1 and 2 cooling towers are constructed as back-to-back cooling towers located in the existing Diablo Canyon parking lots. A brief description of the details of each of the closed-cycle retrofits examined by the EPA is provided in Table 5.[49]

Table 5. Issues Encountered on U.S. Closed-Cycle Cooling Retrofits

Site	Issues
Palisades Nuclear	New equipment, in addition to the two cooling towers, included two circulating water pumps, two dilution water pumps, startup transformers, a new discharge pump structure with pump pits, a new pump house to enclose the new cooling tower pumps, and yard piping for the circulating water system to connect the new pump house and towers.
Yates Units 1-5	Back-to-back 2×20 cell cooling tower. 1,050 feet long, 92 feet wide, 60 feet tall. Design approach is 6 ^{o}F. Cooling tower return pipes discharge into existing intake tunnels. Circulating pumps replaced with units capable of overcoming head loss in cooling tower. Condenser water boxes reinforced to withstand higher system hydraulic pressure. Existing discharge tunnels blocked. New concrete pipes connect to discharge tunnels and transport warm water to cooling tower.
Pittsburg Unit 7	Cooling towers replaced spray canal system. Towers constructed on narrow strip of land between canals, no modifications to condenser. Hookup time not reported.
Canadys Station	Distance from condensers to towers ranges from 650 to 1,700 feet. No modifications to condensers. Hookup completed in 4 weeks.

[48] U.S. EPA, 2002 Phase II TDD, Chapter 4, *Cooling System Conversions at Existing Facilities*. Note - The Brayton Point Station (Massachusetts) and Plant Yates (Georgia) cooling tower retrofits occurred after the U.S. EPA review included in the 2002 Phase II TDD.
[49] Ibid.

Jefferies Station	Distance from condensers to wet towers is 1,700 feet. No modifications to condensers. Two small booster pumps added. Hookup completed in 1 week.

I. Cooling Tower Retrofits Do Not Require Extended Unscheduled Outages

The U.S. EPA estimates the unscheduled outage duration for a nuclear unit cooling tower retrofit at seven months.[50] TetraTech estimates an 8-month outage concurrent outage for Diablo Canyon Units 1 and 2 and a 4-week concurrent outage for non-nuclear coastal plant cooling tower retrofits.[51,52] However, the Unit 1 and 2 cooling systems are not located in the nuclear safety area at Diablo Canyon. There is no operational reason that a cooling tower hook-up at Diablo Canyon should take more time than comparable work at a large non-nuclear coastal power plant.

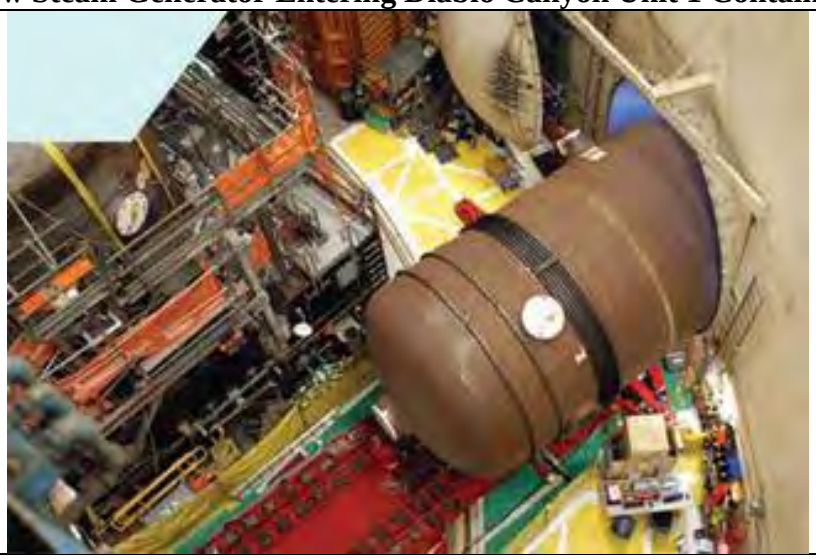
If back-to-back cooling towers are constructed in the available parking and warehouse areas at Diablo Canyon, the only closed cycle cooling construction steps that would require a plant outage are the: 1) sealing and interconnection of the existing seawater discharge structure to the new closed cycle cooling pump house (see Figure 6) and 2) tie-in of new piping to existing seawater supply piping, an outage comparable in duration to the TetraTech four-week outage estimate for non-nuclear coastal plant cooling tower conversions is feasible. The excessive concurrent forced outage duration assumed in the Bechtel report, over 17 months, is not credible.[53]

An example of a major and very invasive construction project within the nuclear safety area at Diablo Canyon being carried-out with only a short forced outage is the Diablo Canyon steam generator replacement project. The four steam generators at Diablo Canyon Unit 2 were replaced in 2008 with a total outage time of 69 days. The Unit 1 steam generators were replaced in early 2009 in 58 days.[54] The work was done concurrently with planned refueling outages in both cases. Refueling outages generally occur on one-and-a-half to two-year intervals.

Since the containment building and original installation of the steam generators was not intended to provide easy replacement, a completely customized system and innovative assembly process were needed to remove them. A photograph of a Diablo Canyon Unit 1 replacement steam generator moving through the Unit 1 containment dome hatch is shown in Figure 12.

[50] Power Engineering, *Project-of-the-Year Award Winners*, January 2009.
[51] TetraTech, *California's Coastal Power Plants: Alternative Cooling System Analysis, Chapter C – Diablo Canyon Power Plant*, February 2008, p. C-1.
[52] TetraTech, *California's Coastal Power Plants: Alternative Cooling System Analysis, Chapter O – Scattergood Generating Station*, February 2008, p. O-1.
[53] Bechtel, September 2013, p. 193. "Hybrid Wet/Dry Cooling – 530 days."
[54] Power Engineering, *Diablo Canyon Unit 1 Steam Generator Replacement Project*, September 1, 2009.

Figure 12. New Steam Generator Entering Diablo Canyon Unit 1 Containment Dome[55]



The sealing and interconnection of the existing seawater discharge structure to the new closed cycle cooling pump house and tie-in of new piping to the existing seawater supply piping would be a much less invasive project than replacing steam generators.

As noted, much of the work related to a closed-cycle retrofit, including construction of the cooling towers and the circulating water supply and return piping, can be carried out while the power generation units are online. Hook-up of the cooling tower requires an outage. The duration of the two retrofits for which detailed information is available, Canadys and Jefferies Station, was four weeks or less. The Yates Unit 1-5 conversion was accomplished without any additional outage time for the retrofit. However, the retrofit was apparently carried out during a time of low power demand when Units 1-5 could be offline for extended periods without impacting the dispatch schedule of the plant.[56]

A typical actual timeline for the retrofit of large cooling towers at nuclear and large non-nuclear power plants is three years from the receipt of permit approvals to commencement of cooling tower operation. 800 MW Palisades Nuclear began procurement and construction of retrofit cooling towers in mid-1971 and the cooling towers were operational in mid-1974.[57]

A 36-month timeline was set in the compliance order for conversion of Dominion Energy's coal-fired 1,500 MW Brayton Point Station to cooling towers.[58] The two Brayton Point natural draft

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[55] Ibid.

[56] EPA Region 1, *Memorandums on conversion of Yates Plant Units 1-5 to closed-cycle cooling*, January and February 2003.

[57] EPA, 2002 TDD, p. 4-3. Procurement and construction of the cooling tower system began in mid- to late-1971. The cooling towers became operational in May 1974.

[58] U.S. Environmental Protection Agency Region I - New England, Docket 08-007, In the matter of Dominion Energy Brayton Point, LLC, Brayton Point Power Station, Somerset, Massachusetts, NPDES Permit No. MA0003654Proceedings under Section 309(a)(3) of the Clean Water Act, as amended, *Findings and Order for Compliance*, pp. 5-6. "Within 29 months of obtaining all permits and approvals, commence tie-in of condenser units

cooling towers constructed by Dominion Energy at the site met this schedule and became operational in late 2011. The Brayton Point cooling towers are shown in Figure 13.

Figure 13. Retrofit Natural Draft Cooling Towers at 1,500 MW Brayton Point Station[59]

Georgia Power received regulatory approval to install the 40-cell back-to-back cooling tower at coal-fired Plant Yates in August 2001 and the cooling tower was operational in 2004.[60,61]

The 13-year construction schedule proposed by Bechtel is not credible when compared to the actual 3-year construction schedule achieved on multiple large cooling tower retrofits around the country.[62]

J. *Closed-Cycle Cooling Particulate Emissions Can Be Mitigated*

1. Offsetting Cooling Tower Particulate Emissions

Bechtel identified the particulate emissions generated by the high solids content in the emitted water droplets of a salt water cooling tower as a fatal flaw of saltwater cooling towers in its report. There is no fatal flaw with saltwater cooling towers at Diablo Canyon. Some aerosol droplets do pass through the cooling tower drift eliminator. The purpose of the drift eliminator is to minimize the amount of circulating cooling water that is entrained and emitted from the tower as fine mist. These aerosol droplets are assumed to eventually evaporate in the atmosphere, creating airborne particulate. Bechtel presumed incorrectly that, due to significant particulate

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to cooling towers. . . Within 36 months of obtaining all permits and approvals, complete tie-in of all condenser units such that all permit limits are met."

[59] See Brayton Point Power Station webpage: https://www.dom.com/about/stations/fossil/brayton-point-power-station.jsp.

[60] Georgia Department of Natural Resources, response letter re Georgia Power Company, Plant Yates Consent Order No. EPD-WQ-3742, NPDES Permit No. GA0001473, Coweta County, Georgia, August 16, 2001. "We (Georgia DNR) concur with your choice to construct an evaporative cooling tower."

[61] T. Cheek - Geosyntec Consultants, Inc. and B. Evans – Georgia Power Company, *Thermal Load, Dissolved Oxygen, and Assimilative Capacity: Is 316(a) Becoming Irrelevant? – The Georgia Power Experience*, presentation to the Electric Power Research Institute Workshop on Advanced Thermal Electric Cooling Technologies, July 8, 2008, p. 18. Plant Yates cooling tower became operational in 2004.

[62] Bechtel, September 2013, Table 1-1, p. 8.

emissions from a salt water cooling tower at Diablo Canyon, it would not be possible to get an air permit for these cooling towers from the local air pollution control authority.

Regulated forms of particulate include particulate less than 10 microns in diameter (PM_{10}) and fine particulate less than 2.5 microns in diameter ($PM_{2.5}$). Diablo Canyon is located in San Luis Obispo County. The San Luis Obispo County Air Pollution Control District (SLO APCD) regulates stationary sources of air pollutants in San Luis Obispo County. The U.S. EPA must also concur with SLO APCD air permitting actions that affect sources classified under federal regulation as major sources of one or more regulated air pollutants.

San Luis Obispo County ambient PM_{10} levels are above the federal PM_{10} ambient standard, although the County has not yet been designated as a PM_{10} non-attainment area by EPA.[63] Non-attainment areas must institute actions that will eventually lead to attainment status. This is achieved in part by requiring that new major sources of the non-attainment pollutant obtain emission offset credits (ERCs) in greater quantity than the potential emissions of the non-attainment pollutant. The PM_{10} major source threshold in moderate PM10 non-attainment areas is 100 tons per year (tpy).[64] The PM_{10} major source threshold is 70 tpy in serious PM_{10} non-attainment areas. In the case of cooling towers at Diablo Canyon, the PM_{10} emissions would be offset by purchasing or creating PM_{10} ERCs.

The PM_{10} stationary source emissions inventory prepared by the SLO APCD for San Luis Obispo County estimates County-wide stationary source PM_{10} emissions of approximately 28.7 tons per day (tpd).[65] About half of these PM_{10} emissions are from unpaved road dust (8.8 tpd) and paved road dust (4.8 tpd).[66] Air permits are required for cooling towers in San Luis Obispo County. Particulate ERCs would be required for cooling towers at Diablo Canyon. However, the SLO APCD would allow the creation of particulate emission offsets by paving dirt roads, subject to EPA approval.[67]

The Mojave Desert Air Quality Management District (MCAQMD), which includes parts of Riverside and San Bernardino counties, has allowed project proponents to utilize road paving to create PM_{10} ERCs. Road paving ERCs have been used to offset potential PM_{10} from emissions new power plant construction in the MDAQMD. The use of PM_{10} ERCs was sanctioned by the MDAQMD and approved by the EPA to offset PM_{10} emissions from the High Desert Power Plant near Victorville. The High Desert Power Plant is located in a federal PM_{10} non-attainment area and is operational. The Blythe I Power Plant is located in the MDAQMD, was also permitted utilizing EPA-approved PM_{10} ERCs generated by road paving.[68]

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[63] Telephone conversation between B. Powers, Powers Engineering, and G. Willey, Engineering Division Manager, San Luis Obispo County APCD, November 14, 2013.
[64] R. Shelton et al – U.S. EPA, *New Source Review (NSR) Basics*, PowerPoint presentation, January 6, 2011.
[65] SLO APCD, *Particulate Matter Report - Implementation of SB 656 Requirements*, July 27, 2005, Appendix B: Emissions Inventory, p. A-4.
[66] Ibid, p. A-4.
[67] Telephone conversation between B. Powers, Powers Engineering, and G. Willey, Engineering Division Manager, San Luis Obispo County APCD, November 14, 2013..
[68] Telephone conversation between B. Powers, Powers Engineering, and A. De Salvio, Supervising Air Quality Engineer, Mojave Desert AQMD, November 15, 2013.

