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FEASIBILITY OF RETROFITTING COOLING TOWERS AT DIABLO CANYON POWER PLANT UNITS 1 & 2

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I. Introduction

This report describes the findings of an independent study of the impacts and engineering feasibility of retrofitting cooling towers at PG&E's nuclear, two-unit, 2,222 MW net output Diablo Canyon Power Plant (DCPP) located near Avila Beach in San Luis Obispo County. DCPP is one of the largest two-unit nuclear power plants in the country. It occupies a relatively small industrially zoned coastal site on a narrow shelf sandwiched between the Pacific Ocean and the steeply sloped Las Canadas mountains in Central California. The DCPP cooling system currently utilizes a total of about 1,725,000 gpm of saltwater, heating it approximately 18°F in the condensers and returning it to the Pacific. Any retrofitted close-cycle cooling system would need to provide an equal amount of cooling as this current water flow to maintain the current electrical output of the plant.

At the outset, it should be appreciated that, much like the nuclear containment area of DCPP, the existing circulating water system and safety related cooling systems were designed and installed to be permanent features of DCPP. They were not constructed to allow future alterations in any significant way. In fact, only a few existing plants throughout the United States have been retrofitted with closed-cycle cooling towers. These backfitted cooling towers were for small power plants or had some accommodating physical feature that facilitated their conversion, such as at the Palisades Nuclear Plant in Michigan. In contrast, the magnitude of a cooling tower retrofit at DCPP would be of an unprecedented scale and complexity. In fact, the proposed cooling tower retrofit project would constitute the largest closed-cycle saltwater mechanical draft cooling tower installation in the United States, retrofit or otherwise.

The main focus of this report concerns the engineering, construction, performance, and environmental issues of the Tetra Tech proposed cooling towers for DCPP. Tetra Tech Inc. is based in Evergreen, Colorado. It had assessed retrofitting cooling towers at DCPP in their November 2002 report entitled, "Evaluation of Cooling System Alternatives" [1]. The approach of this study by Burns Engineering Services, Inc. of Topsfield, Massachusetts was to examine the application of saltwater mechanical draft cooling towers in depth in order to parallel the emphasis of the Tetra Tech engineering study and evaluations because of their conviction that these types of cooling towers had the most potential for installation at DCPP.

Burns Engineering Services, Inc. is a consulting firm that specializes in power plant cooling systems with a particular focus on the condenser, the cooling towers, and the other related equipment. Burns Engineering Services has provided consulting to architect-engineers, utilities, and manufacturers alike to design, evaluate, install and test cooling system equipment. Its Director has been involved in the power industry and cooling system field for the majority of his career since the late 1950's. Burns Engineering Services' evaluation of the cooling tower retrofit at DCPP contained herein is based on an examination of the DCPP design information, drawings that define the site and existing cooling & safety-related systems, and interviews of key DCPP engineers and managers.

Because site-specific factors are of prime importance in any serious cooling tower retrofit assessment study, Burns Engineering Services' site visit occurred over a full three-day period during March 11-13, 2003.

4. **Tetra Tech does not investigate if a suitable substation was available local to their proposed cooling tower cells to provide the level of power needed for the cooling tower operation.** The proposed tower and pumphouse complex requires over 50 MW in auxiliary power. That is enough electrical power to supply the needs of a city of about 50,000 residents. The added costs of both the amount of power required and the design and building of infrastructure to deliver that energy to the cooling tower cells would be appreciable.

5. **Integrating the cooling towers into the existing system will take a minimum of one year with both units of DCPP offline, resulting in lost revenue of $657,000,000.** The time required for this work is double the six months that Tetra Tech estimates. This will be a more lengthy, difficult, and costly process than envisioned in the Tetra-Tech report. Referencing Figure 6, Burns Engineering Services determined that all the cooling system lines and many utilities for both units of DCPP, including the nuclear safety related accident cooling systems, are all intertwined in a very narrow buried area at the front of the common two unit turbine building. Thus, any tie-ins to the existing concrete circulating water lines and the installations of the new lines extending out to the tower would need to occur within that congested underground section while maintaining positive access and the nuclear safety related functions to the two units. As a result, the tie-in construction activities at DCPP will be very difficult, will necessarily proceed slowly and would likely raise licensing and monitoring issues with the NRC. Further, staging the construction tie-in separately to each unit under those conditions would be considered unrealistic. Based on this review and estimates at other nuclear facilities, Burns Engineering Services calculates that the tie-ins would take the entire DCPP off-line a minimum of 1 year. That conclusion causes a major increase in the estimated lost revenue to $657,000,000. This revenue estimate uses the same revenue loss figure Tetra Tech employed of $900,000 per unit per day.

6. **Plume from the cooling towers will create safety and security hazards.** The proposed Tetra Tech 132-cell wet mechanical draft design would produce a substantial vapor plume during the cool weather periods that frequently occur at DCPP. Access roads, buildings and parking lots could be blanketed by those opaque, very visible plumes. The Figure 7 photo of an actual plume illustrates that a lack of visibility occurs even with much smaller towers. The lack of visibility for this proposed site would constitute a safety and security hazard, particularly when considering transporting nuclear fuel for processing or disposal. The cool, damp, conditions common at DCPP will make the formation of these large, opaque plumes a frequent occurrence.

7. **The cooling tower retrofit will create noise pollution.** Noise pollution from the 132-cell cooling tower complex proposed by Tetra Tech, each powered by 250 HP fans with its attendant enormous water flows, would be high and pervasive unless attenuated. While there admittedly are no proximate private houses or properties, the employees at DCPP and the local fauna would be impacted. The continual outdoor noise level at the administration building will be in the vicinity of 74 dBa, a level equivalent to loud street noise (for reference, the OSHA hearing safety limit is 85 dBa). Reducing these effects through noise attenuation would require a major increase in the cost of each cooling tower and an increase in fan power consumption. This environmental aspect was not discussed by Tetra Tech and it is unlikely that the major expense of attenuating this large noise source was included in their performance or cost estimates.

8. **Salt drift from the cooling towers will be substantial, resulting in environmental and plant equipment damage.** Salt drift impacts were not addressed in the Tetra Tech report, so there is no knowledge of whether these were considered by those investigators. Assuming a standard level of drift elimination would be installed on the towers, an added 7 million lbs of salt per year would be deposited by the cooling tower complex. Due to the grand scale of the proposed cooling tower installation, this level of

II. Executive Summary

In this report, Burns Engineering Services Inc. discusses their independent evaluation of the impacts and engineering feasibility of retrofitting cooling towers at PG&E's nuclear, two-unit, 2,222 MW Diablo Canyon Power Plant (DCPP). The plant is located on a relatively small industrially zoned coastal site between the Pacific Ocean and the steeply sloped Las Canadas mountains. Tetra Tech, Inc. had assessed retrofitting cooling towers at DCPP in their November 2002 report[1]. Because that retrofit plan had been developed and proposed by Tetra Tech, the purpose of this study is to examine the technical basis and opinions presented in the Tetra Tech report.

It should be appreciated that the main cooling systems of these power plants were designed and installed to be permanent structures, much like the nuclear containment or nuclear safety related cooling systems. No consideration for future alteration was included. In addition, only a handful of plants, all much smaller than DCPP, have experienced a cooling tower retrofit. Thus, the magnitude of a cooling tower retrofit at DCPP would be of an unprecedented scale and complexity. The proposed retrofit project at DCPP would constitute the largest closed-cycle saltwater mechanical draft cooling tower installation in the United States.

Burns Engineering Services agrees with Tetra Tech that, for a variety of reasons, dry, wet/dry and natural draft cooling towers are not feasible at DCPP. The application of saltwater mechanical draft cooling towers is examined here in depth to parallel the emphasis of the Tetra Tech engineering study and evaluations due to their assertion that these types of cooling towers had the most potential for installation at DCPP.

A summary of the major results of the Burns Engineering Services comparative analysis indicates the following:

1. **Tetra Tech's proposal overestimates the amount of available space at DCPP for the proposed towers.** Burns Engineering Services agrees with Tetra Tech that 132 large saltwater, counterflow mechanical draft tower cells would be required at DCPP to cool its 1,725,000 gpm of salt water if conversion to a closed-cycle system were required. That proposed arrangement is shown on page 15 of the Tetra Tech report[1] and is reproduced in this report under Figure 4. Rather than locate a suitable area for the cooling tower retrofit, the Tetra Tech proposal simply displaces several existing plant structures for which there is no alternative space within the industrially zoned area of the site. The net effect is that the Tetra Tech report does not adequately address the lack of available land for the project.

