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NOISE FROM COOLING TOWERS OF POWER PARKS

by

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TABLE OF CONTENTS

1. INTRODUCTION

This report deals with the noise pollution problem from large power parks proposed for the future. Such parks might have an area of about 75 sq. miles, and a generating capacity up to 48000 MW.

A comparative analysis has been done for two types of cooling systems, namely,natural and mechanical-draft wet towers, as the major sources of acoustic power. Noise radiation from single isolated towers as well as from a dispersed array of towers has been considered for both types of cooling systems. The theoretically predicted results for natural and mechanical-draft towers are discussed in Sections 2.3 and 3.3.

The terms sound pressure level (SPL), sound level or noise level have been used interchangeably. Particular emphasis has been placed on the A-weighted sound levels which are well correlated to the response of the human ear.

Major noise attenuation effects considered in the analysis are due to the atmospheric absorption and A-weighting. Ground attenuation has been neglected and conditions of 60F and 70% relative humidity in a still atmosphere have been assumed.

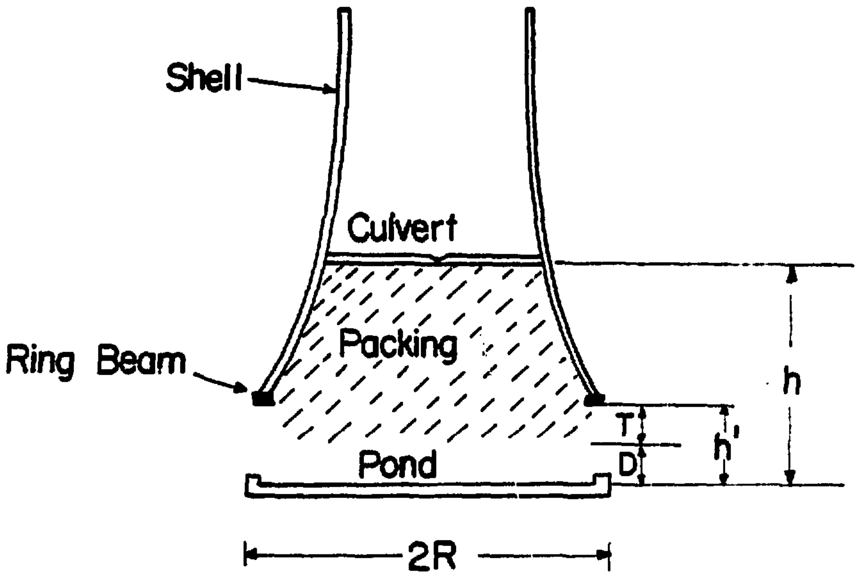
2. POINT SOURCE PROBLEM

In order to analyze the problem of noise radiation from an area source, essentially a power park in our case, the behavior of sound pressure level (SPL) with increasing distance from a point source has to be studied first. The analytical procedure adopted for the prediction of noise levels has been presented in the following pages. Mechanical and natural-draft tower noise has been dealt separately although, in principal, the prediction technique is the same for both the cases.

2.1 NATURAL-DRAFT WET TOWER NOISE ESTIMATION

The first step consists of the determination of cooling tower parameters such as dimensions, water flow rate, etc. Ref. [1] suggests two natural-draft wet cooling towers for a 1200 MW power plant. For the present analysis a 600 MW unit is considered for which, also according to Ref. [1], one tower of base diameter 400 ft will be sufficient. The overall dimensions for a cross-flow tower, inferred from Ref. [2], for a base diameter of 400 ft are presented in Figure 1. The cooling water flow rate in this tower from Ref. [1] will be 620 cfs or 17564 Kg/s.

At this point a brief review of the theoretical background for the estimation of noise levels might be helpful. The average intensity of sound, I, defined as the energy that flows through a unit area in a unit time, in the direction of the sound wave propagation, is the time average of the product of the sound pressure and the particle velocity measured in the direction of the wave propagation.



Cooling water flow rate = 17,564 Kg/s = 620 cfs

h = 60 ft = 18.32 m

T = 37 ft = 11.3 m

D = 14 ft = 4.3 m

R = 200 ft = 61 m

Figure 1: Natural-Draft Wet Tower For A 600 MW Power Plant

Thus $I = \overline{P \times u}$ (1a)

where P = sound pressure in N/m^2

u = particle velocity in m/s associated with the to and fro motions of the air molecules, which always occur along a line parallel to the direction of propagation.

The product $\overline{P \times u}$ can be shown to be equal to $\frac{P_{rms}^2}{\rho C}$

or $I = \frac{P_{rms}^2}{\rho C}$ (1b)

where Prms = root mean square sound pressure

ρ = density of air

c = sound speed in air

Sound pressure level at some point at a distance S from the source is given, by definition, by the following equation:

$$SPL_S = 10 \log_{10} \left\{ \frac{P_{rms}^2 \text{ at } S}{(2 \cdot 10^{-5})^2} \right\} \text{ DB re } 2 \cdot 10^{-5} \text{ N/m}^2 \quad (2)$$

In order to find the sound energy intensity at some distance S from the rim of a natural-draft wet cooling tower, R.M. Ellis, in Ref. [3], has developed the following technique:

$$P_A^2 = \frac{W_{ac} Z_o}{\pi^2 (S^2 + 2SR)} \tan^{-1} \sqrt{\frac{S + 2R}{S}} \quad (N/m^2)^2 \quad (3)$$

where P_A = A-weighted root mean square sound pressure at S m. from the rim of the tower.