Maricopa County (Arizona) received EPA approval of its rule regarding voluntary road paving to generate PM_{10} ERCs in 2007.[69] Maricopa County includes Phoenix and is a federal non-attainment area for PM_{10}. Maricopa County Rule 242, *Emission Offsets Generated by the Voluntary Paving of Unpaved Roads,* was promulgated by Maricopa County in August 2007. Rule 242 applies to projects subject to federal New Source Review (NSR) who need offsets for the construction of new major stationary sources, or major modifications to an existing source, in the Maricopa County PM_{10} non-attainment area. Project applicants can voluntarily elect to generate offsets of PM_{10} by paving unpaved roads in the Maricopa County PM_{10} non-attainment area.[70]

The MDAQMD adopted Rule 1406, *Generation of Emission Reduction Credits for Paving Unpaved Public Roads*, on January 28, 2013.[71] The final version of Rule 1406 incorporates revisions requested by EPA to assure the final rule would meet with EPA approval.[72]The MDAQMD describes the reason for Rule 1406 as: "*The adoption of proposed Rule 1406 is necessary to render PM_{10} ERCs from unpaved public road paving approvable for use to satisfy federal PM_{10} offset requirements for new or modified federal major stationary sources*."[73] According to the MDAQMD Rule 1406 staff report, the content of Rule 1406 was derived from Maricopa County Rule 242 – *Emission Offsets Generated by the Voluntary Paving of Unpaved Roads*.[74]

The EPA has approved the use of road paving to generate PM_{10} ERCs in PM_{10} non-attainment areas. The SLOAPCD has indicated it would allow the use of road paving to generate PM_{10} ERCs for major new sources of PM_{10} emissions in San Luis Obispo County. Bechtel has no basis for presuming that the PM_{10} emissions from salt water cooling towers at Diablo Canyon would prevent PG&E from obtaining air permits for the cooling towers.

2. Estimate of Potential PM_{10} Emissions from Diablo Canyon Cooling Towers

The concentration of dissolved solids in the circulating seawater would be about 50,000 parts per million (ppm), about 1.5 times the natural 35,000 ppm concentration of dissolved solids in seawater. Cooling tower manufacturers have developed, through direct testing, the expected

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[69] Federal Register, Volume 72, Number 150, *Revisions to the Arizona State Implementation Plan, Maricopa County*, August 6, 2007. "EPA is taking direct final action to approve a revision to the Maricopa County portion of the Arizona State Implementation Plan (SIP). This revision concerns reductions of particulate matter (PM) emissions from the paving of unpaved roads and the use of these reductions to satisfy the offset requirements under the new source review provisions of the Clean Air Act as amended in 1990 (CAA or the Act). We are approving a local rule which assures that the PM emission reductions resulting from the road paving meet the criteria for valid offsets under the Act."

[70] Maricopa County Notices, Volume 13, Issue 31, *Notice of Final Rulemaking, Maricopa County Air Pollution Control Regulations, Rule 242 Emission Offsets Generated by the Voluntary Paving of Unpaved Roads*, August 3, 2007, p. 2691.

[71] Mojave Desert AQMD, *Rule 1406 - Generation of Emission Reduction Credits for Paving Unpaved Public Roads*, January 28, 2013.

[72] Mojave Desert AQMD, *Draft Staff Report Proposed Adoption of Rule 1406 – Generation of Emission Reduction Credits for Paving Unpaved Public Roads*, for adoption on January 28, 2013, p.C-14.

[73] Ibid, p. 3.

[74] Ibid, p. 9.

particle size distribution of aerosol droplets that pass through the drift eliminator. This information, combined with the dissolved solids content and the circulating cooling water flowrate, allow the calculation of $PM_{2.5}$ and PM_{10} emissions from the cooling towers.

Assuming use of back-to-back ClearSky™ cooling towers, the Unit 1 and Unit 2 circulating cooling water flowrates would be 776,400 gpm each with a circulating cooling water total dissolved solids content of 50,000 ppm.[75,76,77] Under these cooling tower operating conditions, and using the 90 percent annual capacity factor for Diablo Canyon assumed in the Bechtel report,[78] the total PM_{10} emissions would be approximately 60 lb/hr.[79]

Assuming the Diablo Canyon reactors operate an annual capacity factor of 90 percent, the total annual PM_{10} emissions from the Unit 1 and 2 cooling towers would be about 237 tpy, or 0.65 tpd. This compares to overall San Luis Obispo County stationary source PM_{10} emissions of 28.7 tpd. The PM_{10} contribution from the cooling towers at Diablo Canyon would represent about 2 percent of overall stationary source PM_{10} emissions.

The applicant for a proposed gas-fired combined cycle/solar project to be located in the MDAQMD estimated a PM_{10} emission reduction of approximately 100 tpy for paving 2.86 miles of unpaved road sections. These unpaved road sections had an average number of vehicle trips of approximately 400 per day.[80] The estimated cost of paving single-lane unpaved roads with 2-inch thick asphalt concrete is approximately $100,000 per mile.[81]

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[75] TetraTech, *California's Coastal Power Plants: Alternative Cooling System Analysis*, February 2008, Chapter C – Diablo Canyon Power Plant, Table C-5, p.C-10, temperature rise across condensers = 18 ^{o}F; Table C-7, p. C-14, circulating water flow = 862,690 gpm. Therefore, the circulating water flow rate with a design temperature rise (aka "range") of 20 ^{o}F would be: (18 ^{o}F/20 ^{o}F) × 862,690 gom = 776,421 gpm.

[76] Cooling tower design approach temperature is assumed to be 17°F consistent with the TetraTech cooling tower design basis for Diablo Canyon. Design cooling water temperature range is assumed to be 20 ^{o}F consistent with the SPX generic nuclear plant ClearSky™ design basis provided in Attachment B.

[77] J. Maulbetsch, M. DiFilippo, *Performance, Cost, and Environmental Effects of Saltwater Cooling Towers – PIER Final Consultant Report*, prepared for California Energy Commission, January 2010, pp.2-3. "For salinities typical of seawater makeup to towers operating at 1.5 cycles of concentration (~ 50,000 parts per million)"

[78] Bechtel report, p. 6.

[79] These calculations assume that 30 percent of the total particulate emitted is PM_{10}. See **Attachment D** for detailed calculations. The aerosol droplet size distribution assumes an SPX 0.0005 percent drift eliminator and a 50,000 ppm total dissolved solids concentration in the circulating cooling water. The aerosol droplet size distribution for an SPX 0.0005 percent drift eliminator is available at: CPV Vacaville Station Application for Certification, Volume II, Appendix 5.1A, Emissions and Operating Parameters, pp. A-5 to A-8, http://www.energy.ca.gov/sitingcases/vacastation/documents/applicant/afc/Volume_II/CPVVS_Appendix%205.1A_Emission%20and%20Ops%20Parameters.pdf

[8080] Sierra Research, Inc., *Draft Programmatic Environmental Impact Report Adoption of Proposed Rule 1406 Generation of Emission Reduction Credits for Paving Unpaved Public Roads*, prepared for Mojave Desert Air Quality Management District, July 25, 2011, Table B-1, p. B-4.

[81] Arkansas Highway Department, *Estimated Costs Per Mile* (single lane asphalt concrete overlays), July 2009 : http://www.arkansashighways.com/roadway_design_division/Cost_per_Mile_JULY_2009.pdf

3. Replacement Power for Diablo Canyon Lost Output

The conversion from once-through cooling to closed-cycle cooling will cause a small loss in electricity production efficiency, approximately 2.3 percent for a plume-abated mechanical draft cooling tower assuming Bechtel's efficiency penalty estimate without a desalination plant. The combined 2,200 MW output of Units 1 and 2 would be reduced by about 50 MW on average (total) as a result of the cooling tower conversions, assuming a 90 percent capacity factor for Units 1 and 2. This output reduction would be offset by other existing PG&E supply sources, including geothermal, solar, wind, hydroelectric, and gas-fired generation.

K. Closed Cycle Cooling Conclusion

It is technically feasible and cost-effective to retrofit Units 1 and 2 at Diablo Canyon to closed-cycle cooling. There is adequate space on the existing developed site for back-to-back plume-abated seawater cooling towers. The use of saltwater cooling towers at Diablo Canyon would reduce seawater withdrawals for cooling by 96 percent. Use of plume-abatement would minimize any issues with visible plumes from the cooling towers. Back-to-back plume-abated mechanical draft cooling towers are a low profile design and would also not alter the general appearance of the plant site as seen from the ocean.

Plume Abatement – The Next Generation

Paul Lindahl
Ken Mortensen
SPX COOLING TECHNOLOGIES

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Abstract

Cooling towers have been modified to reduce the visibility of their effluent water vapor plumes for about 40 years. The evolution, breadth of experience and technologies of plume abatement cooling towers will be described. An evolutionary improvement to existing plume abatement designs using a different heat transfer approach will be described, including some of the development and demonstration achievements to date. Differences from currently used coil-type wet/dry tower designs and benefits of the improved technology for cooling tower applications will be presented.

Introduction

The earliest designs for reduction of visibility due to condensation of water vapor plumes from cooling towers were in the 1960's. The applications were wet/dry or other heat sources in a series path, and were industrial or air-conditioning applications. The applications were considered safety related. In the 1970's, designs evolved which were based on parallel path wet/dry technology. For almost 40 years parallel path wet/dry, or hybrid, technologies have been applied to reduce visible plume from cooling towers. A significant level of operating experience in various configurations and application types, in response to various end user needs, has developed over that period of time. A new technology has emerged which is series path, but does not use dry type exchangers. Instead, the technology uses air to air instead of water to air heat exchange. This technology has been developed, demonstrated and emerges as an attractive option for plume abatement in the new century. The new condensing module technology is based on a natural process with value in terms of energy benefits, piping cost, low maintenance and low complexity.

About Cooling Tower Plumes

The air leaving a cooling tower is essentially saturated, e.g. 100% relative humidity, and when discharging into cold, humid ambient air some of the moisture condenses. This condensate becomes visible if enough is present and looks like clouds or ground fog. The tendency for visibility is well correlated to whether human breath would be visible when exhaled. When it is warm and dry, your breath is not visible. The colder and more humid it is, the more visible your breath becomes.

Why does the visibility of the plume matter? There are four main reasons; aesthetics, community relations, regulatory requirements and safety. Aesthetics is simply the perception that the effluent from a tower obscures visibility of whatever is on the other side of the plume, and may be undesirable. Community relations involves the association of the cloud-like water vapor and condensate effluent from a cooling tower on a cold day with smoke leaving an industrial process stack. A plant with a cooling tower may be perceived as emitting smoke. Regulatory requirements relate to aesthetics and community relations, but are translated into public policy that requires use of plume-free, or limited plume technology. Safety typically relates to the potential that a visible plume from a cooling tower might obstruct a roadway, or for an airport application, the view from the control tower. Sometimes, concerns about icing from plumes contacting cold roadway or other surfaces also come into play. This is not directly related to visibility of the plume. Any time there is moisture in the air, whether in clouds or ground fog or a plume (visible or not), there is a potential for this moisture to condense and freeze on cold surfaces.

Series Path History

It was recognized in the mid-1960's that if the humidity leaving the tower could be reduced, the plume would be less visible or visible for fewer hours per year. The earliest designs involved adding heat sources to the air leaving the cooling tower or "wet" section, to reduce the relative humidity of the leaving air by heating it up. Two basic approaches were considered. One was to add a finned tube, or more commonly, a bare tube heat exchanger above (or downstream of) the eliminators to heat all of the wet section discharge air. The other was to add heat to the air using burners above the fans (induced draft with propeller-type fans at the tower discharge). The heat exchanger designs either used all or part of the hot water going to the tower, or used an external heat source, such as steam from some other available process, to provide the heating effect. The burner design was applied at an airport in a concrete tower with concrete fan cylinder, and burned a combustible gas, but the plume control was not found to be necessary and the burner system is believed to have been decommissioned in the 1970's.