2. **Tetra Tech does not address a viable relocation of the existing important, permanent large structures.** These structures include a 98,000 and a 28,000 square foot building, an engineered road that significantly impacts the safety of the nuclear operation at DCPP and an alternative for parking up to 800 employees and contractors cars. This was likely not discussed because there are no practical alternatives.

3. **The Tetra Tech report is also silent regarding the enormous construction required to prepare the area upon which the proposed cooling towers would be built.** An earthwork construction plan that would be needed to level the area upon which they intend to locate the 132 cooling tower cells. The Tetra Tech construction plan basically requires excavating an extensive 1600 x 600 ft long section out of one of the Las Canadas mountains with a fill of the proposed tower site at the lower elevations. Similarly, it does not address the installation of the up to 60 ft. deep pile foundations for the towers, motor control center and pumphouse on that site to ensure a stable foundation.

airborne salt will be much greater than the natural airborne salt concentrations in that area. Besides causing a large number of electrical arcing incidences from deposits on the insulators of the 500 kva lines and increasing the level of plant maintenance costs, the salt drift would have an extreme environmental impact on the local flora and fauna.

9. **The "closed system" retrofit proposed would have its own discharge and environmental impacts.** Though total flow will be cut down significantly, a concentrated salt stream of 69,000,000 gallons per day will be discharged into the ocean. The local effects of such an effluent are not know, but could be significant. The water circulated through the cooling towers will also require chemical treatment to remove the minerals that would otherwise build up due to the evaporative process & and damage the system. Therefore, this system would result in another potential waste issue.

10. **Tetra Tech's assumption of cooling tower efficiency is based on a theoretical value not attainable at DCPP site.** Tetra Tech's report overlooks site conditions that will cut down on cooling tower performance. A key figure used in any estimate of cooling tower performance is the approach. It is the temperature difference between the ambient wet bulb temperature and the temperature of the cooled water exiting the towers. The approach signifies the effectiveness the cooling tower will have in cooling the water. The larger the approach, the less efficient the cooling process. Tetra Tech assumes a theoretical value for the approach that is unachievably small for large commercial towers given the site conditions (the low wet bulb temperature) at DCPP. In other words, Tetra Tech overestimates the cooling ability of the towers. DCPP is a relatively cool site with a low wet bulb temperature of 61°F. The typical cooling tower is specified with a design approach at much higher wet bulb temperatures that near 80°F. With the higher wet bulb temperature, a 9°F approach (the temperature difference between the wet bulb and cold water produced by the tower) is viable. However, at a 61°F wet bulb temperature, the achievable, commercially available, large utility cooling tower approach is much higher than the 9°F approach temperature that was used by Tetra Tech as the base for its retrofit energy penalty impacts. Thus, the potentially achievable, large commercially available utility cooling tower approach is well above the 9°F between the cold water temperature produced by the towers and the local wet bulb temperature that Tetra Tech based its plant performance and retrofit energy penalty impacts upon.

11. **Because of Tetra Tech's erroneous estimate of cooling tower efficiency and recirculation effects, they underestimate the yearly lost revenue due to the retrofit imact on plant output.** Using Cooling Technology Institute data[2] with industry estimating methods[3], it was estimated that the approach at DCPP would instead be about 16°F at the design point. In addition, the topography of this constricted site, the very large numbers of closely-spaced cooling towers proposed indicates significant recirculation will occur[4,5]. This was conservatively estimated to be a minimum of 4°F. Hence the total approach of the cooling tower cold water temperature to the wet bulb would at least 20°F, or 11°F higher than that used by Tetra Tech in its evaluations. The difference indicates the station energy penalty operating with retrofitted cooling towers, including the effect of the modular condenser replacements, would increase annually to 56 MW for both units at the design conditions. Using Tetra Tech's assumed 350-day operation and parasitic loss of 25MW, with an energy cost of $34/MW hour, the total reduction resulting from implementing the cooling tower proposal would come to a yearly lost revenue of over $23 Million ([56 MW energy penalty + 25 MW parasitic load] X $34/MW hour X 24 hours/day X 350 days operation/year).

12. **Condenser modifications will be more costly and more difficult than listed in the Tetra Tech report.** To make the cooling tower retrofit viable, major condenser modifications would be required. Burns Engineering agrees with Tetra Tech that replacing the existing 22 gauge, 1 inch outer-diameter titanium

tubes with 25 gauge, ¾ inch outer-diameter titanium tubes will provide a condenser performance improvement to compensate somewhat for the loss in turbine exhaust vacuum due to the warmer return water expected from the cooling towers. But Tetra Tech has neglected several important aspects of their replacement plan. Primarily, the 25 gauge titanium tubing wall thickness (0.020 inches) is too thin to allow a rolled tube-to-tubesheet joint with sufficient mechanical integrity for this concentrated seawater, highly pressurized application. Only by welding the tubes to the tubesheets could condenser leaks be prevented. That kind of welding would consist of approximately 155,200 joints per unit & necessitates "clean room" conditions that can only be duplicated in a shop. Thus, a modular replacement of the existing tube bundles would be needed.[6] Besides being the largest modular condenser replacement project to date in the world, the complexity of moving not just plate and tubes but the large assembled bundles back into the DCPP condenser would be very difficult. It would require significant cutting of the turbine building wall to allow the large modular bundles access. A significant number of obstacles would need to be cut out of the way to allow for delivery of a modular unit. That added significant obstacle to the construction schedule is not presented by Tetra Tech and apparently is not included in its estimated costs. Burns Engineering Services estimates that this modular replacement of the existing condensers alone would take a minimum of 3 months on an aggressive, accelerated schedule.

13. **Tetra Tech's Operation and Maintenance costs are not adequately justified & too low.** Tetra Tech indicates the Operating & Maintenance (O&M) estimate is 750$/MW and did not define whether that generic cost was applicable to freshwater or saltwater installations. The value was obtained from a respected, large cooling tower manufacturer but not a cooling tower owner who must bear the annual costs. That supplier would not appreciate the 24/7 costs of the extra personnel needed for frequent inspections, upkeep, lighting, instrument, control, electrical and mechanical repairs, replacements, maintenance of the water treating systems, chemical requirements, and blowdown and makeup systems. It could for example be modestly expected that an extra staff of 10-15 people would be required with a range of craft skills from chemists to engineers to welders, instrument technicians, electricians, painters, etc. Estimating current salaries, benefits, office & manual space requirements and the supplies they would need indicates a much higher value at DCPP than the $750/MW cost listed by Tetra Tech. Burns Engineering Services would expect costs to be 6 times higher than the Tetra Tech estimate.

Conclusion: Burns Engineering Services has determined that the Tetra Tech alternative cooling system retrofit proposal and evaluation was too generic and did not properly take into consideration the unique site and design conditions at DCPP. Hence, the major conclusions of the Tetra Tech report are unsound and unrealistic. As a result of our review process, it became evident that retrofitting cooling towers at DCPP would be impractical, have significant negative effects on the plant safety and current generation, and produce adverse airborne environmental impacts. Each of these items will add significantly to the costs of the project presented by Tetra Tech and also make permitting difficult if not impossible.

III. Evaluation of Cooling System Alternatives

A. Overview of Potentially Applicable Systems

The Tetra Tech report considers different types of cooling water systems as alternatives for the retrofit and evaluates them based on land and water availability for the cooling system, regulatory constraints, and technical compatibility with the existing plant. Burns Engineering Services and Tetra Tech are in agreement on the incompatibility of many of the alternatives for the conditions at DCPP and that mechanical draft towers would be least-worst alternative to consider for Diablo Canyon. In this section, we will comment upon the some of the other cooling system alternatives and their applicability to the DCPP case, particularly the air cooled condenser, natural draft tower, and wet/dry tower.

As an overview, a retrofitted direct dry steam condenser, also termed an air-cooled condenser (ACC), would be too large and cause too great an additional turbine exhaust steam pressure drop. These major operational and efficiency problems would need to be addressed. In addition to those retrofit considerations, in a competitive market, the poor efficiency and auxiliary power requirements of a dry system makes this alternative cooling technology the least favorable. This is especially true during warm periods, when the production value of electricity is greatest.