Zo = ρC = atmospheric impedance

= 407 N-sec/m^3 for the atmospheric conditions assumed.

R = base radius of tower in m.

Wac = acoustic power generated by the source in Watts.

Wac can be evaluated by

$$W_{ac} = Mh\left\{.95\cdot10^{-5}\left(\frac{T}{h}\right)^2 + 1.8\cdot10^{-5}\left(\frac{D}{h}\right)^2\right\} \quad (4)$$

where M is the flow rate of cooling water in Kg/s,

and T,h,D are physical dimensions of tower (see Figure 1)

For our tower for a 600 MW power station, from eq. (4) we get

Wac = 1.474 Watts

This implies an efficiency of water pumping power for conversion into sound power of

$$\eta = \frac{1.474}{17{,}564 \times 18.32 \times 9.8} = .47\cdot10^{-6}$$

This value of η is quite reasonable. In fact measured conversion efficiencies stated by R. M. Ellis, Ref. [3], range from 0.37 to 0.81 PPM, for natural-draft wet cooling towers. The A-weighted sound pressure level can now be found by using the value of Wac from eq. (4) in eq. (3), and then substituting P_A from eq. (3) for Prms in eq. (2):

$$SPL_s = 10\log_{10}\left[\frac{P_A^2}{(2\cdot10^{-5})^2}\right] \text{ DBA re } 2\cdot10^{-5}\ N/m^2 \quad (5)$$

The noise spectrum is considered next. It is quite reasonable to assume that the overall shape of the spectrum is nearly the same for different towers and for various distances from the tower source. Table I, from Ref. [3], is used in our analysis.

TABLE I

NATURAL-DRAFT WET COOLING TOWER NOISE SPECTRUM

	Average octave band levels relative to A-weighted SPL in DB re $2\cdot10^{-5}N/m^2$						
Center frequency (KHz)	.125	.25	.5	1	2	4	8
Level at tower rim (DB)	-19.4	-19.8	-13.0	-7.8	-6.3	-4.3	-7.2

As an example, consider a point 100 ft (30.5 m.) from the rim of the tower. With S = 30.5, eq. (3) gives

$$P_A^2 = .01498\ (N/m^2)^2$$

or $P_A = .1222\ N/m^2$

from eq. (5) we get

$$SPL_s\ (S = 30.5m) = 75.7\ DBA\ re\ 2\cdot 10^{-5} N/m^2 \qquad (6)$$

The A-weighted sound level of eq. (6) can now be broken by using Table I into sound levels in each frequency band. For example, the sound level in the frequency band of 1 KHz will be 75.7 - 7.8 = 68.9 DB. Table II presents the spectrum at S = 100 ft from tower rim.

TABLE II

NOISE SPECTRUM OF A NATURAL-DRAFT WET COOLING TOWER AT

S = 100 FT FROM TOWER RIM (WITHOUT ATMOSPHERIC ABSORPTION)

Center frequency (KHz)	.125	.25	.5	1	2	4	8
Average octave band level (DB)	66.3	65.9	62.7	68.9	69.4	71.4	68.5

The effect of atmospheric absorption is now taken into account. The data of Table III is extracted from Ref. [4] for atmospheric conditions of 60F and 70% relative humidity. Finally, the sound levels actually reaching a point 100 ft from the rim of the tower of Figure 1, can be obtained by reducing the levels of Table II by respective atmospheric absorptions presented in Table III. This operation results in Table IV.

TABLE III

ATMOSPHERIC ABSORPTION RATE

Center Frequency KHz	.05	.1	.125	.2	.25	.5	1	2	4	8
Atmospheric absorption DB/983 ft	-	-	-	.01	.014	.7	1.4	3.0	7.7	14.4

TABLE IV

A - Weighted Sound Levels With Atmospheric

Attenuation, at S = 100 ft from the rim of the natural-draft cooling tower

Center frequency KHz	.125	.25	.5	1	2	4	8	DBA re $2 \cdot 10^{-5} N/m^2$
DB from Table II	66.3	65.9	62.7	68.9	69.4	71.4	68.5	75.7
Atmospheric absorption DB	-	.0014	.0072	.143	.305	.73	1.46	
Predicted levels	66.3	65.89	62.69	68.757	69.09	70.62	67.04	73.9