Series path wet/dry (SPWD) towers, with metallic coils above (or downstream) of the eliminators required premium corrosion resistant materials due to the hot moist environment in the tower plenum. Over a period of time close-spaced fins would tend to clog in this environment. Thus the designs typically had what are called "low fins" that are wide spaced and short fin height, or had no fins at all, "bare tube", particularly with higher temperature steam. The drawbacks to these designs were full time pressure drop for the cooling tower fan, and high pump head for hot water coils. The positive was that the entire volume of wet section air was heated in the coils, so the discharge air was well mixed. External heat source designs with steam, in effect, would be trying to control two processes with one fan, and would have some control complexity as

well as a need to insulate the piping to and from the tower in cold climates.

Parallel Path Wet/Dry (PPWD) Towers

Most of the history of wet/dry towers evolved after the development of the basic parallel path tower designs and patents around 1970. This concept involved adding dry sections, using finned tube heat exchangers, above the wet sections, but different from the SPWD's just described, the air was drawn by the induced draft fans in parallel through the dry sections and wet sections, mixed in the plenum, and discharged from the fan at a reduced relative humidity. The air leaving the dry sections is heated without adding moisture, so is hot and has low humidity. The air leaving the wet sections is essentially at 100% humidity (saturated) warm air. The mixed air leaving the tower is at a reduced relative humidity. If the humidity is reduced via a proper balance of dry and wet section performance capability, the air that leaves the tower will not become super-saturated (condensed drops, or visible plume) as it mixes with ambient air, see Figure 1.

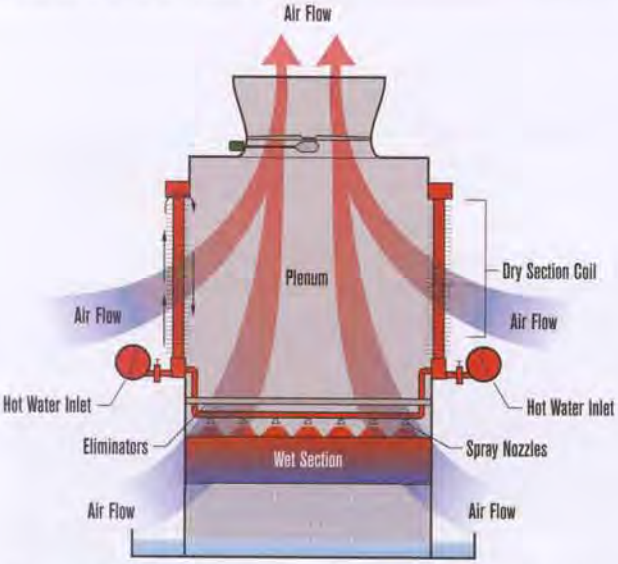

Figure 1. Parallel Path Wet/Dry Tower cross section

Parallel path designs had the advantage of being able to add face dampers on the dry sections that would shut off most of the air flow, enabling nearly full wet cooling tower performance in the summer time at near to wet tower fan power. Dampers typically leak some air, and in addition, some dry section performance may be desired for morning and evening conditions even in the summer, so PPWD towers typically are higher fan power than wet only towers. The selection of PPWD towers for plume abatement is generally against a summer thermal design point and a winter plume design point. Figure 2 shows ambient weather points divided by the saturation curve, to the left of which are super-saturated air, or visible fogging conditions. To the right of the saturation curve are sub-saturated, or non-visible conditions. If one looks at a visual map of the distribution of ambient points for a given location, the map would look like the gold band across the chart. For a typical wet-only cooling tower, the curve toward the right of the chart is the fogging frequency curve for design flow and cooling range, which divides the weather points into conditions for which the tower would produce visible plume to the left, and those which would not to the right. A substantial percentage of the ambient points are in the visible plume zone for this example case. The fogging frequency for the un-abated tower is about 60%. The fogging frequency curve for a plume abatement tower selected for approximately 10% of the hours per year of visible plume is shown toward the left of the chart. This would allow visible plume at the coldest and most humid hours of the year, typically in early mornings, before dawn. The plume abatement design point would be the point (Wet Bulb & Dry Bulb Temperatures) where the fogging frequency curve crosses the uppermost edge of the weather data band for a location.

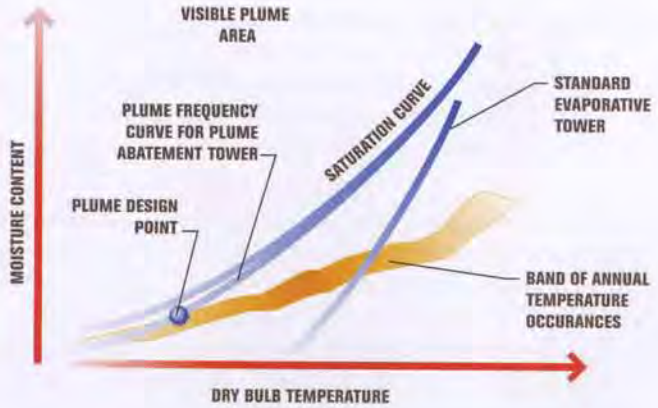

Figure 2. Plume Abatement Design Point Determination

PPWD towers also generally use hot water passing first through the dry section, then through the wet section to get maximum dry performance. This involves additional pumping head to move water both through the coils and above the wet section. Since a risk of freezing the metal coils exists if water is left standing in the coils or if water distribution is not even enough, substantial design effort has gone into hydraulic design and controls to protect the dry sections. Some manufacturers also utilize vacuum pumps to assure that air does not become trapped in portions of the coil system, potentially also trapping water that could freeze. Note also, that PPWD towers involve mixing of low velocity streams of air that do not generate sufficient turbulence for complete mixing across the plan area of the tower plenum. Mixing devices have commonly been used, particularly for counterflow designs, to gain sufficient mixing of the dry and wet streams to prevent unmixed wet air from discharging from the tower visibly.

The first PPWD tower was sold commercially and operated in 1970, in response to a safety issue. A tower, located in a refinery in Pasadena, TX, that was sited close to and just north of a highway produced a visible plume on a cold day with a north wind that was perceived to contribute to a fatal traffic accident on the highway. The insurance company for the plant required that the tower be moved or the plume prevented from reaching the road. The replacement tower, which can be seen in figure 3, was designed to reduce, not eliminate plume, such that the plume did not leave the plant boundary. In figure 4, it can be seen that the PPWD tower produces drastically less visible plume than the tower in the foreground, which is operating at about the same tower duty.

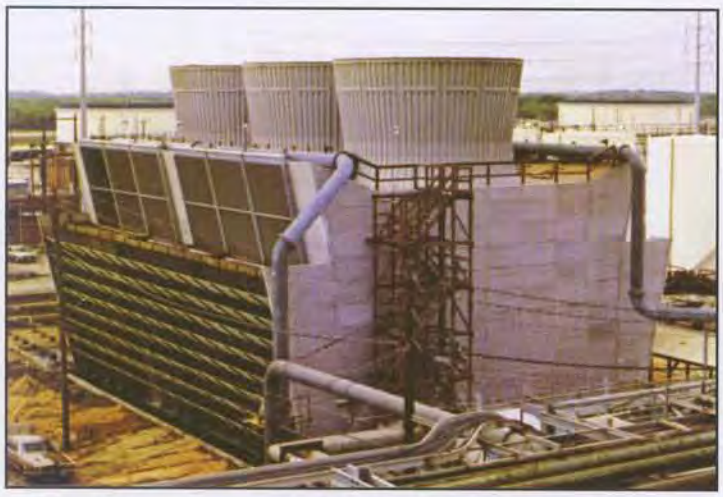

Figure 3. First commercial PPWD installation in Pasadena, TX

Figure 4. Significantly reduced plume from first commercial PPWD in 1970

Since 1970, PPWD towers have been applied in many configurations and for many different types of application from small air conditioning to large power plant cooling towers. The total number of PPWD installations by multiple manufacturers is well over 80. An example of another safety related application is the Chicago OHare Airport cooling tower in Figure 5. This tower was designed for no plume, even in transients while the loads are just coming up or going to shutdown. The tower has wet and dry section dampers and variable frequency drives. This enables operation of the tower for lowest cold water temperature when plume is not an issue, or minimum plume when it is. The objective was to prevent the plume from obstructing the view of taxiways from the control tower.

Figure 5. Example of a zero plume tower at a major airport

Figure 6. Example of a large power plant retrofit to PPWD

Plume abatement towers also evaporate less water than wet cooling towers. The next example, in Figure 7, is a water conservation installation in New Mexico designed for 70% water savings compared to a wet tower. The towers are over 1000 feet from end to end x 135 feet wide, with 50 fans total. The portion of the heat transfer from the water in the dry sections does not lead to evaporation, so the total evaporation is reduced. The tower below was designed to operate completely dry at 32°F.

Figure 7. Water conservation tower on a power plant

Over the 40+ year history of wet/dry towers for plume abatement, the technology has adapted to new needs, and has successfully satisfied most of the customer's needs. However, additional new technology was required to meet the remainder of the customer's needs.

Next Generation Plume Abatement Technology

An alternative technology has been developed in recent years for plume abatement. This condensing module technology combines series path and parallel path configurations, based on patented heat exchangers that transfer heat from wet section discharge air to ambient air, see Figure 8. In the plume abatement mode, moisture is removed from the saturated wet section air by condensing in the heat exchanger, resulting in lower temperature saturated air leaving the heat exchanger. The combination of warm dry air from one side of the heat exchangers and the removal of some moisture content by cooling of the wet section air on the alternate side of the heat exchangers, reduces the relative humidity of the discharge air. The number of hours per year of plume visibility is thus reduced, similarly to PPWD and SPWD tower designs.

Figure 8. Condensing module heat transfer schematic [note that condensate comes only from the hot moist face, not the cool ambient face]

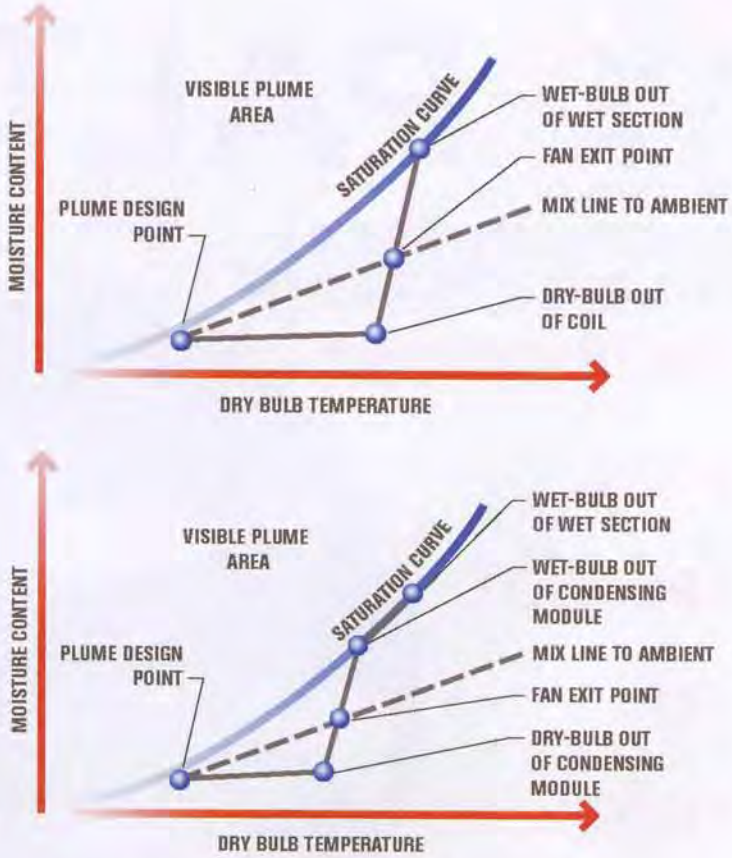

Figure 9. Comparison of coil type and condensing module psychrometrics

Figure 9 shows the psychrometric behavior of a PPWD compared with that of the condensing module plume abatement process. In a PPWD, the air condition leaving the wet section is on the saturation curve, having gained heat and moisture in the wet section process. The air leaving the dry section is heated, but has no moisture added, so the line is horizontal on a psychrometric chart. The resulting condition at the fan after mixing the two air streams is a function of the mass flow of air from each of the sections. If the tower is designed properly for a plume point, the mix line back to ambient is below the saturation curve, showing that the plume never goes into the fog region above the saturation curve and no plume is visible. For the condensing module case, the air leaves the wet section similarly, but is now cooled down along the saturation curve to a lower wet bulb temperature, condensing water in the modules as the moisture content goes down. The air from the outside air ducts goes through the other side of the condensing modules, is heated without adding moisture, a horizontal line on the psychrometric chart. The two streams mix to a fan condition that again has a mix line below the saturation curve at the plume design point if designed properly. The fan condition is dependent on the relative mass flows from the two sides of the condensing modules. The processes are similar, but are clearly different.