Based on a projection of experience from other smaller projects that have utilized direct air-cooled steam condensers, it was estimated that the size of the towers needed by the two units of DCPP would be an aggregate of about 350 cells. The plan area projection of each cell would be approximately 45ft by 45ft and these cells would correspondingly be served by 350 large diameter fans. This size estimate is essentially in accord with Tetra Tech. Comprised of a total of 175 cells per unit, the inherent size of each DCPP ACC arrayed in smaller unit clusters would be about 5 times the size of the typical current commercial installations. A large separation would also be required between these tower clusters to minimize exhaust air interference and recirculation. The physical characteristics of the ACC installation by themselves preclude their application at the comparatively small DCPP site.

Another major technical problem for the ACC, (in this instance, mentioned by Tetra Tech) would be the length, size and routing of the steam distribution line(s) along with its impact on generation from the large turbine steam duct between the tower clusters and plant. An approximately 40 ft by 40 ft duct under an extreme vacuum load would be needed to supply the steam from the three large working ends of the two existing central turbine exhaust locations to the cooling tower clusters. In any event, our conclusion was in general agreement with Tetra Tech that a direct air-cooled condensing system would not be feasible or viable at DCPP.

In their report, Tetra Tech appears to confuse a patented parallel wet & dry system that only one manufacturer (GEA) markets for very small plants (typically generating 50 MW or less) with what the rest of the cooling tower industry refers to as a wet/dry cooling tower. However, we agree with Tetra Tech that installing the patented parallel wet/dry tower at DCPP is not applicable or feasible due to technical concerns associated with the distribution of large amounts of steam, land requirements, O&M costs, lack of performance and other cost constraints.

We also concur with Tetra Tech that any wet cooling tower system designed to use freshwater makeup would not be a suitable alternative at DCPP because of the lack of adequate freshwater supplies in the region. Unless a substantial source of water becomes available for industrial use at a later date, this alternative cannot be considered.

Like Tetra Tech, Burns Engineering Services determined that natural draft cooling towers would not be a viable cooling alternative at DCPP. Numerous factors suggest the non-viability of an installation of a total of 10 of these large concrete structures, each 37 stories tall, at the DCPP site. Application of this technology to DCPP would create the largest natural draft complex in the world. In addition to the Tetra Tech reasons for rejecting natural draft towers as a candidate system, the estimated 9°F approach Tetra Tech used as a base for the energy penalty is unattainable. This occurs because of the previously cited low wet bulb temperatures at DCPP, but also because natural draft towers have inherently poor performance compared to mechanical draft towers. In fact, Burns Engineering Services estimates indicate a natural draft approach temperature could be as high as 25°F, rather than the 9°F listed by Tetra Tech. To realize any effective natural draft, the condenser would have to be modified to two-pass units with a temperature rise of 36°F. No related discussion by Tetra Tech was evident.

B. Mechanical Draft Retrofit Feasibility Review

1. Land & Space Considerations

This section of the report deals with the challenges in locating and constructing the proposed cooling tower retrofit compatible with the existing plant and conforming to the geographic and zoning conditions of the site.

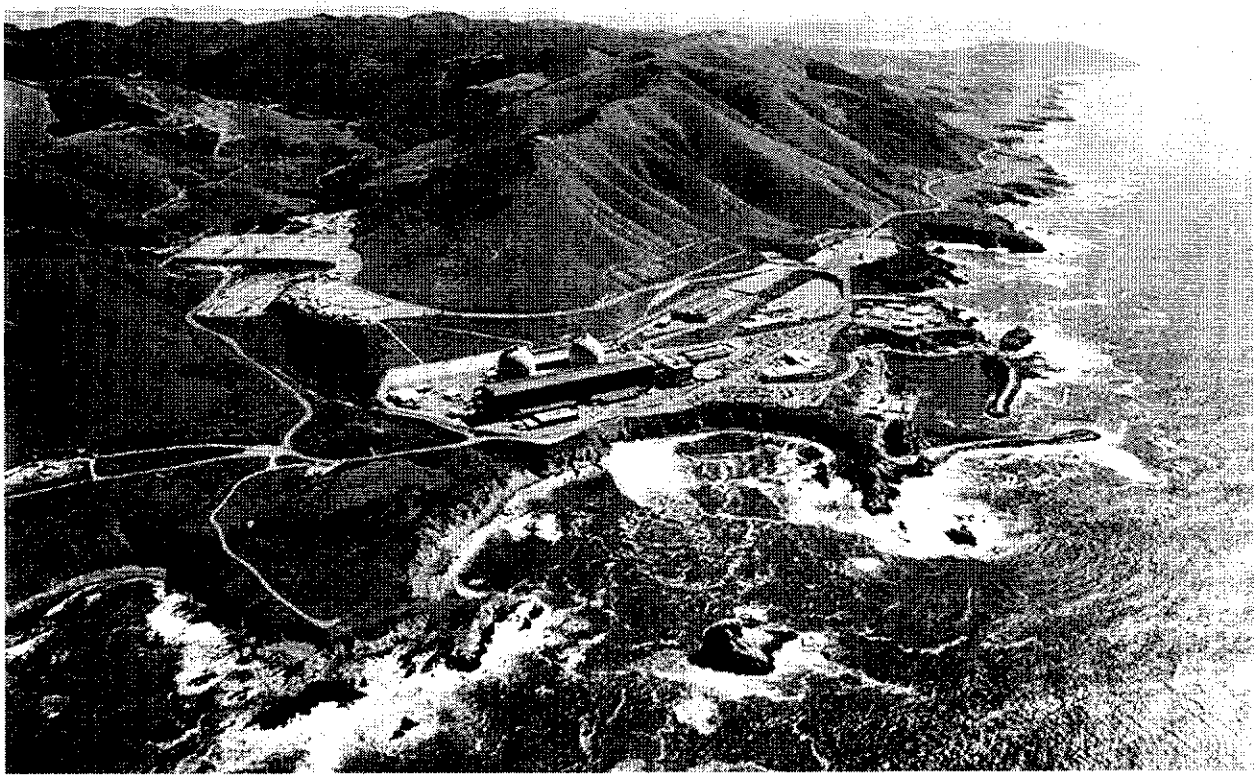

FIGURE 1- Overview of Diablo Canyon Geographical Site

The surroundings upon which Diablo Canyon Power Plant (DCPP) is built are unique. The plant sits on a marine terrace surrounded by cliffs on one side and steep mountains on the other. Due to a combination of factors, including the relatively small amount of the lot zoned for industrial use, geologic stability of different site areas for construction, underlying material, steep mountain gradient, and existing use of buildable space, there is very little land available for building. Insertion of any major new construction, such as the 132

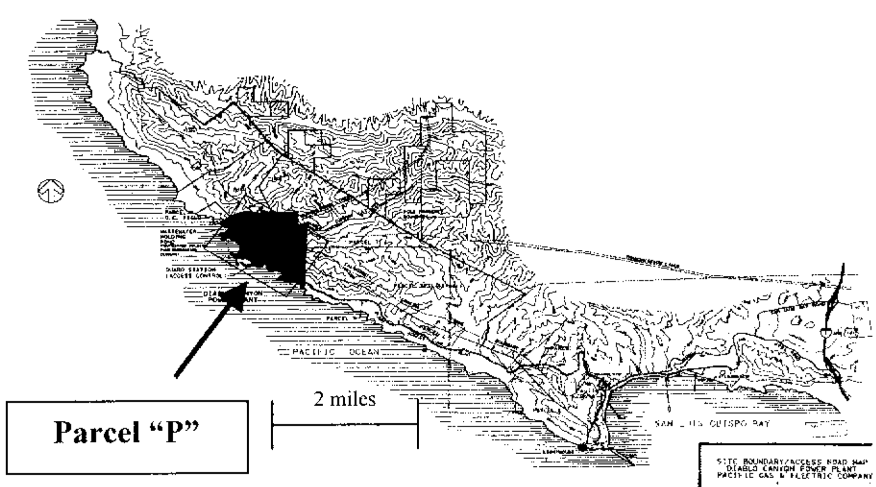

FIGURE 2- Industrially Zoned Area

cooling towers proposed by Tetra Tech, is virtually impossible. An understanding of the geographic and geologic characteristics of the Diablo Canyon site is critical to be able to accurately consider any building or retrofit plans for the site.