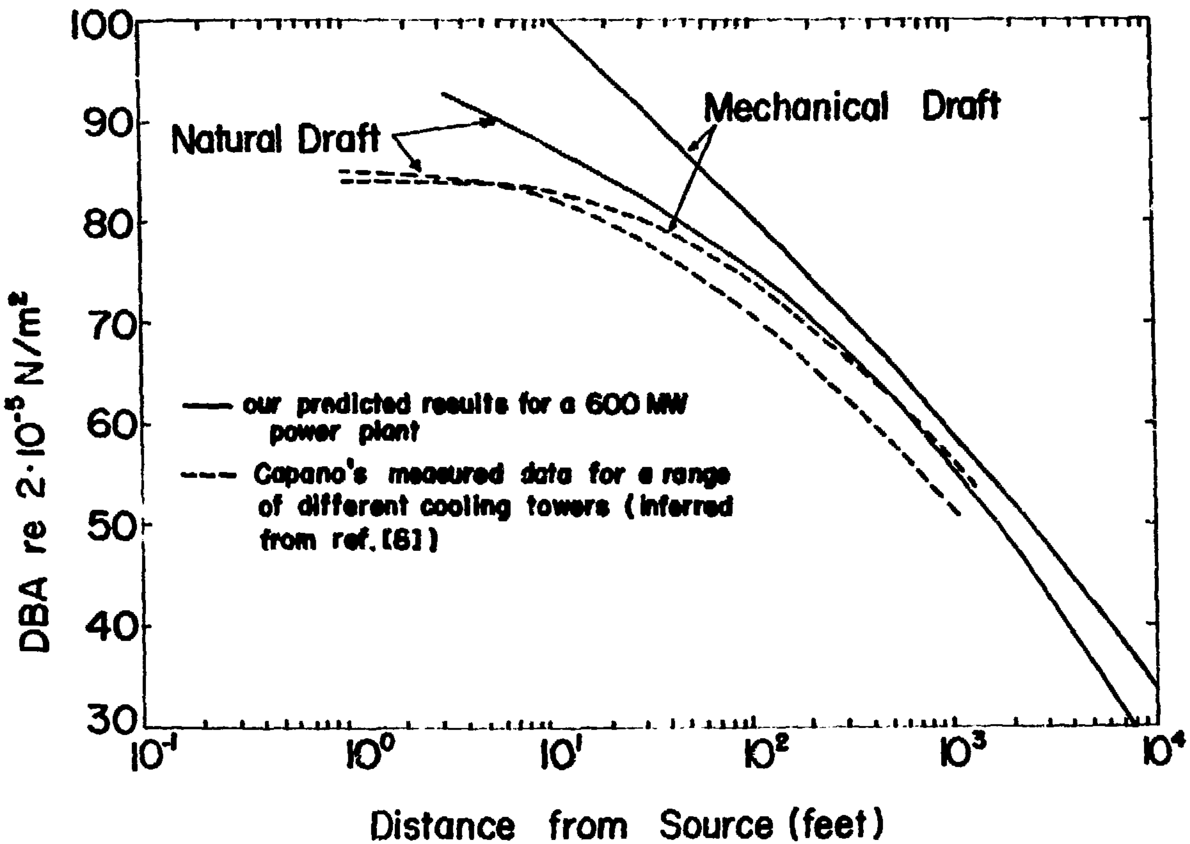


Figure 2: Behavior of Sound Pressure Levels (with A-weighting and Atmospheric Absorption) with increasing distance from single isolated cooling towers. For Mechanical-Draft Towers for a 600 MW Power Plant, rated fan power = 3625 hp; and an efficiency of conversion from rated fan power to acoustic power = 3 PPM. for Natural-Draft Tower for a 600 MW Power Plant, data used is: one wet tower; cooling water flow rate = $.23 \cdot 10^6$ gal per min; pumping head = 60 ft; tower base dia. = 400 ft; efficiency of conversion from cooling water potential energy into acoustic power = 0.47 PPM.