A typical configuration for the condensing module plume abatement tower is illustrated by Figure 10. Ambient air in stream 1A passes through the wet section of this counterflow tower. The warm, saturated air from the wet section, stream 1B, passes up through one side of the crossflow heat exchanger modules which are oriented in a diamond pattern, leaving at a cooler, but still saturated, condition. Ambient air also passes into the tower via ducts, stream 2A, and into the alternate side of the heat exchanger modules, leaving warmer and with lower relative humidity, stream 2B. Streams 1B and 2B mix in the plenum above the modules, stream 3, leaving the tower as reduced humidity air, stream 4. Proper proportions and air flow through the wet section and the condensing modules result in the targeted plume abatement design point. The flow of air through the modules can be dampered to maximize the wet section air flow in the summer. In addition, the ducts supplying air to the modules can be vented to enable wet section air to pass through both sides of the modules, increasing wet section air flow still more. Note that the airflow from the condensing modules is well distributed across the plan area, resulting in effective mixing of the two air streams without a need for mixing devices.

The condensing modules are based on technology backed, in part, by grants from the U.S. Department of Energy (DOE) via the National Energy Technology Laboratory (NETL) The grants from the DOE were part of the Innovation for Existing Power Plants program as an improvement over traditional PPWD technology.

In addition to extensive test cell and prototype work at our Research and Development center, and CFD simulation of designs, a full scale demonstration project was installed at a power plant in New Mexico. Note CFD modeling examples in Figure 11, illustrating temperature and velocity distributions in the demonstration tower configuration.

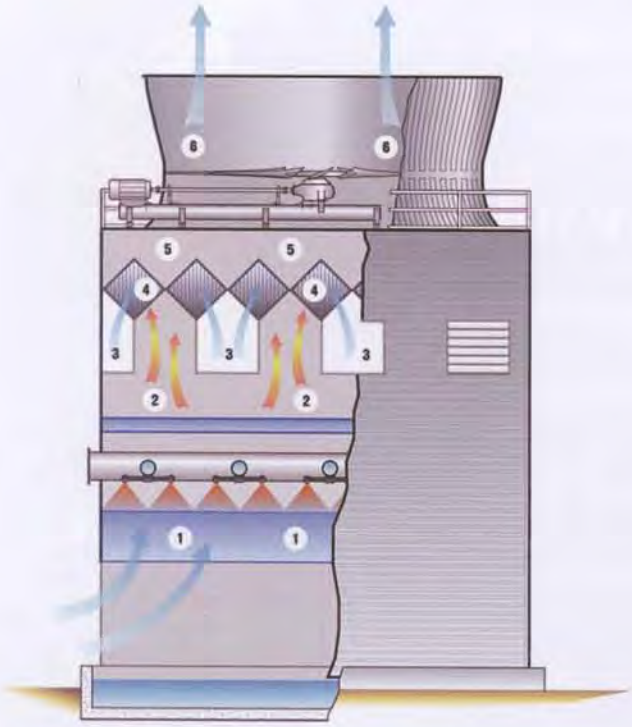

Figure 10. Schematic cross section of the tower and condensing module design for plume abatement

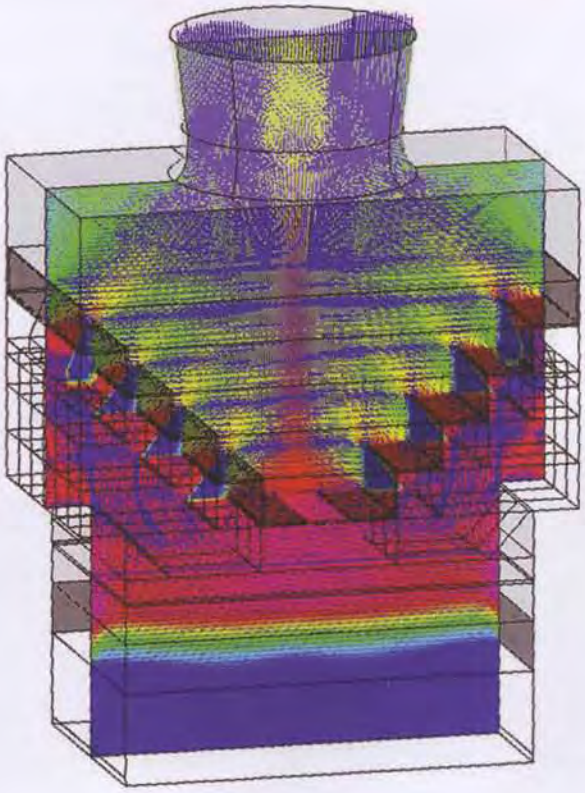

Figure 11-B

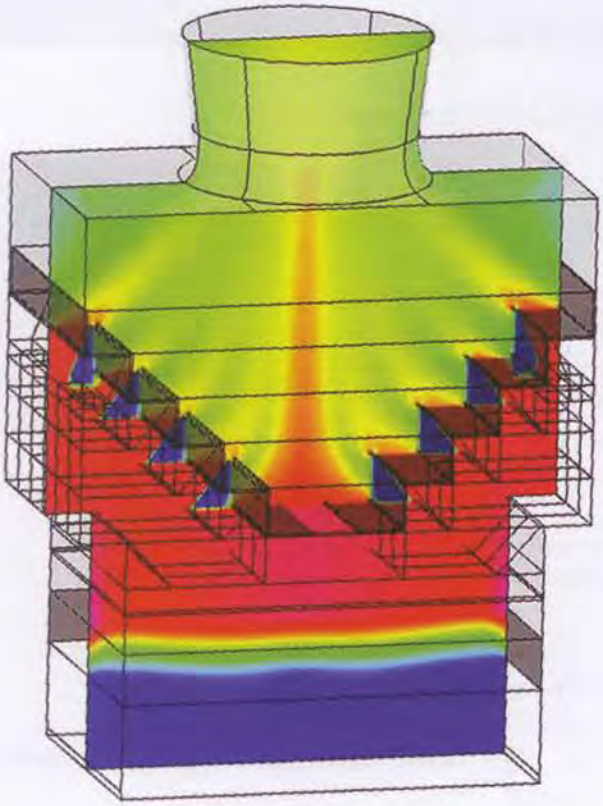

Figure 11-A

Figure 11. Illustration of CFD modeling of the demonstration installation, temperature in figure A and velocity in fibure B

The demonstration installation is in a base-loaded coal-fired power plant that operates 24/7. An end-cell of the original tower was demolished, and a new demonstration cell installed. The demonstration installation was completed in 2007 and has operated successfully for more than a year. Figure 12 shows two photographs of the tower, taken on different dates, both operating at 27°F dry bulb, with one having 60% humidity and the other 65% humidity, without visible plume, on either date, in comparison to the substantial plume coming from the rest of the tower.

Figures 13, 14 and 15 show the factory assembled modules being hoisted up into the tower, and the configuration when all are in place. Figure 16 shows the windows in the side casing where ambient air enters the ducts that feed the dry side of the modules. The configuration shown was designed for high water conservation capability for this high desert location. The condensing module configuration is an evolution for plume abatement purposes, but also accomplishes significant water savings.

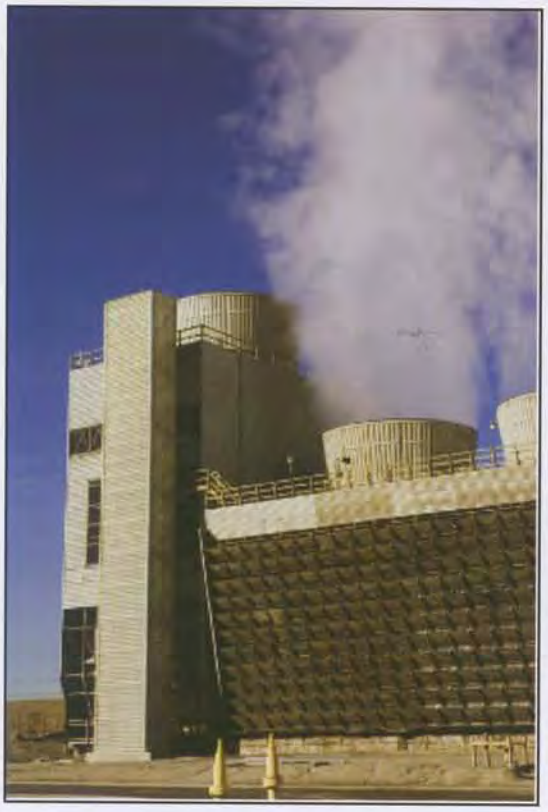

Figure 12. Operation of the demonstration cell, side view [Date 1/21/09 Temperature 27°F Relative Humidity 65%, photo by Ken Mortensen, end view [Date 3/11/08 Temperature 27°F Relative Humidity 60%, photo by Tom Ruisinger]

Figure 13. Hoisting of factory assembled condensing modules [photo by Dennis Parker]

Figure 14. Tower under construction, showing position of modules [photo by Dennis Parker]

Figure 15. Condensing modules positioned in demonstration cell [photo by Dennis Parker]

Figure 16. Windows in casing for air supply ducts to modules [photo by Tom Ruisinger]

This water conservation/plume abatement cooling tower has operated over two winters, without issues during cold weather operation. Since there is no circulating water in the modules, and condensation can only happen with warmed wet effluent air in direct contact with the condensate flowing downward in counter-current flow, the risk of any freezing is very low. Figure 17 shows the demonstration tower operating in winter conditions, 35°F dry bulb and 50% relative humidity.

Figure 17. Cold operation of the demonstration cell [Date 2/09/09 Temperature 35°F Relative Humidity 50%, photo by Jared Hickman]

The demonstration project accomplished measured water savings of about 18% and virtually non-existant plume according to the owner's public statements.

Why condensing modules?

The PPWD designs have been successful for many years, however, there were unmet needs for which improvements could be made. These improvements have come in the areas of design flexibility, reduced associated non-tower installation costs incurred by the EPC/owner and reduced operating costs and complexity at competitive tower cost with the new condensing module technology. Overall, a significant benefit may result for the end user and the Engineer/Procure/Construct (EPC) contractor. The environmental benefit of this technology parallels the benefits of a PPWD, with the added benefits of having a very low drift rate and of replacing a portion of the lower quality tower make-up water quantity by the near condensate quality water recovered from air leaving the wet section. The net make-up water requirement is reduced both by the water quantity returned and by the higher quality returned which enables operation at fixed cycles of concentration with less blowdown and make-up. Figure 18 shows the greatly reduced dissolved solids content in the condensate recovered in the modules. The water produced by the modules can be returned to the tower basin, or can alternatively be substantially extracted for use in other plant applications. The percentage of water saved on an annual basis will vary with the difficulty of the plume point and the weather at a location, but may be expected in the 3-15% range for proportions of condensing module to wet section typical of plume abatement applications. The demonstration project referenced above was designed for greater water savings. The small amount of solids content shown in Figure 18 is a result of drift being captured in the condensing modules. There is direct impingement on the module surfaces, as well as the drift drops being the nucleation sites for condensation to form as the air is cooled below the dew point in the condensing modules. Since the water would otherwise be pure condensate, note that the capture of some drift is validated by the detection of circulating water chemicals at low levels in the recovered condensate stream, as there is no other mechanism for the circulating water chemicals to end up in the condensate. Resulting drift rates leaving the tower are likely to be very difficult to measure, as the rates leaving the eliminators can be less than 0.0005% of circulating water. Measurements are planned. Low drift rate translates to lower calculated PM10 emissions for the plant. US EPA requirements include cooling tower drift as a particulate emission by calculation from the drift rate and water composition. This is an environmentally beneficial resource recovery technology.