As shown in Figure 1, the topography upon which Diablo Canyon sits is extraordinarily challenging in terms of lending itself to development. Construction cannot be carried out too close to the cliff edges, where erosion would endanger the safety of any large surface structure. Beyond this perimeter, there is only a small swath of land before the mountains rise steeply. Even this land is terraced, which limits the area available for any large project without a gargantuan leveling effort.

Not only do natural barriers to construction abound- zoning restrictions severely limit the area which can be considered for the cooling tower sites or any other buildings, parking lots, or roads that might be relocated by the tower construction. Although PG&E owns a vast amount of area, most of it is off limits to any construction. Only parcel P is zoned for industrial use, & is therefore the only area that can be practically considered for this project. As can be seen from Figure 2, Parcel P represents only roughly 5% of the area owned by PG&E at this site.

Things get even worse from there. Most of Parcel P is occupied by steep mountains that rise rapidly from the plateau. The summits surrounding Parcel P reach heights of between 1231 feet and 1573 feet. Most of Parcel P is unusable due to its steep gradient (see Figure 3 below).

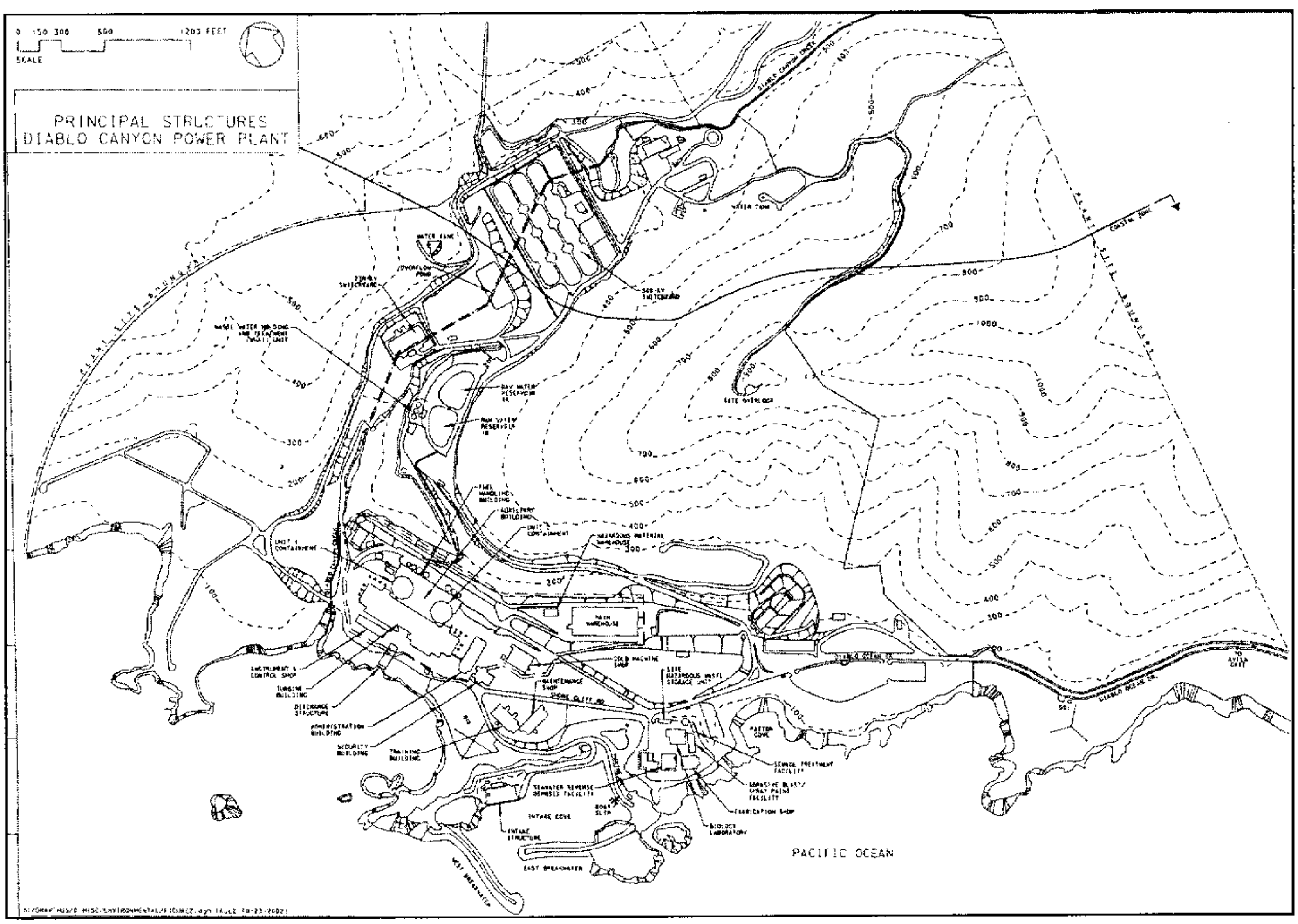

FIGURE 3- Parcel P Detail

Roughly 25% of the land in Parcel P is able to support construction. The gradient of the rest is simply too steep. Existing structures and parking lots already occupy nearly all of the usable space.

Most of the land remaining is not available for construction due to its steep gradient, or geologic unsuitability. Desirable underlying geology, such as exists under the reactor and turbine building, is hard rock. Other parts are composed of a clay matrix, which requires reinforcement in order to be able to support any building.

Tetra Tech has proposed displacing a substantial area in the center of the marine terrace for construction of the cooling towers (see below). Each of the cooling towers proposed have a 60' x 60' footprint. The total area required would be roughly 1600' long and 600' wide. The construction would be a massive project, extremely costly in terms of both money and time.