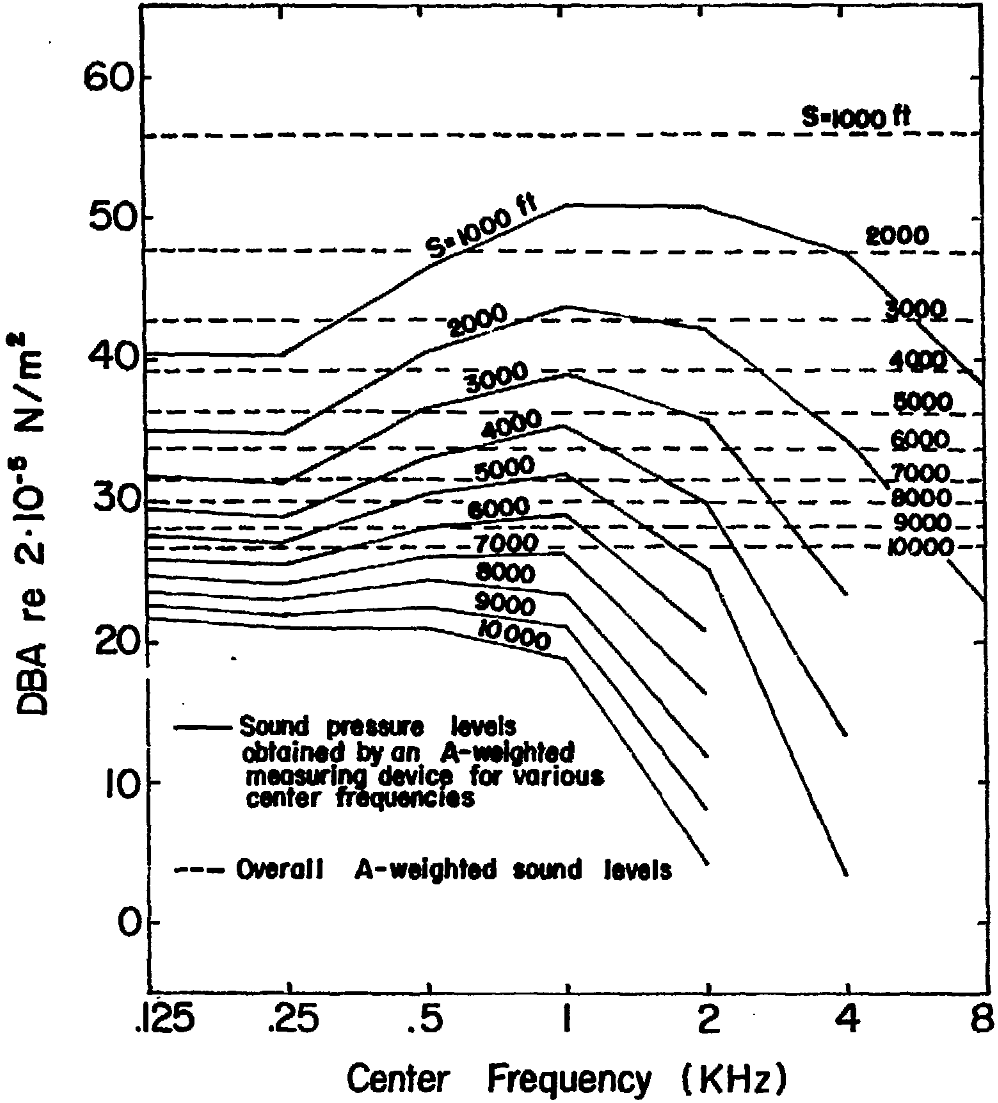


Figure 3: A-weighted noise spectra at S ft from the Natural-Draft Tower
for a 600 MW Power Plant.

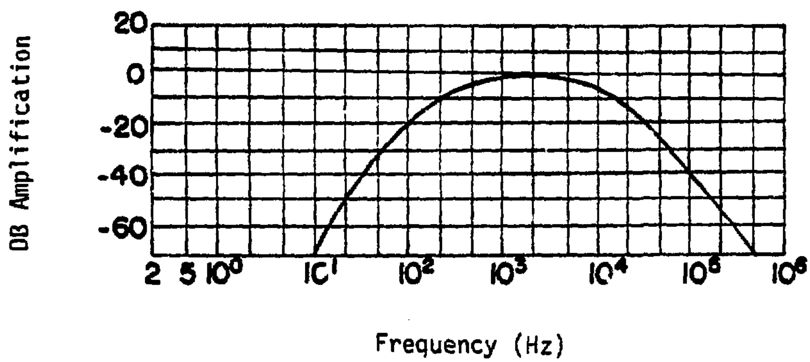


Figure 4: The internationally standardized A-weighting curve for sound level meters.

of the spectrum. This has been done by using Table V prepared from Ref. [5]. It is worth mentioning that after reducing the SPL_S by the values of Table V in a similar manner as we did for natural-draft towers, the resulting DB's for each center frequency would be relative to $2 \cdot 10^{-5}$ N/m^2. Sound levels for each frequency band obtained as such can then be reduced to A-weighted levels by using Table VI which has been prepared from Figure 4.

Atmospheric attenuation is applied next by using Table III. For example, consider the center frequency of 500 Hz. The A-weighted predicted sound level at S ft from the source, with atmospheric absorption will be

SPL (for a center frequency of 500 Hz)

$$= \underset{\text{eq. (9)}}{SPL_S} - \underset{\text{Table III}}{\frac{.7 \times S}{983}} - \underset{\text{Table V}}{11} - \underset{\text{Table VI}}{3} \qquad (10)$$

Finally, consider as an example, a 600 MW power plant for which 3625 hp* will be required to drive the fans of its mechanical-draft cooling towers. Using this number in eq. (9) and following the procedure described in this section, Table VII results for S = 1000 ft. Various stages involved in prediction of the noise levels are presented. The overall results for various S are plotted in Figure 2 along with those for natural-draft towers. Figure 5 is a presentation of mechanical-draft wet tower noise spectrum, corresponding to Figure 3 for natural-draft.

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*A fan power of 3625 hp for a 600 MW LWR power plant has been inferred from Ref. [7].

TABLE V

MECHANICAL-DRAFT WET COOLING TOWER NOISE SPECTRA

	Average octave band levels relative to overall sound level in DB re 10^{-13} Watts							
Center frequency (KHz)	.05	.1	.2	.5	1	2	4	8
Level at tower rim (DB)	-5	-6	-8	-11	-15	-17.5	-21	-27

TABLE VI

EFFECT OF A - WEIGHTING

Center frequency (KHz)	.05	.1	.2	.5	1	2	4	8
DBA re average octave band levels	-30	-20	-10	-3	-	-	-1	-3