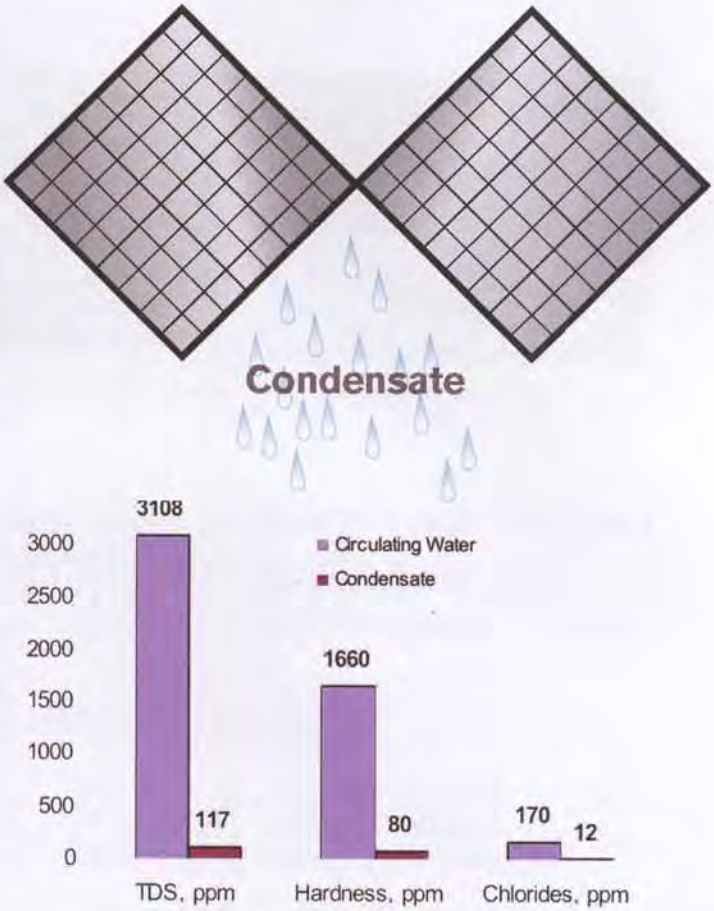

Figure 18. Condensate quality and drift reduction

Design flexibility is improved via the potential for back-to-back plume abatement towers for constricted plant sites. The back-to-back configuration combines two lines of cooling tower cells into one tower, with a common wall down the centerline of the "dual row" tower, potentially fitting the tower onto sites where two towers would not fit. This has not been practical for PPWD towers due to the difficulty of getting adequate dry section air to the centerline of the tower. The new technology requires ducting of ambient air to feed the condensing modules which cover the entire tower plan area. Thus, the ducts can be sized to carry air to the centerline of a back-to-back tower as well. As more attention is focused on larger nuclear, coal with carbon capture and integrated gasification combined cycle power plants, the need to compress the tower footprint becomes more important. Flexibility and cost in foundation design is also improved by way of the even distribution of weight in the condensing module tower, rather than having concentrated weight on the perimeter columns to support the metal coils (and often face dampers) of a PPWD. This is likely to be more significant for a retrofit of an existing tower to plume abatement, as the existing tower foundations would not have been designed for the coil plus damper loads on the side columns. Specialized cold water basin and foundation designs may sometimes be avoided. Foundation loads and costs are highly site specific, influenced by wind loads and soil conditions as well as the dead and operating loads of the tower. Figure 19 visualizes a simple comparison.

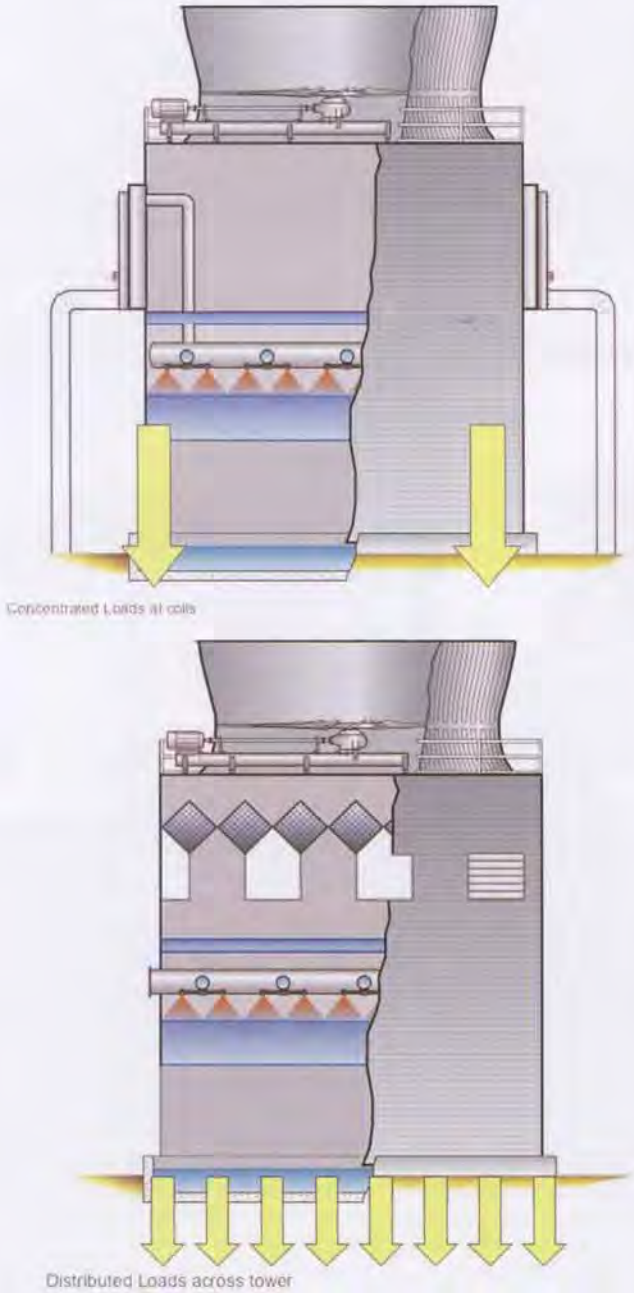

Figure 19. Comparison of load distribution

Associated non-tower installation costs include hot water piping to the tower, wiring, conduits and controls for metal coil PPWD systems. For single row PPWD towers, it is common, but not always the case, for the end user and EPC to provide buried piping down both sides of the tower, and also risers with valves to connect with each tower cell, again on each side of the tower. This is to supply hot water to the metal coil inlets on both sides of the tower. Piping can also be run down one side of a PPWD, with an internal crossover pipe for each cell in the manufacturer's scope to provide water to one or more coils on the other side of the tower. This requires careful design, orifice plates or balancing valves to equalize flow to the two sides. Only piping to one side of the tower is necessary for a single row condensing module tower, as water is only piped to the wet sections with conventional water distribution systems. In one recent example comparing piping on one side of the condensing module design vs. two sides of a coil type tower, the difference in price of pipe, excavation and backfill, and risers, control valves and sway bracing was equal to more than 5% of the tower price. The difference in cost of controls and wiring for extra valves, vacuum pumps and damper actuators for coil type vs. the condensing module design is also going to be a significant number, varying with the extent to which end users instrument and automate their towers. Figure 20 shows a comparison in site requirements for two in-line towers compared to one back-to-back tower. Back-to-back is about 17% of the space required for two in-line towers, assuming the 1 tower length spacing recommended for parallel banks of towers[1].

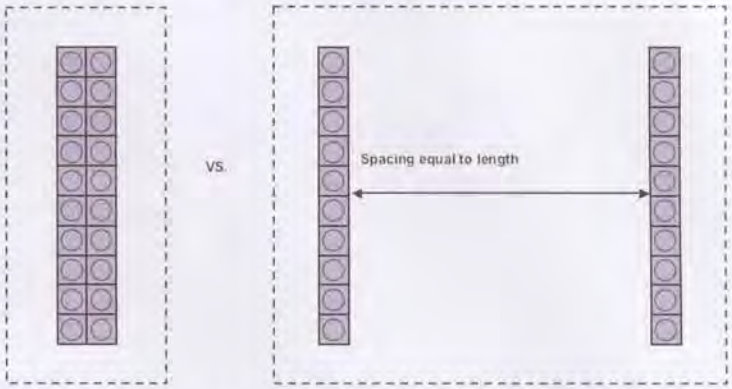

Figure 20. Comparison of siting requirements

Coil type towers are subject to higher maintenance and repair costs than is expected with the new technology. Coil towers have, of necessity, a design focus on prevention of freezing damage, as well as plume control and cold water temperature management. The greatest freezing risk for any finned tube exchanger with water in it is from leaving standing water in the exchanger during freezing weather operation. This means that the towers have to be circuited, valved and designed to enable getting water out of the coils quickly and completely when the water is shut off, and getting water distributed evenly and quickly to the coils during start-up. Some amount of valving and controls, and often vacuum pumps, are used to protect the investment in the coils from freeze damage. Continuous operation vacuum pumps require particular maintenance attention, and redundant pumps are sometimes employed to minimize risk if a

shutdown is needed. Metal coils may be subject to internal scaling and corrosion if water chemistry is not adequately maintained for the metallurgy selected. The outside of the finned tubes is often exposed to particulate or fibrous material (like cottonwood fluff) that builds up between the fins. This can be made worse by having humid air from the tower or the local climate cause this "foreign matter" to aggregate. Figure 21 shows particulate fouling from flyash and coal dust in a power plant environment. Fouling reduces the performance of the exchangers, increasing plume and water consumption. If coils have freeze damage, or the fouling is too bad to be cleaned effectively, replacement or repair costs will occur. Cleaning of finned tubes is necessary on many, if not most, tower locations. Cleaning is typically done with water jets, and needs to be done from the inside of the coil to prevent packing the material tighter into the fins. This requires access provisions to the inside of coils, and will also necessitate water containment with plastic sheeting on the outside to keep the water and material cleaned from the tubes from reaching the ground to meet ground water impact regulations for many plant sites. The condensing module technology has none of these characteristics. The outside air or "dry" channel side of the modules is dry, utilizing mainly flat pvc surfaces (Note Figure 8.) with no small cross-sections in which particulate or fibrous materials would tend to build up as with finned tubes. The other "wet" channel of the modules also has the mainly flat configuration and receives air which has been scrubbed by the wet section and eliminators. The condensing module tower design has no valves added to the system beyond what is normally required for wet towers and has external face dampers on the ducts but, only about 60% of the face area of coil dampers. The total number of damper operators and linkages is greatly reduced. A recent comparison showed a difference in maintenance cost on an annualized basis that equals about 1% of the tower price.

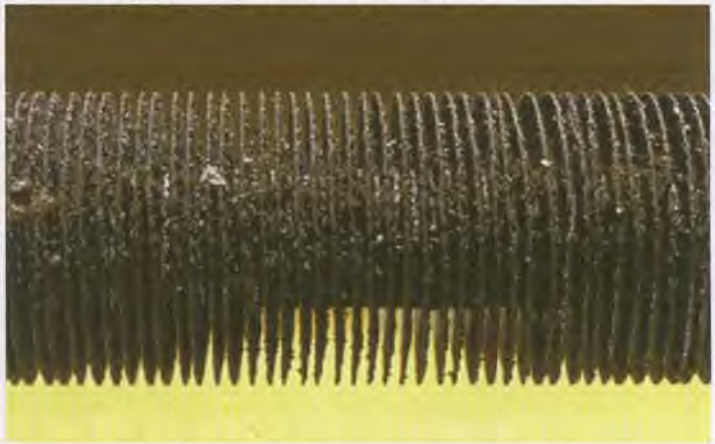

Figure 21. Fin fouling by particulate clumping

The largest operating costs for PPWD or condensing module towers are fan and pumping power. The condensing module tower has no pumping head above the level of the wet section, and thus has significantly lower pump head than a coil type tower. Pumps run nearly 24/7 in most cases. Because the condensing module design is a series air path, there is always pressure drop on the air side through the modules that the fans must overcome. Fans, however, don't usually run full time. The comparison will vary on a case by case basis, but typically the lower pumping power of the condensing module tower tends to outweigh the fan power increase, sometimes significantly.

Conclusions

A robust history of PPWD application has resulted in significant application experience in solving plume abatement needs for end users in power and other industries. Customer needs for reduced operating and capital costs for plume abatement and the emerging need for large back-to-back plume abatement towers have driven the development of the condensing module technology. This technology satisfies many of the unmet needs of the end user, while also satisfying the regulatory, safety or neighbor driven plume abatement drivers. Value is added in the areas of design flexibility, reduced non-tower installation costs and reduced operating costs at competitive tower cost. Reduced water consumption is also accomplished, with the added potential for extraction of a cleaner, higher quality water stream than enters the tower as make-up. The combination offers interesting potential for new and existing facilities.

References:

1. Cooling Tower Fundamentals, Second Edition, revised 2009, Ed. John Hensley et al., SPX Cooling Technologies, Overland Park, KS, 2009, pp 26-28.

Step up to the "Vari-Flow" Distribution Valve

Internal Guide & Support System

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Nuclear Plant Retrofit Comparison for Powers Engineering 9-June-2009

	Case 1A	Case 2A	Case 1B	Case 2B
Water	Salt	Salt	Fresh	Fresh
Type	ClearSky BTB	Wet BTB	ClearSky BTB	Wet BTB
Cells	3x22=66	3x18=54	3x20=60	3x18=54
Footprint	3@529x109	3@433x109	3@481x109	3@433x109
Rough Budget	$115.6 million	$38.6	$109.1	$36.4

Basis: 830,000 gpm at 108-88-76. Plume point is assumed at 50 DB/90% RH.