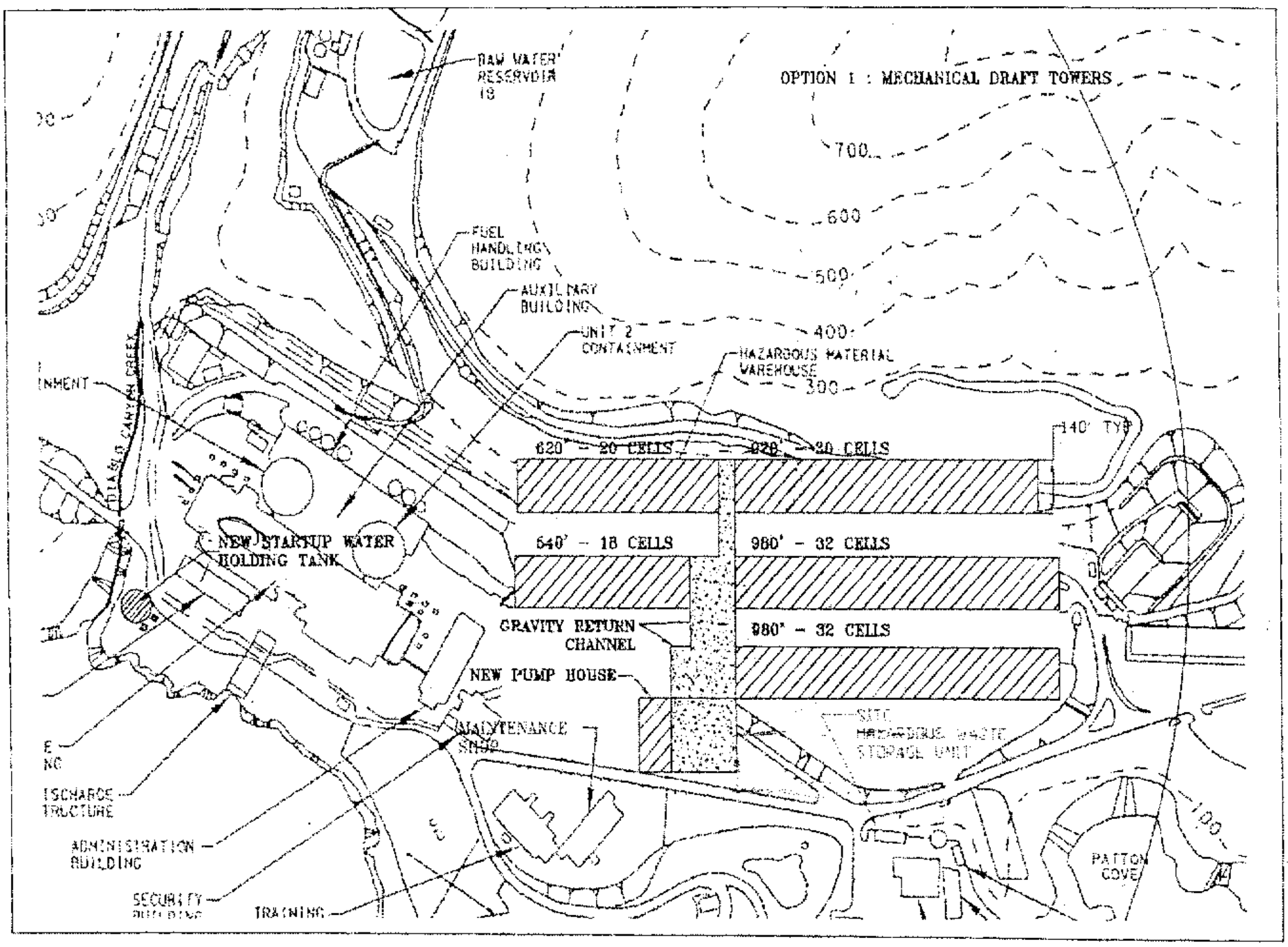

Figure 2: Mechanical Draft Cooling System Layout

Diablo Canyon Power Plant, Evaluation of Cooling System Alternatives

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FIGURE 4 - Tetra Tech's Proposed Siting of the Cooling Towers[1]
(This is a duplicate of Figure 2 from Tetra Tech's November 2002 report)

The parking lot area is "underlain by a thick sequence of older colluvial fan deposits consisting of gravelly clay colluvium up to about 60 feet thick."[7] To prepare the site, pilings penetrating this level would need to be installed to maintain ground stability.

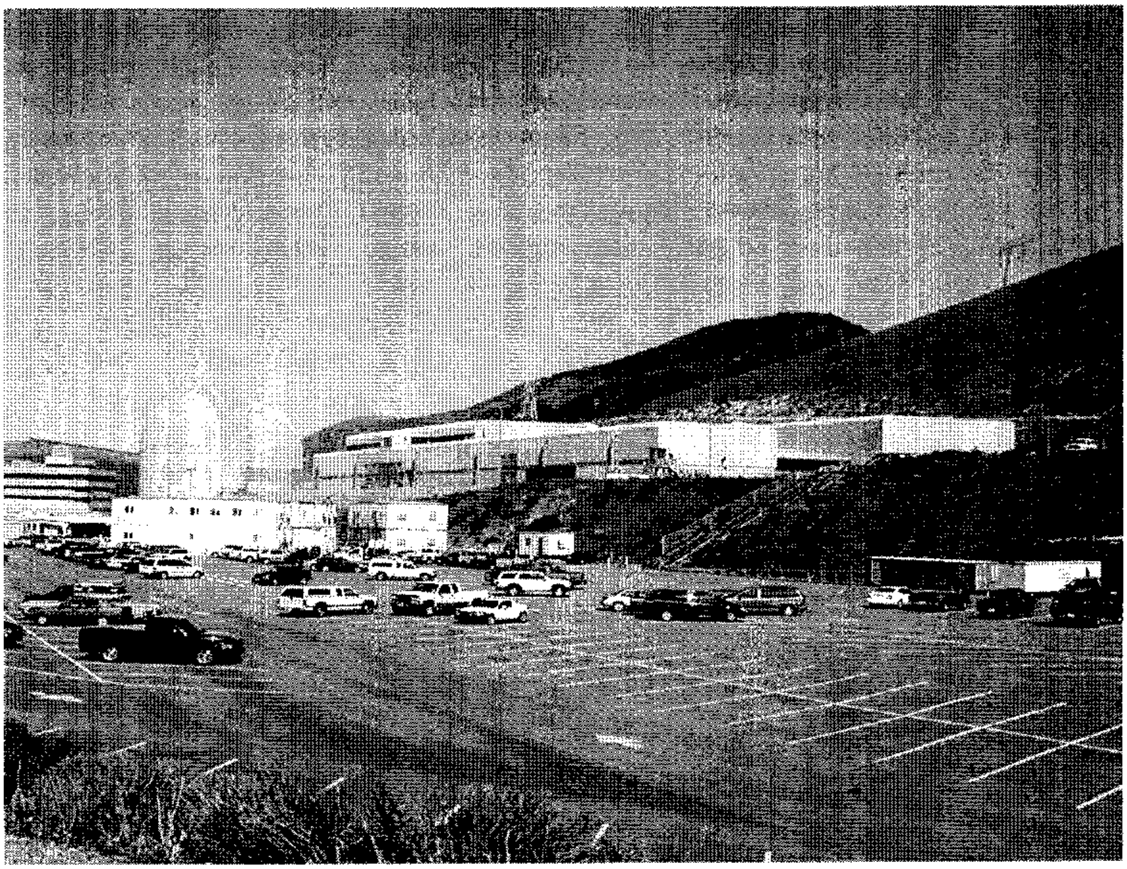

FIGURE 5 - Gradient Between Parking Lot & Warehouse.

This area between the main parking lots 7&8 would need to be leveled to accommodate the proposed cooling towers as opposed to maintaining its current terraced configuration. Towers could not be built on the two existing terraces because exhaust from the lower level (where the current main parking lot stands) would too easily recirculate into the cooling towers on the upper level and destroy their ability to supply any cooling.

Tetra Tech's proposed cooling tower build site is currently occupied by the warehouse, the machine shop, main parking lots 7 & 8, and the access road and transportation route. The warehouse is not a simple building as the name implies. It is a permanent structure 475' X 207'[8] that stores parts required for plant operations & maintenance and also provides a number of offices. The only area large enough to accommodate the warehouse inside the industrial area is located across from the reservoirs on land already claimed for a used fuel storage area.

This bank of 132 cooling towers would eliminate current means of transport and access to the plant and would require major changes. The access road that would be destroyed to make way for the new cooling towers is the engineered route taken to carry the very heavy spent nuclear fuel casks to the site storage area. For safety reasons, such a road may not have a gradient exceeding six percent. With the leveling of the area to build the cooling towers, it is hard to conceive how the access road could be redesigned to remain serviceable. Further, loss of the parking lots would require the construction of a replacement facility and a new transport entry system somewhere offsite.

In conclusion, the following disturbances to the site caused by the building of the cooling towers would need to be addressed:

- The areas that currently are at different levels would need to be leveled. This will require a large amount of backfill.
- The cooling towers will need to be supported with pilings that pass through the layer of soft, claylike material down to the rock.
- A massive retaining wall will have to be built to maintain the slope behind the cooling towers.
- A way would need to be found to build a new access road, sufficiently hardened, around the new site without a gradient so steep as to make the transportation of radiological material hazardous.
- The massive permanent warehouse and large parking lots would need to be relocated. The space does not exist to do so in the area zoned for industrial use.
- Construction of the towers would effectively surround the plant with construction, both for the installation of the actual cooling towers, and for routing of the circulating water tunnels and lines. During construction, a safe means of access into the plant would need to be devised.

2. Retrofit Construction of CW System

Implementation of the cooling tower retrofit project would require modification of the CW lines and tunnels to handle the higher CW pressures of the closed-cycle system. New tunnels would have to be dug in order to direct the flow of water from the condensers to the new bank of cooling towers, with connections to the inlet and outlet water flows established in the area in front of the turbine building.

The underground section of that area has been heavily utilized with a labyrinth of service connections laid in below ground in layers that reach 50 feet under the surface. These include safety related systems, CW tunnels & electrical lines. The cooling water tunnels are substantial ~12' X 12' and are underneath a nest of conduit and safety systems in front of the unit two turbine building. Connections to these would need to be made to provide service to the new proposed bank of cooling towers. This work would have the potential to damage safety related systems.

A sense of the complexity of the existing lines in this area is given in Figure 6. No less than 46 discrete electrical and plumbing systems converge here. The lines in this relatively small area in front of the turbine are so dense that one could only be able to follow the tangle of interwoven systems with an oversized 30"x40" drawing. Any construction here would be painstakingly difficult, to say the least. Carefully avoiding and selectively removing parts of the existing infrastructure is a far more difficult and expensive task than building everything new.