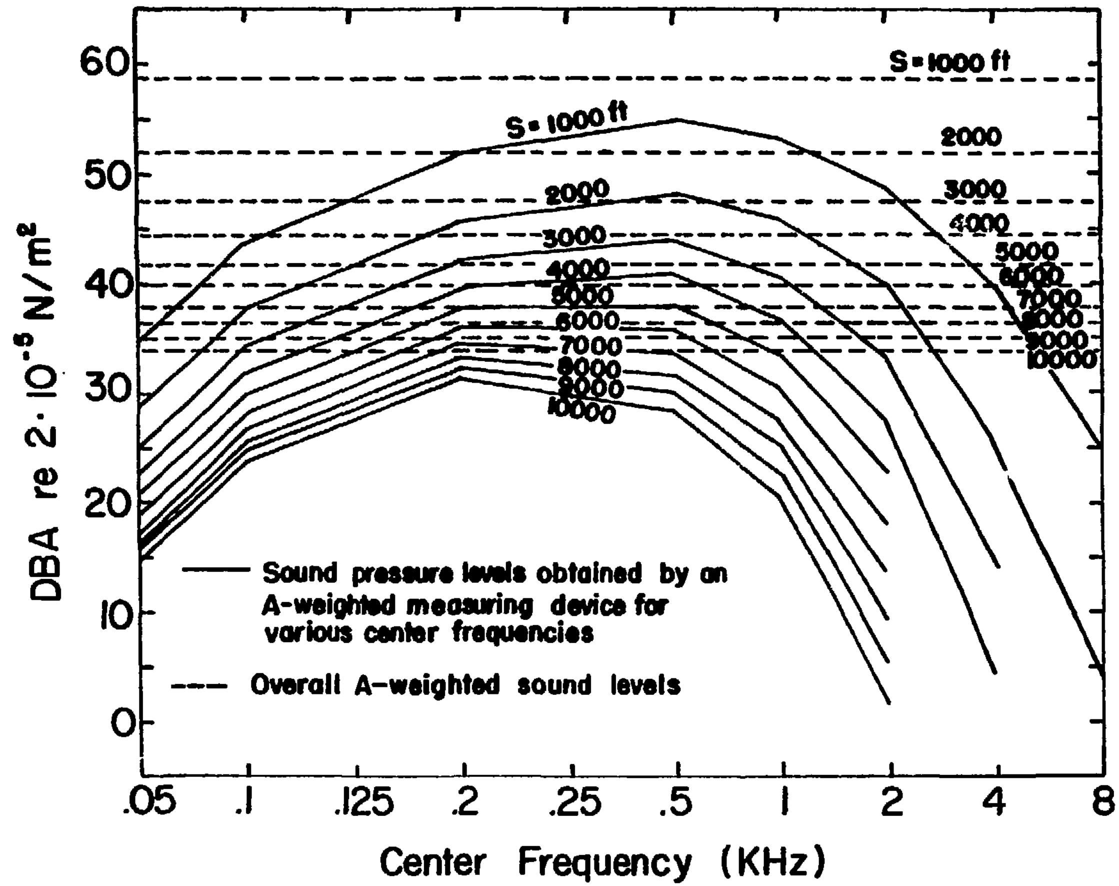

Figure 5: A-weighted noise spectra at S ft from the Mechanical-Draft Tower for a 600 MW Power Plant.

TABLE VII

PREDICTION OF A-WEIGHTED SPL WITH ATMOSPHERIC ATTENUATION FOR MECHANICAL-DRAFT WET TOWERS FOR A 600 MW LWR POWER PLANT

$S = 1000$ ft $SPL_s = 69.6$ DB re 10^{-13} Watt

Center frequency KHz	.05	.1	.2	.5	1	2	4	8	DBA re $2 \cdot 10^{-5} N/m^2$
SPL_s DBre $10^{-13}W$	69.6	69.6	69.6	69.6	69.6	69.6	69.6	69.6	
Band level re SPL_s Table V	-5	-6	-8	-11	-15	-17.5	-21	-27	
DBA reduction Table VI	-30	-20	-10	-3	-	-	-1	-3	
Atmospheric abs. Table III	-	-	-	-.7	-1.4	-3.1	-7.8	-14.6	
Predicted levels DB re $2 \cdot 10^{-5} N/m^2$	34.6	43.6	51.6	54.9	53.2	49.0	39.8	25.0	58.9

2.3 DISCUSSION

Before proceeding on to the area-source problem we should comment briefly on our predictions for single towers. In Ref. [8] Capano has presented his experimentally measured sound pressure levels at varying distances from cooling tower sources. The mean values of Capano's measured envelope of data for a range of different mechanical and natural-draft wet towers are plotted in dotted lines in Figure 2. Owing to the lack of data presented in Ref. [8] we are not in a position to interpret or generalize Capano's results. The dotted curves, however, give us some idea about what would be the overall behavior of sound pressure levels at increasing distances from the tower sources. When we compare our predicted curves (obtained as described in Sections 2.1 and 2.2 for a 600 MW power plant) with the measured (dotted) ones, we notice that for small distances from towers the overall shape of our curves is quite different from Capano's measured data. This difference becomes less significant for higher distances. Also our predicted results for natural and mechanical-draft tower noise levels show that acoustic power generation from mechanical-draft towers will be much greater.* On the other hand Capano's data plotted in Figure 2 implies that total acoustic power generated from natural and mechanical-draft towers for a certain power station will almost be the same. These discrepancies between our estimates and Capano's measurements lead us to the point where we can suggest that there is a need for further investigation of both experimental and theoretically prediction procedure for noise levels, so that improved techniques could be devised for a better comprehension of the overall problem of noise radiation from cooling towers.

* Acoustic power generated from natural-draft tower for a 600 MW power plant, from Section 2.1 will be 1.474 Watts. And from Section 2.2 for mechanical-draft towers this will be 8.1 Watts, or 5.5 times greater.

Proceeding on with discussion, as far as this report is concerned, we note from Figure 2 that noise levels of our natural-draft towers exhibit a shallower slope for distances up to 100 ft as compared to the mechanical-draft tower noise. This can be explained by considering the following two factors simultaneously.

i) atmospheric absorption

ii) sensitivity of A-weighted measuring instruments

Atmospheric absorption increases linearly with distance and is greater at higher frequencies (see Table III). The A-weighted sensitivity, Figure 4, is greatest in the range of 1 to 2 KHz. Therefore the higher frequency noise due to the splashing of water of natural-draft wet towers is sensed more efficiently by an A-weighting device. But at large distances, beyond 1000 feet, the atmospheric absorption becomes predominant, causing the noise level to fall more rapidly. In the case of mechanical-draft tower noise, the A-weighting has less effect owing to the presence of lower frequencies. The almost uniform slope is thus due to the spherical attenuation of acoustic energy intensity.