Low clog film type fill is used for all of the selections, assuming any fresh water used would likely be reclaimed water of some sort. Low clog fill has been used successfully in various sea water applications. Intake screens would be required for the make-up sea water to limit shells, etc. Make-up for the ClearSky tower would be approximately 80-85% of the wet tower make-up on an annual basis. Budget is tower only, not including basins. Infrastructure cost is estimated by some at 3 times the cost of the wet tower, including such things as site prep, basins, piping, electrical wiring and controls, etc. Sub-surface foundations such as piling can add significantly, and may be necessary for a seacoast location. The estimates above are adjusted for premium hardware and California seismic requirements, which are a factor in the taller back-to-back (BTB) designs both for wet and ClearSky. These are approximate comparisons. Both the wet towers and ClearSky towers could likely be optimized more than what has been estimated here, and may have to be tailored to actual site space in any event. ClearSky has pump head like a wet tower, is piped like a wet tower, and has higher fan power than a wet tower to accommodate the increased air flow and pressure drop.

Coil type wet dry towers would cost significantly more, with premium tube (titanium for sea water, and possibly for reclaimed water) and header materials. An appropriate plenum mixing design has yet to be developed, but would also require non-corrosive materials and high pressure drop on the air side. No coil type BTB wet dry towers are likely to be proposed.

Bill Powers

From: PAUL.LINDAHL@ct.spx.com
Sent: Tuesday, June 09, 2009 9:27 AM
To: bpowers@powersengineering.com
Subject: Nuclear Comparison

Bill,

A comparison of wet and ClearSky back to back towers for a reference duty is included in the attached summary.

Paul Lindahl, LEED AP
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SUBJECT: **COOLING TOWER PERFORMANCE**
Basic Theory and Practice

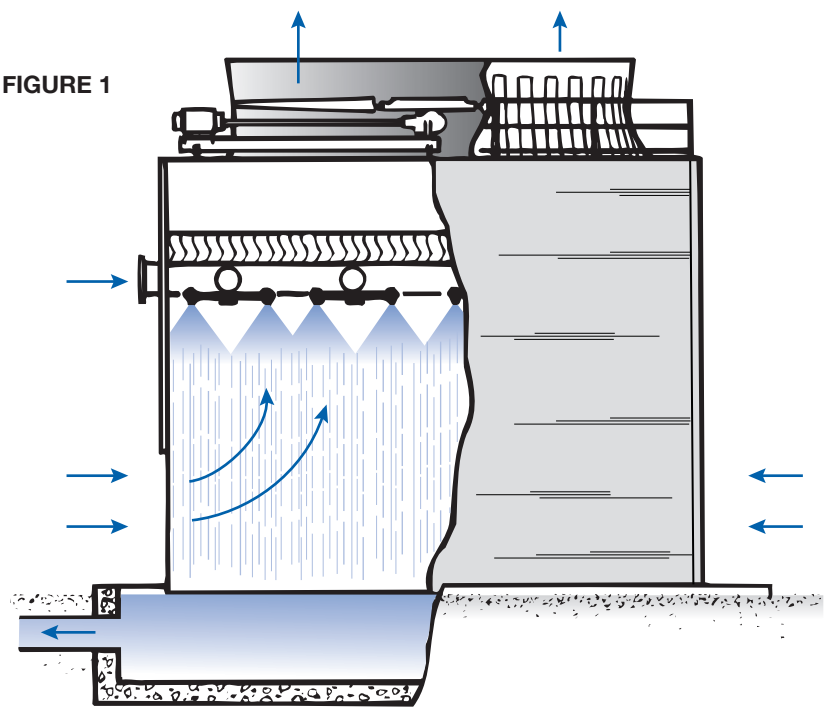
INTENT

In the foreword of *Cooling Tower Fundamentals* (published by SPX Cooling Technologies, Inc.) the scope of cooling tower knowledge was recognized as being too broad to permit complete coverage in a single publication. As a consequence, treatment of the subject matter appearing in that book may have raised more questions than it gave answers. And, such was its intent—"to provide a level of basic knowledge which will facilitate dialogue, and understanding, between user and manufacturer." In short, it was designed to permit questions to spring from a solid foundation—and to give the user a basis for proper evaluation of the answers received.

This is the first of a series of papers intended to expand upon the basic information already published. The plan for the series is to limit individual topics to as few aspects of cooling tower design, application, and operation as necessary to make for quick and informative reading. From time to time, however, subjects will arise whose scope precludes adequate coverage in a short paper, and whose thread of continuity would be lost in separate installments. Those subjects will be treated in "Technical Reports" of somewhat greater length, receiving the same distribution as will have been established by evidence of reader interest. In addition, existing publications whose content remains current and fundamentally sound will become part of the useful cooling tower library that recipients will compile.

Although this first paper touches briefly upon the theory of cooling tower performance, the basic content of future papers will be far more practical than theoretical. This is because the brands of SPX Cooling Technologies, in their course of existence, have designed and manufactured every type of tower currently utilized in the industry, which allows all information and comparisons given to come from experience. However, since the operating characteristics of any cooling tower are governed by the laws of physics, psychrometrics, and thermodynamics, such laws may be described occasionally for purposes of promoting complete understanding.

FIGURE 1



TOTAL HEAT EXCHANGE

An open circuit cooling tower, commonly just called a cooling tower, is a specialized heat exchanger in which two fluids (air and water) are brought into direct contact with each other to affect the transfer of heat. In the "spray-filled" tower shown in **Figure 1**, this is accomplished by spraying a flowing mass of water into a rain-like pattern, through which an upward moving mass flow of cool air is induced by the action of a fan.

Ignoring any negligible amount of sensible heat exchange that may occur through the walls (casing) of the tower, the heat gained by the air must equal the heat lost by the water. Within the air stream, the rate of heat gain is identified by the expression $G\ (h_2 - h_1)$, where:

G = Mass flow of dry air through the tower—lb/min.
h_1 = Enthalpy (total heat content) of entering air—Btu/lb of dry air.
h_2 = Enthalpy of leaving air—Btu/lb of dry air.

Within the water stream, the rate of heat loss would appear to be $L\ (t_1 - t_2)$, where:

L = Mass flow of water entering the tower—lb/min.
t_1 = Hot water temperature entering the tower—°F.
t_2 = Cold water temperature leaving the tower—°F.

This derives from the fact that a Btu (British thermal unit) is the amount of heat gain or loss necessary to change the temperature of 1 pound of water by 1° F.

However, because of the evaporation that takes place within the tower, the mass flow of water leaving the tower is less than that entering it, and a proper heat balance must account for this slight difference. Since the rate of evaporation must equal the rate of change in the humidity ratio (absolute humidity) of the air stream, the rate of

FIGURE 2

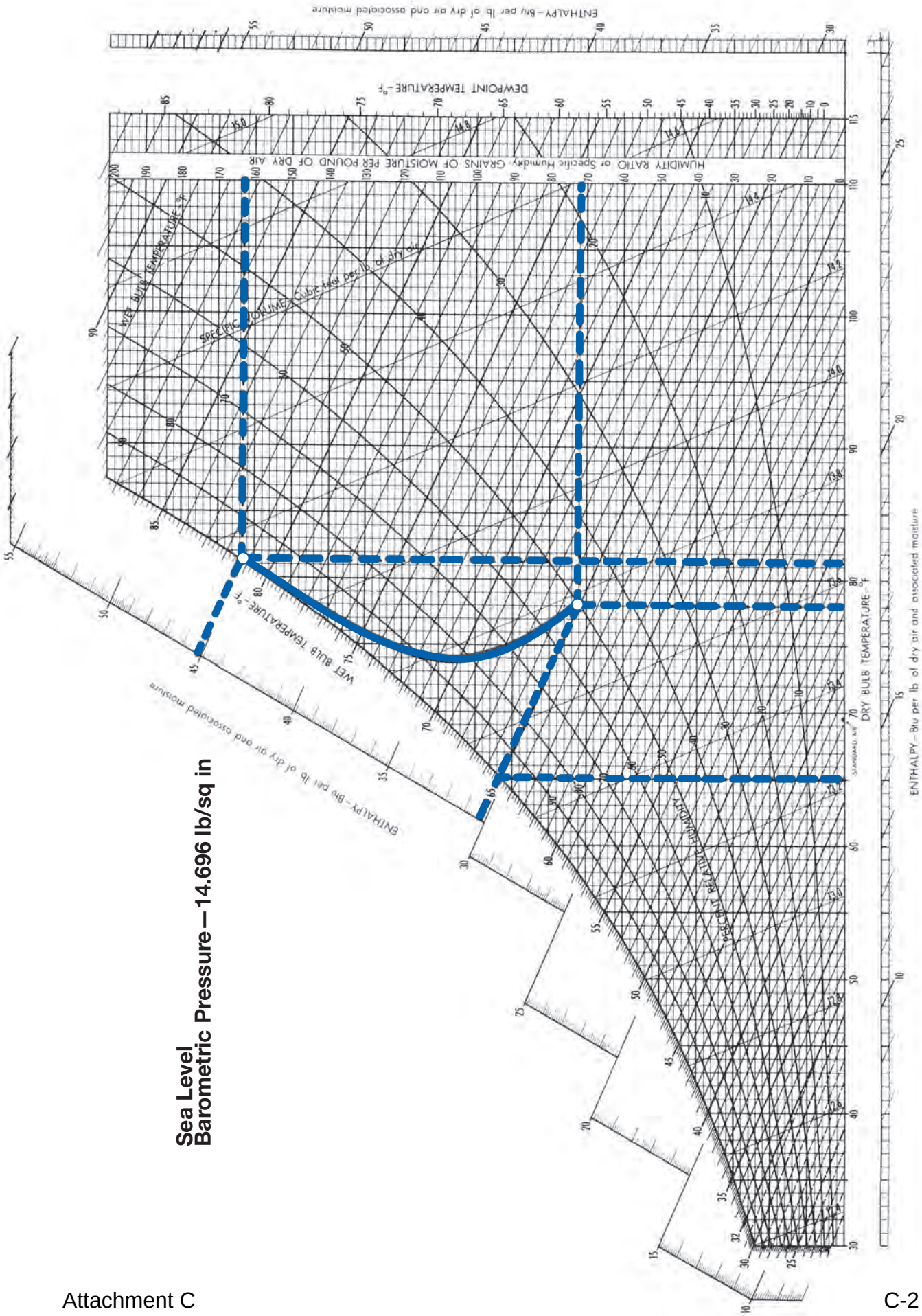
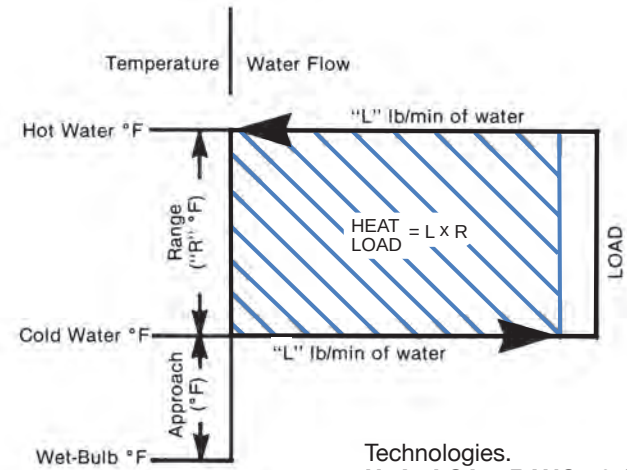

Sea Level
Barometric Pressure—14.696 lb/sq in
WET BULB TEMPERATURE-°F
DRY BULB TEMPERATURE-°F
DEWPOINT TEMPERATURE-°F
HUMIDITY RATIO or Specific Humidity, GRAINS OF MOISTURE PER POUND OF DRY AIR
ENTHALPY-Btu per lb of dry air and associated moisture
SPECIFIC VOLUME, Cubic feet per lb of dry air
PERCENT RELATIVE HUMIDITY
STANDARD AIR

FIGURE 3



heat loss represented by this change in humidity ratio can be expressed as $G (H_2 - H_1) (t_2 - 32)$, where:

H_1 = Humidity ratio of entering air—lb vapor/lb dry air.
H_2 = Humidity ratio of leaving air—lb vapor/lb dry air.
$(t_2 - 32)$ = An expression of water enthalpy at the cold water temperature—Btu/lb. (The enthalpy of water is zero at 32°F)

Including this loss of heat through evaporation, the total heat balance between air and water, expressed as a differential equation, is:

$$Gdh = Ldt + GdH (t_2 - 32) \qquad (1)$$

The total derivation of equation (1) can be found in *A Comprehensive Approach to the Analysis of Cooling Tower Performance* by D.R. Baker and H.A. Shryock, printed in the August 1961 issue of the Journal of Heat Transfer, and available from Marley Cooling Technologies.