In addition, excavating this area would significantly impede access to the turbine building, and would raise issues of safety both in terms of plant access and operation. The operation of both units one and two would be severely impacted by any such construction. For the aforementioned reasons, it is unlikely safe operation would be allowed to continue during the excavation and construction efforts.

CHECKING ON SECURITY ISSUES BEFORE PROVIDING
FIGURE 6

FIGURE 6 - Plan View of Tie- in Underground Construction Conditions in Front of Turbine Building

The majority of heat exchangers from the service cooling water system (SCWS), component cooling water system (CCWS) and auxiliary saltwater system, or safety system, (ASWS) have been identified as requiring some major modifications or replacement if the alternative closed-cycle system were implemented. These exchangers include hydrogen coolers, and numerous closed-cycle component exchangers. This is mainly due the substantial increase in supply temperatures well above their design basis. Either Tetra Tech's relatively low supply temperature of 70°F, or a more realistic temperature of ~81°F as shown in Table 1, would force many of these heat exchangers outside of their performance and design limits. A thorough, detailed evaluation of each heat exchanger and its effect on component/system performance would be required to identify the many modifications or replacements necessitated by the proposed cooling tower retrofit.

The conversion to a closed-system would also require a new facility to treat the highly concentrated and chemically charged blowdown. The closed-system saltwater cooling towers would use a number of chemicals to prevent build-up of biological or scale formation in the relatively warm circulating seawater. Any build-up or scale on the fill would reduce fill performance. In an effort to keep the cycles-of-concentration ratio at 1.5 or below, the plant would continually blowdown or discharge a large volume of circulating water ~48,000GPM. This discharge would need to be treated before being released back into the Pacific. Hence, there is a requirement for a new water treatment facility. No costs or construction schedule for this new multi-million dollar facility is included in the Tetra Tech report.

3. Condenser Modifications

Another significant condenser retrofit project that will take a minimum outage of 3 months was not directly mentioned in the Tetra Tech report. The main project stems from the requirement of using thinner-wall 25 BWG titanium tubing to partially offset the thermal efficiency losses of conversion to a closed-cycle system.

As will be discussed later, the Tetra Tech backpressure estimate at design is flawed due to, among other things, use of an unusually optimistic low cooling water approach temperature and lack of sufficient compensation for recirculation and interference effects. These create a misconception that the design inlet temperature to the condenser will be in the vicinity of 70 °F, as reported by Tetra Tech. Actually, the Tetra Tech conceptual design basis should be at an inlet circulating water temperature of ~81°F. The result of this large miscalculation by Tetra Tech is to increase the turbine backpressure by ~.8 inHg from the data shown in the USFAR (1.71 inHgA) [13] and by ~1.0 inHg from the actual design. The Tetra Tech CW inlet temperature with its correspondingly lower estimate of backpressure minimizes generation losses. Also, it appears that Tetra Tech overestimated generational losses at the 1.89 inHgA backpressure from the Westinghouse exhaust pressure correction curves [11].

Table 1 below shows the skewed energy penalty result one obtains by minimizing the CW inlet temperature data compared to an accurate site-specific representation of the performance of the closed-system. The performance variation in total generator output between the proposed conceptual closed-system and the existing once-through design is a reduction of 55.9 MWe. These estimates are only valid at the full load design point.

Applying the same economic factors listed in the Tetra Tech report to the 55.9 MWe, we determine an annual performance penalty or reduction in revenue to be ~ $11,625,000 in addition to the figure of $13,000,000 presented by Tetra Tech. Therefore, a realistic annual energy penalty associated with performance losses for conversion to the proposed wet mechanical draft system with retrofitted modular condenser to be $24,625,000.

However, as noted above, an important practical aspect of the proposed condenser retubing has been neglected in the Tetra Tech estimate. Since the replacement tube-tubesheet joints would need to be welded for this conceptual pressurized, highly concentrated seawater application, the conventional method of field retubing on-site could not be employed. Instead, modular factory fabricated tube bundles would need to be installed.

A typical modular retubing involves removal of the existing tube bundles, tubesheets, support plates, & any other lines or interferences inside the shell. An entire tube bundle including tubesheets, support plates & supports is factory fabricated to be a self-supporting structure that is then shipped via truck or rail to the site. Shipping bracing of these bundles is then cutoff as they are inserted directly into the shell, aligned & installed. All connections must then be reattached.

TABLE 1. – ENERGY PENALTY ESTIMATES OF PERFORMANCE - DCPP UNITS 1 & 2

Parameter	Conceptual Closed - System Modular Condenser (Tetra Tech*[1])	DCPP Site-Specific Conceptual Closed-System Modular Condenser (BES)	Difference between Burns Engineering Services Versus Tetra Tech estimates	Difference between Existing Once-Through Design and Conceptual Closed-System (BES)
Cooling Tower Approach Temperature	9 °F	16 °F	7 °F	Not Applicable
Interference & Recirculation Temperature	0 °F	4 °F	4 °F	Not Applicable
Approach plus Interference & Recirculation	9 °F	20 °F	11 °F	Not Applicable
Condenser Inlet Water Temperature	70 °F	81 °F	11 °F	24.5 °F
Backpressure	1.89 inHgA	2.55 inHgA	.66 inHg	1.05 inHgA
Generation Losses*[2]	**15.2 MWe**	**55.9 MWe**	**40.7 MWe**[*3]	**55.9 MWe**

*[1] - *Data provided from Tetra Tech report – November 2002 save the value of 15.2 MWe. Tetra Tech provided 21 MWe based on 1.89 inHgA backpressure. BES estimates 15.2 inHgA at the same point.*

*[2] - *Based on Westinghouse Electric LP Turbine Exhaust Pressure Correction Factors[11] for Units 1 & 2.*

*[3] - *Based on the correct value from column 1 instead of Tetra Tech overestimate at 1.89 in hga of 21 MW.*

Tetra Tech fails to mention that both Unit 1 & 2 condensers are not easily accessible. Both condensers sit on the lower floor of the turbine building. A large hole in the turbine building will need to be "cut open" to allow access for the new ¾" outside diameter tube bundles. Based on the tubing parameters and surface area of 617,536 square feet provided by Tetra Tech, it is estimated there will be ~77, 600 tubes per unit.

Each condenser would most likely be comprised of a quantity of 8 modular bundles, each bundle having ~ 9,700 tubes. Special hoist & rigging would be necessary to convey the large tube bundles through the opening in the turbine building walls. The most probable access route would be to first bring a modular bundle to the turbine mezzanine. For both Unit 1 & 2, all interferences would be required to be cut out down to the basement floor and also a path cleared to access the front of the discharge waterboxes. The welded inlet waterboxes would be cut off from the shell and stored out of the way. Similarly, the area in between the NE & SE bundles and the NW & SW bundles for each unit would need to be cleared of all interferences.

For each unit, the inside bundles (qty. 8) would then be lowered one-by-one and pushed on rails through the outer bundles and inserted into the inside bundles. The outside bundles (qty. 8) would then be lowered from the turbine mezzanine and inserted into the discharge end of the waterboxes. The condenser waterboxes, circulating water CW lines and their connections would all have to be removed and stored out of the way. Another smaller project of the retrofit which was overlooked would require modification of the existing waterboxes to support the higher CW pressures of the closed-cycle system.

Burns Engineering Services believes that the construction and retrofit activity for replacing the existing condensers would pose a safety hazard and therefore not allow operation of either unit while another was being worked on. None of these items drew mention in the Tetra Tech report. The modular rebundling by itself for both condensers would take a minimum of 3 months on an aggressive, fast track schedule. This retrofit activity will add substantially to the costs & scheduling requirements of the proposed alternative.

4. Cooling Tower Performance

Wet cooling towers function because of the evaporative effect that occurs between the warm water of the condenser when it comes into direct contact with the cooler air flowing through the tower. The physics of the process is governed by the inherent ability of the air to absorb moisture and that is determined by the local wet bulb temperature. The higher the wet bulb temperature, the closer the temperature of the cooled water can "approach" that wet bulb and the lower the wet bulb temperature, the larger the "approach" of the cooled water to the wet bulb temperature. Hence, wet cooling towers can perform without freezing in below zero climates because their approach is perhaps 50 °F to the low associated wet bulb. Conversely, at high wet bulb temperatures where cooling towers are traditionally specified by architect-engineers for large cooling projects, an approach of about 8°F is considered practical.