The environmental impact of noise radiation from single towers can be studied by first devising, according to Ref. [9], a Community Noise Equivalent Level (CNEL). In our case, since the noise will be continuous (24 hrs. a day), the CNEL correction to the predicted data will be zero. The same reference gives permissible levels for the following categories:

		DBA
A ————	ultra critical areas (24 hrs)	38
B ————	suburban residential (24 hrs)	43
C ————	urban residential (24 hrs)	48

Noise levels which do not exceed 45 DBA more than 30 min. per 24 hours, have been classified in Ref. [10] as acceptable. With this information available, we observe from Figure 2, that for single isolated towers* for a 600 MW power plant, a level of 45 DBA is reached at a distance of 2500 ft from natural-draft and at a distance of 3800 ft from mechanical-draft towers. These are therefore the safe distances from sources at which noise levels will not create any problem. It also appears that natural-draft systems will be much quieter.

3. POWER PARK

The noise problem from a power park as a whole is analyzed by considering it to be an area of distributed acoustic power sources. This is done by averaging the total acoustic power over the whole area and then dividing the area into smaller elements. Each element, or strip, can be thought of as a separate noise-generation source. And then by adopting the same technique as for the point source, we can find the total sound intensity reaching at some point of interest by integrating, at that point, the intensities from each area element over the entire area of the power park.

It has been suggested that the 48000 MW generating stations should be enclosed in an area of 75 sq. miles. We assume for simplicity that this site is circular, of radius C. We then consider that power stations are uniformly distributed over a smaller concentric circular area of radius r. Figure 6(a) presents the overall configuration, with shaded area representing the power park, acting as a uniform source of acoustic power. We are interested in finding the total sound pressure level at the point O located on the site boundary. The shaded area, shown in Figure 6(b), drawn along an arc of radius S, is a presentation of an area element mentioned above. All the sources in this area element will thus be approximately equidistant from O, and may as well be considered as a single acoustic generation source of strength:

$$W_{hc} = 2S\theta \; dS\left(\frac{W_t}{\pi r^2}\right) \quad (11)$$

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* See Figures 1 and 2 for relevant physical parameters of towers.

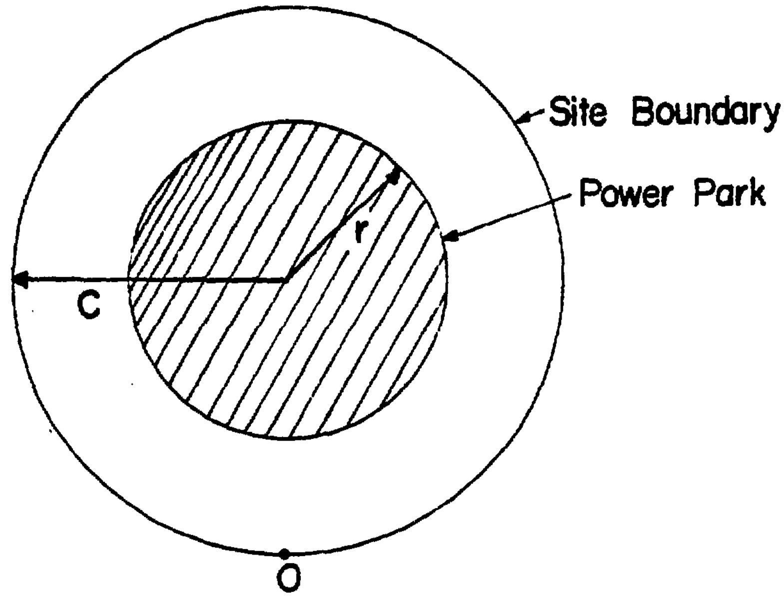

Figure 6(a): Overall configuration of the site containing 48000 MW of power generation.

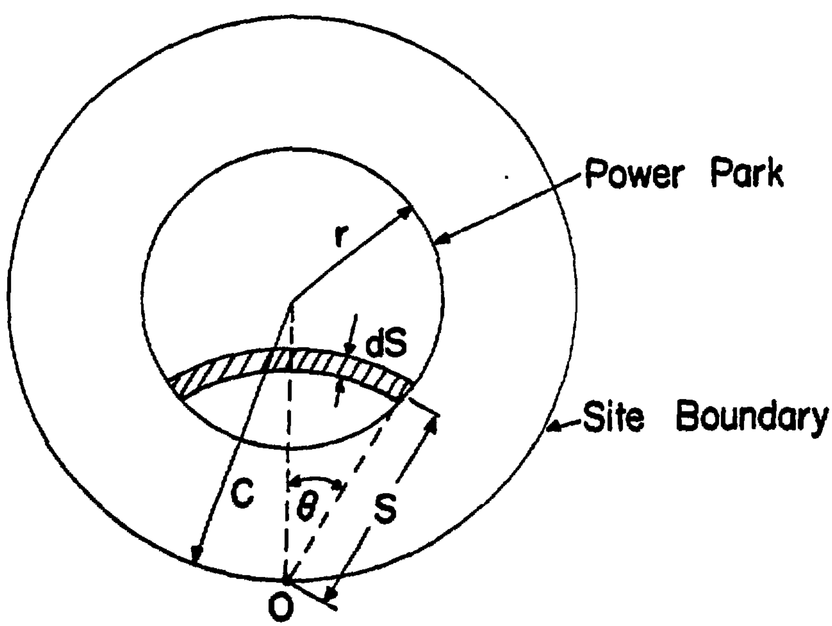

Figure 6(b): Geometrical configuration of site for the purpose of Problem Analysis.