HEAT LOAD, RANGE & GPM

The expression "Ldt" in equation (1) represents the heat load imposed on the tower by whatever process it is serving. However, because pounds of water per unit time are not easily measured, heat load is usually expressed as:

Heat Load =
gpm x R x 8⅓ = Btu/min. (2)

Where:
gpm = Water flow rate through process and over tower—gal/min.
R = "Range" = Difference between hot and cold water temperatures—°F. (See Fig. 3)
8⅓ = Pounds per gallon of water.

Note from formula (2) that heat load establishes only a required temperature differential in the process water, and is unconcerned with the actual hot and cold water temperatures themselves. Therefore, the mere indication of a heat load is meaningless to the Application Engineer attempting to properly size a cooling tower. More information of a specific nature is required.

Optimum operation of a process usually occurs within a relatively narrow band of flow rates and cold water temperatures, which establishes two of the parameters required to size a cooling tower—namely, gpm and cold water temperature. The heat load developed by the process establishes a third parameter—hot water temperature coming to the tower. For example, let's assume that a process developing a heat load of 125,000 Btu/min performs best if supplied with 1,000 gpm of water at 85°F. With a slight transformation of formula (2), we can determine the water temperature elevation through the process as:

$$R = \frac{125{,}000}{1{,}000 \times 8\tfrac{1}{3}} = 15°F$$

Therefore, the hot water temperature coming to the tower would be 85°F + 15°F = 100°F.

WET-BULB TEMPERATURE

Having determined that the cooling tower must be able to cool 1,000 gpm of water from 100°F to 85°F, what parameters of the entering air must be known? Equation (1) would identify enthalpy to be of prime concern, but air enthalpy is not something that is routinely measured and recorded at any geographic location. However, wet-bulb and dry-bulb temperatures are values easily measured, and a glance at **Figure 2** (psychrometric chart) shows that lines of constant wet-bulb are parallel to lines of constant enthalpy, whereas lines of constant dry-bulb have no fixed relationship to enthalpy. Therefore, wet-bulb temperature is the air parameter needed to properly size a cooling tower, and its relationship to other parameters is as shown in the **Figure 3** diagram.

FIGURE 4

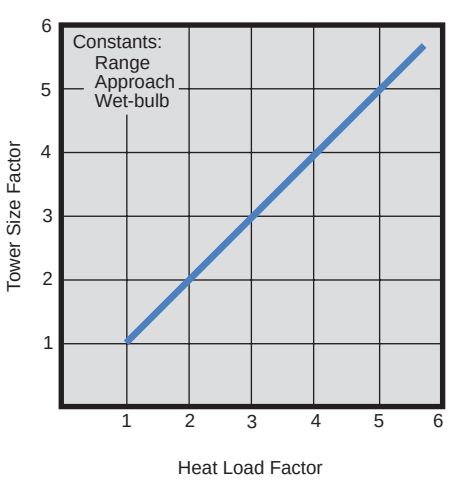
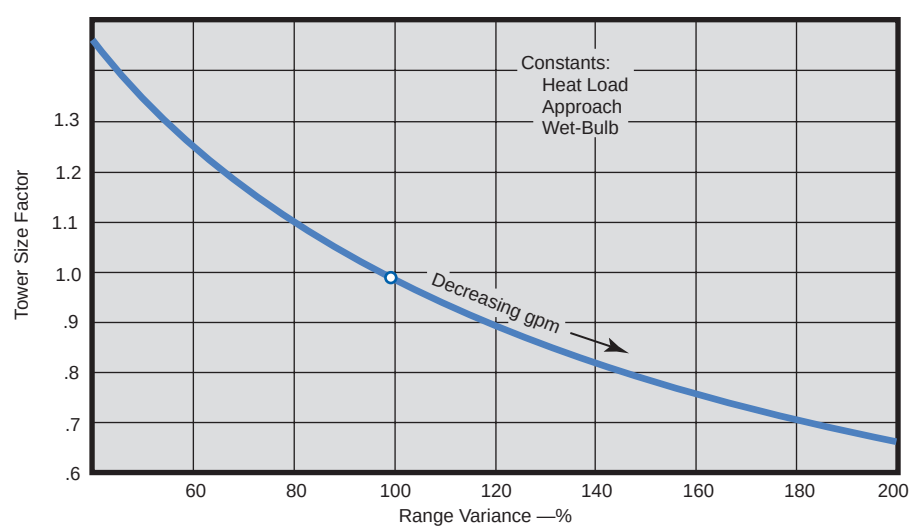


FIGURE 5



EFFECTS OF VARIABLES

Although several parameters are defined in **Figure 3**, each of which will affect the size of a tower, understanding their effect is simplified if one thinks only in terms of 1) heat load; 2) range; 3) approach; and 4) wet-bulb temperature. If three of these parameters are held constant, changing the fourth will affect the tower size as follows:

1) Tower size varies directly and linearly with heat load. See **Figure 4**.
2) Tower size varies inversely with range. See **Figure 5**. Two primary factors account for this. First; increasing the range—**Figure 3**—also increases the ITD (driving force) between the incoming hot water temperature and the entering wet-bulb temperature. Second, increasing the range (at a constant heat load) requires that the water flow rate be decreased—Formula (2)—which reduces the static pressure opposing the flow of air.
3) Tower size varies inversely with approach. A longer approach requires a smaller tower. See **Figure 6**. Conversely, a smaller approach requires an increasingly larger tower and, at 5°F approach, the effect upon tower size begins to become asymptotic. For that reason, it is not customary in the cooling tower industry to guarantee any approach of less than 5°F.
4) Tower size varies inversely with wet-bulb temperature. When heat load, range, and approach values are fixed, reducing the design wet-bulb temperature increases the size of the tower. See **Figure 7**. This is because most of the heat transfer in a cooling tower occurs by virtue of evaporation (which extracts approximately 1000 Btu's for every pound of water evaporated), and air's ability to absorb moisture reduces with temperature.

FIGURE 6

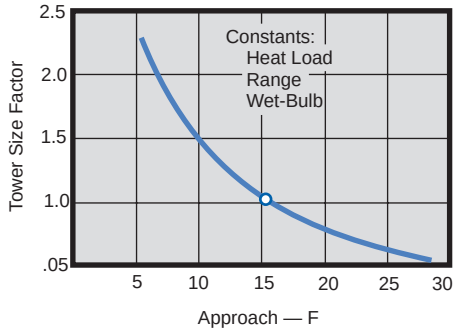
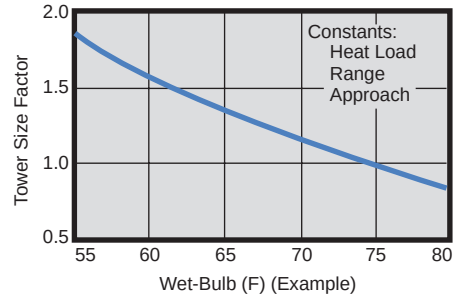


FIGURE 7



ENTHALPY EXCHANGE VISUALIZED

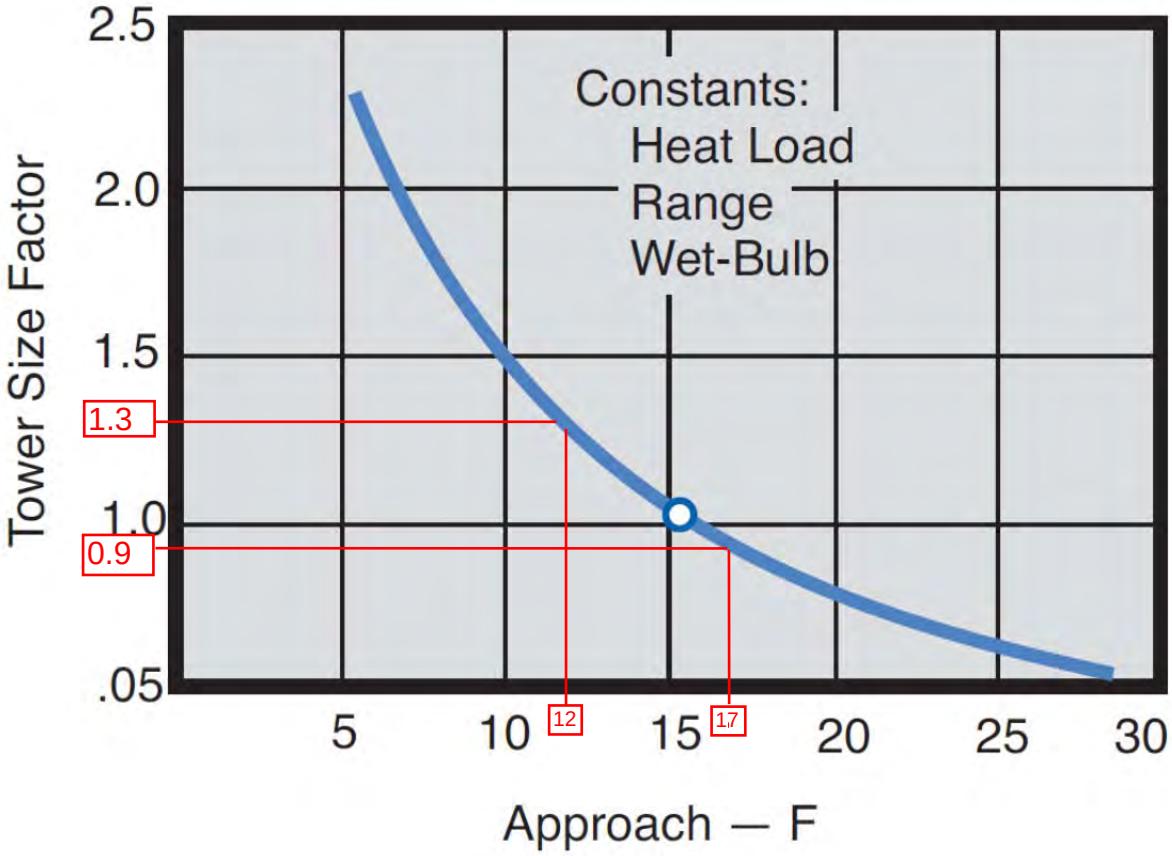
To understand the exchange of total heat that takes place in a cooling tower, let's assume a tower designed to cool 120 gpm (1000 lb/min) of water from 85°F to 70°F at a design wet-bulb temperature of 65°F and (for purposes of illustration only) a coincident dry-bulb temperature of 78°F. (These air conditions are defined as point 1 on **Figure 2**) Let's also assume that air is caused to move through the tower at the rate of 1000 lb/min (approximately 13,500 cfm). Since the mass flows of air and water are equal, one pound of air can be said to contact one pound of water and the psychrometric path of one such pound of air has been traced on **Figure 2** as it moves through the tower.

Air enters the tower at condition 1 (65°F wet-bulb and 78°F dry-bulb) and begins to gain enthalpy (total heat) and moisture content in an effort to achieve equilibrium with the water. This pursuit of equilibrium (solid line) continues until the air exits the tower at condition 2. The dashed lines identify the following changes in the psychrometric properties of this pound of air due to its contact with the water:

– Total heat content (enthalpy) increased from 30.1 Btu to 45.1 Btu. This enthalpy increase of 15 Btu was gained from the water. Therefore, one pound of water was reduced in temperature by the required amount of 15°F (85-70). See page 1.
– The air's moisture content increased from 72 grains to 163 grains (7000 grains = 1 lb). These 91 grains of moisture (0.013 lbs. of water) were evaporated from the water at a latent heat of vaporization of about 1000 Btu/lb. This means that about 13 of the 15 Btu's removed from the water (about 86% of the total) occurred by virtue of evaporation. (The latent heat of vaporization of water varies with temperature, from about 1075 Btu/lb at 32°F to 970 Btu/lb at 212°F. Actual values at specific temperatures are tabulated in various thermodynamics manuals.)

At a given rate of air moving through a cooling tower, the extent of heat transfer which can occur depends upon the amount of water surface exposed to that air. In the tower depicted in **Figure 1**, total exposure consists of the cumulative surface areas of a multitude of random sized droplets, the size of which depends largely upon the pressure at which the water is sprayed. Higher pressure will produce a finer spray—and greater total surface area exposure. However, droplets contact each other readily in the overlapping spray patterns and, of course, coalesce into larger droplets, which reduces the net surface area exposure. Consequently, predicting the thermal performance of a spray-filled tower is difficult at best, and is highly dependent upon good nozzle design as well as a constant water pressure.