At DCPP the highest wet bulb temperature is ~61°F and so a potentially achievable commercial approach for a large utility cooling tower is well above the 9°F suggested. Based on Cooling Technology Institute data [2], it was estimated that the approach at DCPP would be about 16°F at the design point and not the 9°F that Tetra Tech used in its evaluations. That additional 7 °F approach temperature with recirculation and interference (discussed below) effects directly increases the turbine exhaust pressure(s) by ~1.0 inHgA and correspondingly reduces the station generation to a much larger 55.9 MW. This is almost 3 times the value Tetra Tech estimated.

Recirculation occurs when the warm exhaust air gets drawn back into the tower inlets effectively raising the inlet wet bulb temperature of the air above the ambient condition and negatively impacting tower performance. Undoubtedly, the recirculation and interference effects would be substantial at this densely packed site of 132 cells. The back-back tower arrangement, spacing, tower orientation relative to wind, tower length and wind speed would make this tower susceptible to a large amount of recirculation. An educated estimate of the tower recirculation on the proposed Tetra Tech design would likely be at a minimum of 4–5 degrees. Burns Engineering used a conservative estimate of a total of 4 °F for the recirculation and interference effects. Again, Tetra Tech failed to include or compensate for the enormity of this critical effect on increases to the cooling water approach temperature or even mention its occurrence in their report. The effect of this 4 °F recirculation is an energy penalty of 17.5 MW. Using Tetra Tech's assumptions of 350 day operation and power at a cost of $34/MW hour, recirculation will cost DCPP $5 million in lost revenue per year.

Finally, another important design aspect that Tetra Tech did not mention was the large amount of noise emitted from a cooling tower complex of its 132 cells, each with a 250 hp fan. The noise emitted from those fans would be appreciable and would be required to be substantially attenuated. A typical 10 cell utility cooling tower would produce 66 dBa at a distance of 400 ft. from the tower. Propagating the noise from this simple model for132 similar cells at DCPP to the greater distances of the site Training Building or the Administration building, suggests that the continual, outdoor noise level will be in the vicinity of 74 dBa, a level that would be unacceptably high. The use of low noise fans and other attenuation air-side features on this site would likely be a requirement. An attenuation device would also probably be required to reduce the noise from the huge volume of cascading tower water, 1,725,000 gallons per minute. To provide the requisite noise reduction, it could also be necessary to increase the tower size or fan power to compensate for the greater resultant air pressure drops. No mention of these important noise design issues were brought forward in the Tetra Tech report.

5. Operating & Maintenance

Tetra Tech indicates their Operating & Maintenance (O&M) estimate is 750$/MW and whether applicable to freshwater or saltwater installations was not defined. The value they obtained was from a respected, large cooling tower manufacturer but not a cooling tower owner who must actually bear the annual costs. That supplier would not appreciate the 24/7 costs of the extra personnel needed for frequent inspections, upkeep, lighting, instrument, control, electrical and mechanical repairs, replacements, maintenance of the water treating systems, chemical requirements, blowdown, and makeup systems. It could for example be modestly expected that an extra staff of 10-15 people would be required with a range of craft skills from chemists to engineers to welders, instrument technicians, electricians, painters, etc. Estimating current salaries, benefits, office & manual space requirements and the supplies they would need indicates a much higher value at DCPP than the $750/MW cost listed by Tetra Tech.

Because the makeup consisting of 35,000 PPM TDS (total dissolved solids) salt water is concentrated by the cooling tower evaporation effect to be about 1.5 times that value, the water treatment is more demanding than a freshwater cooling system. In addition, the discharge water chemistry and temperature, including intermittent chlorine, would be required to be within EPA and State mandated guidelines. Water treatment would require a separate, dedicated facility. The concentrated salt drift would mandate a major increase in outdoor maintenance at the plant. All vehicles parked on-site, including those of the plant and employees alike, will be blanketed with salt and subject to its corrosive effects. They will deteriorate faster and require more extensive washing and maintenance. Air moving equipment will require continual maintenance. Because of the immense size and added complexity of the closed-cycle cooling system at DCPP, the cost of supplies, testing, sampling and replacement equipment alone could be significant.

Other cost indicators of the maintenance, based for example on using 1% of the capital cost of the cooling system annually, suggest the Tetra Tech maintenance cost estimate is low by a factor of 6 times the $1,700,000 estimate proposed by Tetra Tech for both units.

6. Energy Penalty

The energy penalty is the loss in electrical generating capacity incurred because the retrofitted cooling system is unable to perform at its previous once-through levels. It is manifested by a comparative increase in the turbine backpressure. The seasonal temperatures of the water of the Pacific Ocean would control the performance of the existing once-through system. However, the performance of the proposed retrofitted mechanical draft cooling system is linked to the local wet bulb temperature, the tower approach, the recirculation and interference effects and the improved performance of the condenser. In aggregate, that results in a higher turbine backpressure and a loss in generation. Though in the power industry parlance, the auxiliary power to run the retrofitted cooling tower fans and pumps is considered an operating cost, to stay aligned with the Tetra Tech report method, it will be assumed as a component of the energy penalty. Furthermore, like Tetra Tech it will be assumed the retrofit CW pump power is similar to that of the existing CW pumps.

The estimated energy loss for both units at the design conditions of the retrofitted cooling towers is listed on Table 1. Calculation methods for determining the loss in turbine backpressure have been outlined in the Condenser Modification Section 3. That estimate resulted in a relative turbine backpressure increase above the existing once-through system performance of 1.0 inHg at retrofit design conditions and represents about a 33% increase more than the Tetra Tech estimate. The corresponding loss in generation for both units at DCPP would be about 56 MW, almost three times the Tetra Tech loss estimate. In any event, adding the 25MW auxiliary power required by the 132, 250 BHP fans results in a total generation loss at the design conditions of 81 MW for both units.

Since 81 MW would therefore be unavailable by the installation of the proposed retrofitted cooling system, these losses would need to be compensated by either an increased annual operation at another station or at the cost of replacement power.

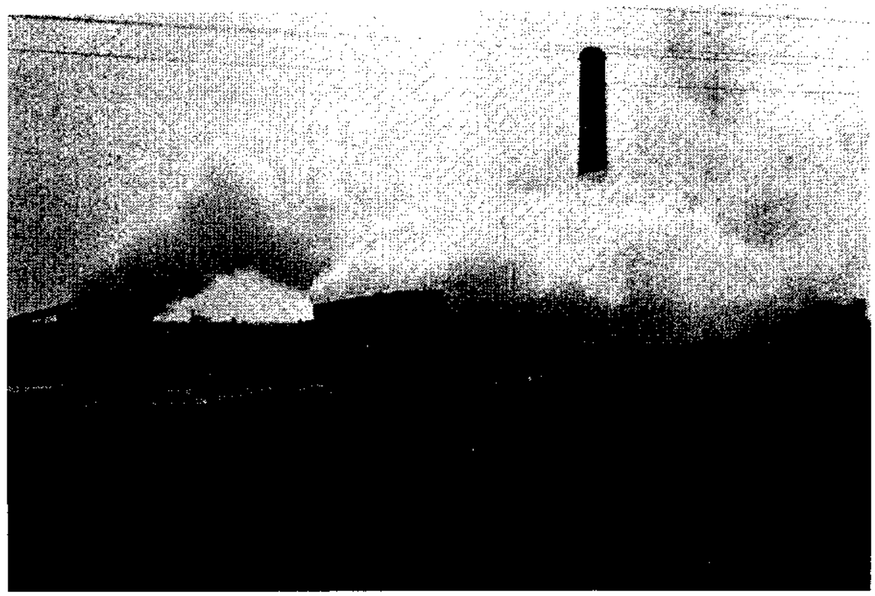

Figure 7- Plume of a Modest Wet Mechanical Draft Cooling Tower

7. Plume Incidence

The proposed Tetra Tech ~132 cell wet mechanical draft design as shown in Figure 2 of their report would produce a substantial plume during certain periods. A plume looks like a massive cloud of smoke that would rise from the tower stacks and would be more than just an aesthetic nuisance. A plume is formed when the relatively warmer saturated exhaust air mixes with cooler ambient air after leaving the stack. The frequency and intensity of a plume are related to heat load and atmospheric conditions. The measure of visible intensity or opacity of a plume is exacerbated when the ambient air temperature becomes cooler as colder air cannot hold as much moisture.