Where Wt is the total acoustic power radiation from the power park of area πr^2. The radius of the 75 sq. mile power-park site is

$$C = 25{,}800 \text{ ft}$$

and, for purposes of later integration, we record the geometrical relation

$$\theta = \tan^{-1} \frac{\sqrt{4C^2S^2-(S^2-r^2+C^2)^2}}{S^2-r^2+C^2} \tag{12}$$

3.1 NATURAL-DRAFT WET TOWERS

The acoustic power generated for a 600 MW plant considering one wet tower of Figure 1, was found in Section 2.1 to be 1.474 Watts. For 48000 MW, it would be 80 times as great, or Wt = 117.92 Watts. Now using the inverse square law for intensity, at a distance S from any source for a hemispherical propagation, we have

$$I = \frac{W_{ac}}{2\pi S^2} \tag{13}$$

from eqs. (1b) and (13) we get

$$P_{rms}^2 = \frac{W_{ac}\, Z_o}{2\pi\, S^2} \tag{14}$$

where Zo, as stated earlier, is the atmospheric impedance. For any area element of Figure 6(b), eqs. (11) and (14) give

$$P_{rms}^2 = \frac{117.92\ Z_o\, \theta\, dS}{\pi^2\ r^2\ S} \tag{15}$$

where θ is given by eq. (12).

The SPL at a distance S from any element area source is then found by using eq. (15) in eq. (2) :

$$SPL_S = 10 \log_{10}\left[\frac{117.92\ Z_o\, \theta\, dS}{\pi^2 r^2 S\,(2\cdot 10^{-5})^2}\right] \text{DB re } 2\cdot 10^{-5}\ N/m^2 \tag{16}$$

Eq. (16) is analogous to eq. (5) except that in eq. (5) we directly got the A-weighted level, but in eq. (16) we have yet to allow for the A-weighting. Following the steps of Section 2.1, for a center frequency of, for example, 8000 Hz, we get from eq. (16) and Tables I, III and VI, A-weighted SPL, with atmospheric attenuation:

$$SPL_S = 10\log_{10}\left[\frac{117.92\ \theta\ dS\ Z_o}{\pi^2 r^2 S\,(2\cdot 10^{-5})^2}\right] - 7.2 - \frac{S \times 14.4}{983} - 3 \quad \text{DBA re } 2\cdot 10^{-5}\ N/m^2 \qquad (17a)$$

writing eq. (17a) in a different form

$$SPL_S\ (\text{for } 8\,KHz) = 10\log_{10}\left[\frac{117.92\ Z_o\ \theta\ dS}{\pi^2 r^2 S\left(10^{\frac{14.4S}{9830}+1.02}\right)(2\cdot 10^{-5})^2}\right] \qquad (17b)$$

From eqs. (5) and (17b), the intensity of sound for a center frequency of 8 KHz reaching point O, at a distance S from the area strip of Figure 6(b), will be

$$I = \frac{P_A^2}{Z_o} = \frac{117.92\ \theta\ dS}{\pi^2 r^2 S\ 10^{\frac{14.4S}{9830}+1.02}} \quad \text{Watts} \qquad (18)$$

where P_A is the A-weighted root mean square sound pressure in N/m^2. Thus for any r, and C being constant (= 25800 ft), eq. (18) can be integrated over the area πr^2 to give total sound intensity at the point O for 8KHz.

$$\text{total } \frac{P_A^2}{Z_o} \text{ for } 8KHz = \frac{117.92}{\pi^2 r^2}\int_{C-r}^{C+r} \frac{10^{-\left(\frac{14.4S}{9830}+1.02\right)}}{S}\,\theta\ dS \qquad (19)$$

In this way intensities for all center frequencies in the spectrum can be found and the total sound level can then be computed by summing all such sound intensities as given by eq. (19):

Total $\frac{P_A^2}{Zo}$ for the whole spectrum =

$$\frac{117.92}{\pi^2 r^2}\int_{C-r}^{C+r}\Bigg\{10^{-3.74} + 10^{-\left(\frac{.01S}{9830}+2.68\right)} + 10^{-\left(\frac{.7S}{9830}+1.6\right)}$$

$$+ 10^{-\left(\frac{1.4S}{9830}+.78\right)} + 10^{-\left(\frac{3S}{9830}+.63\right)} + 10^{-\left(\frac{7.7S}{9830}+.53\right)}$$

$$+ 10^{-\left(\frac{14.4S}{9830}+1.02\right)}\Bigg\}\left(\frac{\theta}{S}\right) dS \qquad (20)$$

Net DBA's reaching at the point 0 are then calculated by using eqs. (5) and (20):

$$SPL_s = 10 \log_{10}\left[\frac{P_A^2 \text{ from eq. (20)}}{(2\cdot 10^{-5})^2}\right] \text{DBA re } 2\cdot 10^{-5}\ N/m^2$$

The integral of eq. (20) was evaluated by the help of the computer by taking dS = 90 ft. The results are plotted in Figure 7 for r ranging from 3000 ft to 21000 ft.

3.2 MECHANICAL-DRAFT TOWERS

Using a 3PPM efficiency of rated fan power for conversion into acoustic power (see Section 2.2), the total acoustic power generation from the area of power park will be 80 times of that from a 600 MW power plant. The acoustic power of any elemental area of Figure 6(b) is then found from

$$W_{ac} = \frac{3625 \times 80 \times 3\cdot 10^{-6} \times 746 \times 2 \times S\theta\ dS}{\pi r^2} \text{ Watts}$$

The rest of the procedure is exactly the same as presented in Section 3.1. In this case data for mechanical-draft towers, given in Section 2.2, has to be used. The results for r ranging from 3000 ft to 21000 ft, are plotted in Figure 7 along with those for natural-draft towers for comparison.