Subsequent issues will deal with water distribution system arrangements used in other types of towers, along with the various types of "fills" utilized to increase water surface area exposure and enhance thermal performance.



Assume 66-cell ClearSky back-to-back salt water tower necessary for 830,000 gpm flow with 12 oF approach and 20 oF range per SPX specification in Attachment B.

- - - -

Assuming 776,400 gpm flow for each unit at Diablo Canyon assuming 12 oF approach and 20 oF range, the number of cells necessary would be:

(776,400 gpm/830,000 gpm) x 66 cells = 61.7 cells

- - - -

Substitute 17 oF approach temperature for 12 oF approach. Tower size is reduced 30% per figure above. Therefore, the number of cells necessary for a 17 oF design approach temperature is: 62 cells x (1 - 0.30) = 43.4 cells (44 cells)

Potential PM_{10} Emissions from Salt Water Cooling Towers at Diablo Canyon

B. Powers, Powers Engineering, November 18, 2013

I. Assumptions:

Cooling tower: SPX ClearSky™ back-to-back plume-abated salt water cooling tower

Drift eliminator design performance:	0.0005%
Cooling tower flowrate (20 ^{o}F range):	776,400 gpm (each)
TDS concentration in circulating water:	50,000 ppm
Percentage of emitted particulate > PM_{10}:	70%
Density of seawater:	8.6 lb/gallon

II. Aerosol drift emitted per tower:

(776,400 gallon/min)(0.000005) = 3.9 gallon/min

(3.9 gallon/min)(8.6 lb/gallon) = 33.5 lb/min

III. Total particulate emissions, two towers:

2 × (33.5 lb/min)(60 min/hr)(50,000/1,000,000) = 201 lb/hr

IV. PM_{10} emissions, two towers:

Assume 70% of particulate emitted from cooling towers is greater than PM_{10} with 50,000 ppm TDS in cooling water, per attached calculations. Therefore:

PM_{10}, lb/hr = 201 lb/hr × (1 – 0.70) = 60 lb/hr

V. Potential annual PM_{10} emissions, assuming 90% annual capacity factor, two towers:

PM_{10}, tons/yr = (60 lb/hr)(8,760 hr/yr)(0.90)(1 ton/2,000 lb) = 237 tons/yr

California Energy Commission, CPV Vaca Station, 2008 Application for Certification, project webpage:
http://www.energy.ca.gov/sitingcases/vacastation/index.html

APPENDIX 5.1A

Emissions and Operating Parameters

Table 5.1A-4
Cooling Tower Emissions

PM10 Emissions based on TDS Level	
TDS level, ppm	9000
PM10, lb/hr	4.16
PM10, lb/day	99.9
PM10, tpy	18.22
PM10, lb/hr	1.83
PM10, lb/day	43.9
PM10, tpy	8.02
PM2.5, lb/hr	0.62
PM2.5, lb/day	15.0
PM2.5, tpy	2.73

Based on 8760 hrs/yr

12	cells	
44.34	Height, ft	
10.8	Diameter, ft	
69	exhaust temp, F	
1513000	air flow, CFM	
	PM10 fraction[a]	0.44
	PM2.5 fraction[a]	0.15

Heat rejection rate: not explicitly included in the design specification sheet
Exhaust mass flow rate: 107,900 lb/min
Liquid to gas mass flow ratio: 0.918

Note:
a. See notes for calculations.

Notes to Table 5.1A-4

Calculation of PM10 and PM2.5 from cooling towers

Wet cooling towers cool water by evaporating a portion of the water through contact with the air. The nature of the contact is such that water droplets are entrained in the air and are carried out of the cooling tower. The entrained droplets are called "drift."

Modern cooling towers have high efficiency drift eliminators which recover much of the entrained water. The high-efficiency drift eliminator proposed for this project will reduce drift to less than 0.0005% of circulated cooling tower water.

The water that is entrained contains dissolved solids. When a water droplet that contains solids evaporates, the dissolved solids form a single particle, which remains suspended in the air. The volume of a droplet can be calculated if its diameter is known. The mass of water in the droplet can be calculated from the volume. The mass of solids in the droplet (and the resulting particle) can be calculated from the mass of the water droplet and the concentration of solids in the water. The volume of the particle can be calculated if the density of the solid is known. The diameter of a spherical particle can be calculated from the particle volume.

The size of the final aerosol particle depends on the volume fraction of solid material and the droplet diameter as follows:

$$D_s = D_d \times (F_v)^{1/3}$$

Where:

D_s = diameter of solid particle
D_d = diameter of liquid droplet
F_v = volume fraction of solid material

This equation can be converted to calculate the resulting particle diameter for a cooling tower by accounting for the density of the particle:

$$D_s = D_d \times (\square_d / \square_s \times TDS/1{,}000{,}000)^{1/3}$$

Where:

D_s = diameter of solid particle
D_d = diameter of liquid droplet
$\square_d$ = density of droplet = 1 g/cm^3
$\square_s$ = density of solid particle = 2.2 g/cm^3 for sodium chloride
TDS = total dissolved solids, ppmw

The above equation predicts the physical diameter of a particle formed from a cooling tower droplet. This equation assumes that a single particle will be formed when a droplet evaporates, because there is no evidence that multiple particles will be formed.

The term "aerodynamic diameter" has been developed by aerosol physicists in order to provide a simple means of categorizing the sizes of particles having different shapes and densities with a single dimension. The aerodynamic diameter is the diameter of a spherical particle having a density of 1 gm/cm3 that has the same inertial properties [i.e.

terminal settling velocity in the gas as the particle of interest. The PM_{10} and $PM_{2.5}$ standards refer to aerodynamic diameter.

Therefore, in order to calculate PM_{10} and $PM_{2.5}$ emissions, the aerodynamic diameter of the cooling tower particles must be calculated as follows[1]:

$$D_a = D_s \times (\square_s)^{0.5}$$

The following table represents the predicted mass distribution of drift droplet size for cooling tower drift dispersed from Marley TU12 Excel Drift Eliminators. This table was provided by the cooling tower vendor.

Mass in Droplets (%)		Droplet Size (Microns)
0.2	Larger Than	525
1.0	Larger Than	375
5.0	Larger Than	230
10.0	Larger Than	170
20.0	Larger Than	115
40.0	Larger Than	65
60.0	Larger Than	35
80.0	Larger Than	15
88.0	Larger Than	10

Using the equations described above, a solids density of 2.2 gm/cm^3 (based on the density of sodium chloride), and the droplet size distribution in the previous table, the following particle diameter distribution can be derived:

[1] http://www.epa.gov/air/oaqps/eog/bces/module3/diameter/diameter.htm accessed August 8, 2008

Mass in Droplets (%)		Aerodynamic Particle Size (Microns)
0.2	Larger Than	124.5
1.0	Larger Than	89.0
5.0	Larger Than	54.6
10.0	Larger Than	40.3
20.0	Larger Than	27.3
40.0	Larger Than	15.4
60.0	Larger Than	8.3
80.0	Larger Than	3.6
88.0	Larger Than	2.4

Based upon this particle size distribution, 44% of the particles emitted from the cooling tower will be PM_{10} or smaller. 15% of the particles emitted from the cooling tower will be $PM_{2.5}$ or smaller.

Bill Powers

From: PAUL.LINDAHL@ct.spx.com
Sent: Monday, October 05, 2009 10:48 AM
To: Bill Powers
Subject: Re: 2008 California analysis RE: cumulative mass fraction - aerosol droplets - 0.0005% drift eliminators

Bill,

Yes, the data in the report looks to be from the same internal document that I used for table in the paper I presented in San Diego.

It should be ok to use.

Thanks,

Paul Lindahl, LEED AP
Director, Market Development
SPX Thermal Equipment & Services
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Bill Powers <bpowers@powersengineering.com>

Sent on: 09/26/2009 07:11 PM

To <PAUL.LINDAHL@ct.spx.com>
cc
Subject 2008 California analysis RE: cumulative mass fraction - aerosol droplets - 0.0005% drift eliminators

Paul,

I just came across a 2008 analysis (attached, see p. A-4) done by the applicant for a 660 MW CC plant that calculates the amount of PM10 emitted from the cooling tower assuming a Marley TU12 Excel drift eliminator guaranteed at 0.0005% with a circulating water TDS of 9,000 ppm.

Here is the project webpage: http://www.energy.ca.gov/sitingcases/vacastation/index.html

The PM10 fraction is calculated as 44% of total particulate. It would be much lower in a salt water cooling tower with a TDS of 50,000 ppm.

Does the aerosol size distribution out the drift eliminator look accurate to you? If so, I will use these data/calculations as the basis for estimating the PM10 fraction of drift with a TDS concentration of 50,000 ppm.

Thanks,

Bill

From: PAUL.LINDAHL@ct.spx.com [mailto:PAUL.LINDAHL@ct.spx.com]
Sent: Tuesday, September 22, 2009 11:35 AM
To: Bill Powers
Subject: Re: cumulative mass fraction - aerosol droplets - 0.0005% drift eliminators

Bill,

I have some concerns relative to the methods that may have been used for the 1988 measurements that the drop size distribution in the referenced paper is based upon, insufficient information is included to determine how it was done. What are you trying to do with this data?

Thanks,

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"Bill Powers" <bpowers@powersengineering.com>

Sent on: 09/20/2009 06:22 PM

To <paul.lindahl@spx.com>
cc

Subject cumulative mass fraction - aerosol droplets - 0.0005% drift eliminators

Hello Paul,

I came across a reference to Marley data on the cumulative mass fraction distributions of droplets exiting drift eliminators in the following reference in a Colorado State University paper:

A review of the literature produced nine sets of data for the cumulative mass fraction distributions of droplets (Lindahl, 2003 [typical Marley MDCT]

I need to corroborate the Brentwood Industries aerosol size distribution data for a 0.0006% drift eliminator presented in the attached Greystone paper that was given at the 2003 EUEC conference in Tucson.

Thanks,

Bill[attachment "2002_EUEC conf_Greystone_calculating realistic PM10 emissions from cooling towers.pdf" deleted by PAUL LINDAHL/CT/SPX] [attachment "CEC_Vaca Station AFC_calculation_cooling tower_PM10_drift emissions.pdf" deleted by PAUL LINDAHL/CT/SPX]

Percentage of Particulate > 10 um Emitted from SPX ClearSky Salt Water Cooling Towers at Diablo Canyon: ~70%

Vaca Station, 0.0005% drift eliminator, SPX inline cooling tower, 9,000 ppm TDS

Mass in droplets (%)		Droplet size (microns)
0.2	larger than	525
1	larger than	375
5	larger than	230
10	larger than	170
20	larger than	115
40	larger than	65
60	larger than	35
80	larger than	15
88	larger than	10
percent of particles (%)		aerodynamic particle size (microns)
0.2	larger than	124.5
1	larger than	89
5	larger than	54.6
10	larger than	40.3
20	larger than	27.3
40	larger than	15.4
60	larger than	8.3
80	larger than	3.6
88	larger than	2.4

$D_s = D_d \times (\rho_d/\rho_s \times TDS/1000000)^{1/3}$

$D_a = D_s \times (\rho_s)^{0.5}$

$D_a = [D_d \times (\rho_d/\rho_s \times TDS/1000000)^{1/3}] * (\rho_s)^{0.5}$

Ds = solid diam

Dd = droplet diam (water)

Da = aerodynamic diam

ρs = solid density — NaCl (g/cm): 2.2

ρd = droplet density — water (g/cm): 1

makeup ocean water TDS 35,000 ppmw

droplet TDS = 50,000 ppmw

This assumes 1.5:1 cycles of concentration in cooling tower between make-up raw seawater TDS and TDS concentration in emitted droplets.

Calculation results - Approximately 70% of emitted particulate is > PM10 when 50,000 ppm is assumed in emitted droplets and drift eliminator is designed for 0.0005% performance.

Diablo Canyon, 0.0005% drift elim, 50,000 ppm TDS

Mass in droplets (%)		Droplet size (microns)
0.2	larger than	525
1	larger than	375
5	larger than	230
10	larger than	170
20	larger than	115
40	larger than	65
60	larger than	35
80	larger than	15
88	larger than	10
percent of particles (%)		aerodynamic particle size (microns)
0.2	larger than	220.6
1	larger than	157.6
5	larger than	96.6
10	larger than	71.4
20	larger than	48.3
40	larger than	27.3
60	larger than	14.7
80	larger than	6.3
88	larger than	4.2

70%

10 um