All access roads, buildings and parking lots would be blanketed by a plume during certain atmospheric conditions with the proposed Tetra Tech design – a condition aptly termed ground fogging. The lack of visibility along the access roads to the turbine building would constitute a grave danger. This condition could not be allowed by the NRC or PG&E for obvious safety and security reasons.

The potential in the Tetra Tech proposed design for the plume to envelop DCPP restricting site access and disrupting operations is immense. Low visibility on the access road to DCPP would hinder safe transport of people and materials to and from the site. Poorly designed or situated cooling towers in other places have enveloped nearby facilities, resulting in the shutdown of the plume-generating plant. The Tetra Tech report did not mention the hazardous impact of this proposed cooling tower design on plant safety and security.

Beyond the serious risks plumes could pose to safety and security, aesthetics of the plume formation could create permitting obstacles. Plume visibility is often unacceptable to communities surrounding the plants. During cold, clear days with light winds, the plume created from the monstrous bank of mechanical draft towers proposed in this retrofit would rise many thousand feet into the atmosphere and be visible from tens of miles away. Plume visibility is a highly sensitive environmental and aesthetic issue that must be dealt with during the permitting process.

A wet/dry tower would help to eliminate a visible plume. However, a wet/dry tower is not as efficient as the proposed wet tower. Hence, the wet/dry tower would require a larger footprint, and use more auxiliary power. All things equal, the wet/dry tower typically has a cost of approximately 2 times that of the more efficient wet tower. As the area needed for such an installation is so great as to be ruled out for this case, no further estimate of the wet/dry tower was made.

8. Salt Drift

Heat removal in a cooling tower is accomplished through the process of evaporation. In addition to the large amount of water absorbed into the air and expelled through this process, a corresponding amount of minerals in solution will also be carried by the fans with the exhaust and settle in areas over which the plume travels. The exhaust plume will carry with it the salt & disperse it in the form of droplets like rain in the vicinity of the tower with a composition representative of the circulating water. In the case of the proposed seawater-cooled tower, huge amounts of salt drift will be sent into the atmosphere and deposited in a pattern corresponding to that of the exhaust travel. Thus, the phenomenon is known as salt drift.

The circulating water will be concentrated seawater at no more than 1.5 cycles-of-concentration. Any structures surrounding the tower will likely be permanently coated with salt and other mineral deposits. Salt deposits will rapidly corrode any unprotected structures. The amount of salt drift will depend upon the selected tower design and the amount of evaporation that occurs.

The magnitude of the salt to be deposited by the new cooling towers proposed would be enormous. Commercially available drift eliminator design guarantees were used to estimate the drift from this proposed design. Although only ~0.002% of the concentrated salt water CW flow would become an entrained drift in the exhaust, the vast scale of this proposed retrofit project means that appreciable salt will be dispersed into the atmosphere and deposited. Assuming the plant operates on average at 90% capacity factor, the new cooling towers would spread over 6.8 million pounds of salt over the area per year.

Tera Corp. [14] has modeled likely patterns of drift for mechanical draft cooling towers sited in the general area proposed by Tetra Tech for the cooling towers. See Figure 6 on the following page. Salt will blanket an area extending beyond the plant boundary to the north and south. The center of highest salt deposition will occur approx. 1/3 mile south of the cooling towers within the plant boundary at the southeast section of parcel P. However, a substantial amount will settle over the agricultural zone as well.

As a figure for comparison, salt deposition along the ocean shoreline is only about 86 lb/acre per year [12]. Even the lowest concentration boundary of the Tera study shows a salt concentration of more than five times the natural salt deposition from the sea. Salt will disperse beyond this outer boundary in concentrations lower than that figure, but, given the massive volume of salt, it will impact the local terrestrial ecosystem in the areas surrounding the plant even beyond Parcel P.

Another overlooked engineering discussion in the Tetra Tech report is the close proximity of the 500 kva transmission lines that run from the back of the turbine building for both units up the hill to the switchyard. The probability of arcing due to salt drift depositing itself on and coating insulators of these nearby 500 kva transmission lines is very real. A recent rash of arcing has occurred at brackish and saltwater plants throughout the country. In all cases, the cause of the arcing was attributed to drift from a nearby cooling tower whose drift deposited salt on the insulator. Salt will inevitably settle upon the closely situated insulators of the 500 kva power lines resulting in forced shutdown of the facility and higher maintenance costs.

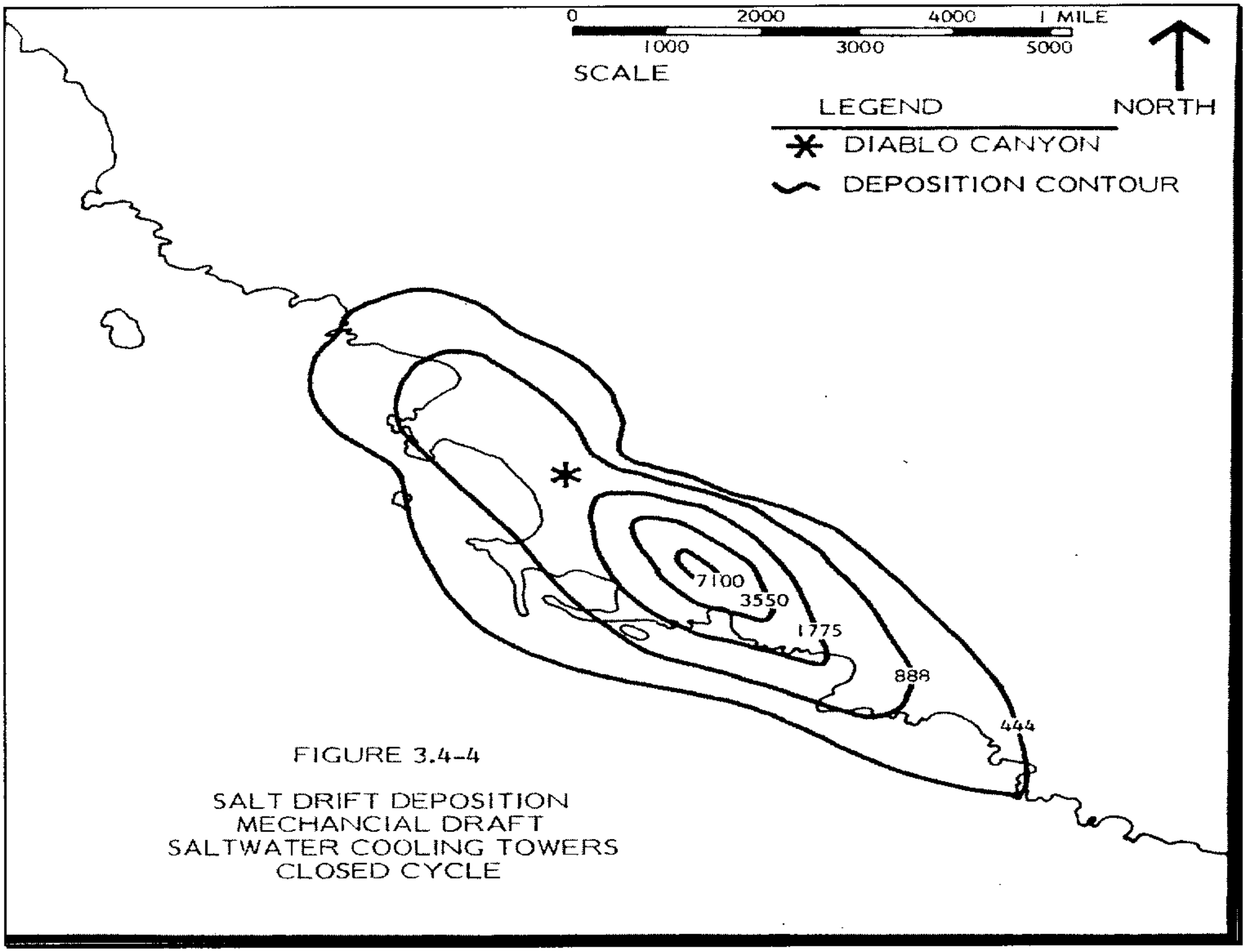

FIGURE 8- Salt Drift Patterns from Tera Corporation Report, lb/acre-yr (In contrast, typical ambient salt deposition from ocean ~86 lb/acre-year)

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