3.3 DISCUSSION

Figure 7 shows that mechanical-draft tower noise is nearly constant over the range of r considered. While natural-draft tower noise has initially a shallow slope with r, it increases more rapidly with greater r than does the mechanical-draft noise. Considering the natural-draft towers first, we notice that the noise level at the site boundary increases significantly beyond an r of about 10,000 ft or in other words, as the shortest distance from the periphery of the area source to the point 0 decreases. This happens because at large radii, small (C-r), sound energies emanating from the far side of the park are relatively ineffective. The major effect is due to the nearer area elements. But as r is decreased, (C-r) increases, the effect of dispersed sources becomes insignificant and the area source behaves more like a point source. This results in an almost constant noise level of about 28 DBA for r less than 8000 ft.

For mechanical-draft tower systems the atmospheric absorption is negligible, A-weighting rejects about 16 DB's, and is the major reason why actual sound levels are considerably lower than the unweighted, unattenuated levels (Figure 7). Impact of scattered sources, like natural-draft towers, becomes insignificant at smaller r resulting in about a constant sound level of 42 DBA.

Finally, we should indicate briefly the possible range of park radii for which sound levels at the site boundary (Figure 6(a)) would not exceed 45 DBA* For mechanical-draft tower systems this level will be reached at a park radius

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* See Section 2.3

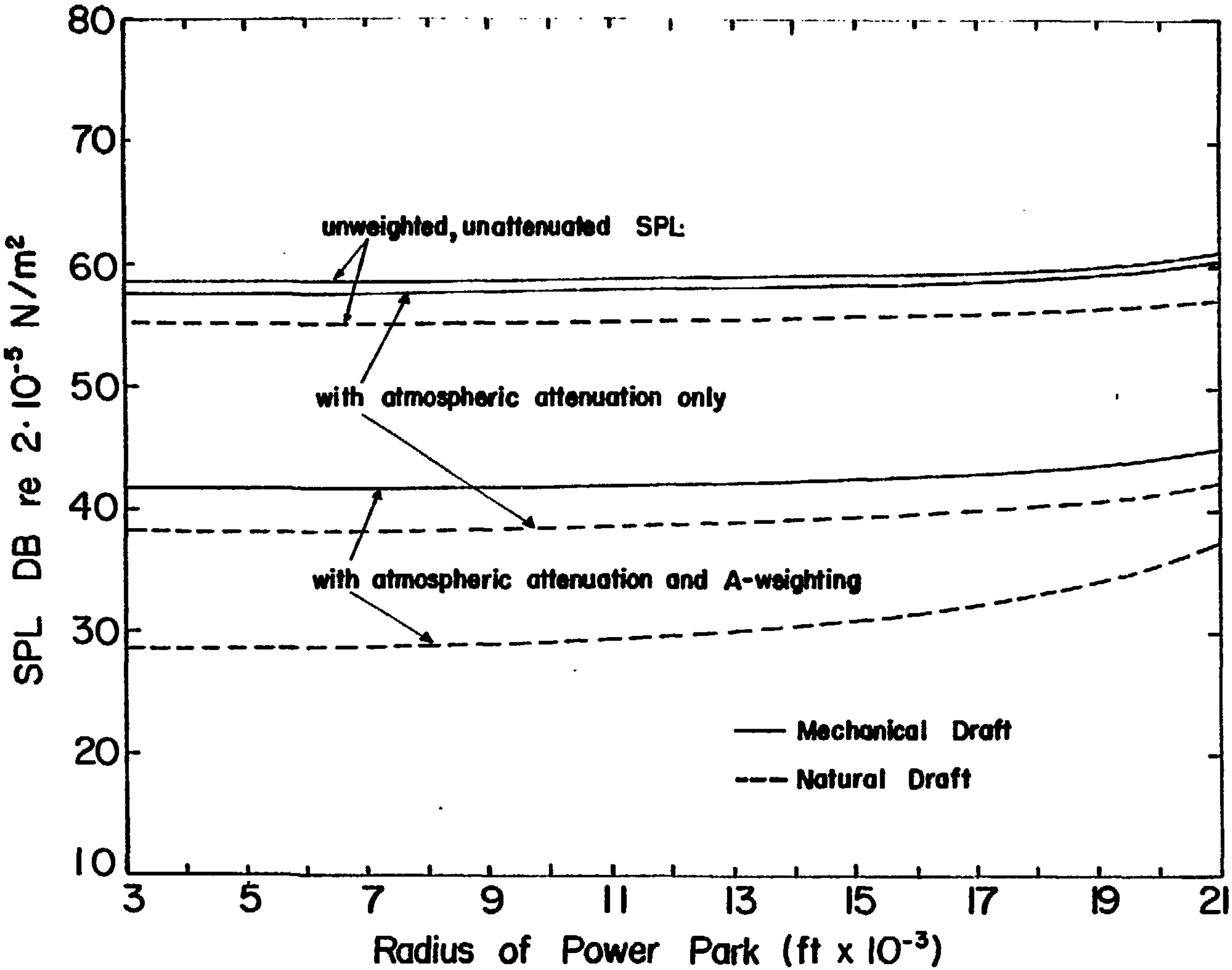

Figure 7: Variation of Sound Pressure Levels at the site boundary with Radius of Power Park.

of 21000 ft. This radius will be about 24000 ft (beyond the scale of Figure 7) for natural-draft towers.

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