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EXPERIMENTAL DESIGN FOR A CASE STUDY OF DRIFT FROM A MECHANICAL DRAFT COOLING TOWER

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EXPERIMENTAL DESIGN FOR A CASE STUDY OF DRIFT FROM A MECHANICAL DRAFT COOLING TOWER

N. S. Laulainen*

ABSTRACT

A comprehensive experimental study of drift emissions and downwind deposition from a mechanical draft cooling tower is planned for eary spring 1978. The objective of the experiment is to develop a data base which can be used for validation of drift deposition models. The key aspects of the study are to measure the characteristics of the drift emitted from the tower, the ambient meteorological conditions responsible for the transport and dispersion of the drift, and the downwind deposition and near surface air concentration patterns of the drift. The source characteristics, including air temperature and velocity profiles at the tower exit, and the transport parameters are to be used as inputs to the models, while the deposition patterns are to serve as comparisons to the outputs of the models.

Some preliminary data may be available for presentation.

Introduction

Drift from a cooling tower is defined as that component of the circulating water which is entrained in the airflow as small droplets and carried out beyond the tower. The drift droplets are produced mechanically within the tower whereas the visible plume condensate droplets are created through cooling of the saturated tower exhaust air. The differentiation between these droplet sources is important as the drift will contain concentrations of dissolved minerals and chemicals similar, if not identical, to concentrations of the circulating water. Depending upon the chemicals present in the circulating water, drift may have an adverse effect on the environment. Consequently, in order to assess environmental impact, it is important that the amount of drift and the resulting distributions in the air and on the ground be determined.

Each cooling tower can be expected to have a unique drift distribution, depending on the type and size of the units and the design of the drift eliminators. Meteorological conditions also play an important role in determining drift distribution. Thus a complex model will be required to provide cooling tower drift assessment for any particular tower under the varied modes of its operation and the range of meteorological conditions to which it will be subjected.

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A number of models have been developed to estimate drift distributions; ten of these models have been reviewed by Chen.[1] Using a common set of input parameters, Chen finds that the maximum deposition differs among the models by two orders of magnitude with a wide range in downwind location of peak deposition. He concludes that no particular model can claim superiority over another without verification from field data, especially ground mineral deposition measurements.

The most comprehensive study to date of drift from a single cooling tower has been the Chalk Point Cooling Tower Project.[2-4] In this study, measurements were made of salt water drift exiting from the natural draft tower, drift concentrations within the airborne plume and near the surface air concentration and surface drift deposition. Because of drift emissions from the stack plume, it was necessary to conduct an experiment where Rhodamine-WT dye was added as a tracer to the cooling tower circulating water in order to separate drift components from the two plumes.[5] It is anticipated that this study will provide important field data to test various drift deposition models for natural draft cooling towers.

The objective of the experimental work described here is to develop a data base which can be used for validation of drift deposition models for mechanical draft cooling towers. The key aspects of the proposed work are to measure the source characteristics of the meteorological conditions responsible for transport and dispersion of the cooling tower plume containing the drift component and to measure the downwind deposition and air concentrations of drift. The source and transport parameters serve as inputs to the models while the deposition pattern serves as a comparison to the model outputs. A comprehensive experimental effort is planned for June 1978 on mechanical draft cooling towers of the PG & E Pittsburg Power Plant at Pittsburg, CA.

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[1] N.C.J. Chen, "A Review of Cooling Tower Drift Deposition Models," ORNL/TM-5357, Oak Ridge National Laboratory, Oak Ridge, TN, June 1977, 96 pp.

[2] G.J. Woffinden, P. R. Harrison, J. A. Anderson, "Airborne Monitoring of Cooling Tower Effluents, Vol. 1, Technical Summary," EPRI-EA-420/EPA No. 803969, Meteorology Research Inc., June 1977, 43 pp.

[3] R. O. Webb, G. O. Schrecker, D. A. Guild, "Drift from the Chalk Point Natural Draft Brackish Water Cooling Tower: Source Definition, Downwind Measurements, Transport Modeling," Environmental Systems Corporation,

[4] J. H. Meyer and W. D. Stanbro, "Chalk Point Cooling Tower Project Final Report FY 1977, Vol. 2, Cooling Tower Drift Dye Tracer Experiment, June 16 and 17, 1977," JHU PPSP-CPCTP-16, John Hopkins University, Applied Physics Laboratory, Laurel, MD, August 1977.

[5] J. H. Meyer and W. D. Stanbro, "Fluorescent Dye, A Novel Technique to Trace Cooling Tower Drift," Presented at 4th Joint Conference on the Sensing of Environmental Pollutants, November 6-11, 1977, New Orleans, LA John Hopkins University, Applied Physics Lab., Laurel, MD 20810.

Measurement Program

A major deficiency in evaluating drift transport and deposition is the lack of good field data. As models have become more refined, the need for more accurate measurements of both the source and sink terms has also grown. Thus it is necessary that simultaneous measurements be made of the mineral (or other additive) concentration in the tower basin, the rates of mineral mass and drift water emission and the associated drift droplet size distribution at the tower exit, the ambient meteorological conditions to evaluate plume rise, transport and dispersion, and the spatial distribution of ground drift deposition including both mineral mass and drift droplet size distribution. In addition measurements of updraft wet-and-dry bulb air temperature and updraft air velocity profiles are necessary for predicting plume rise and the locus of points where the drift droplets of various sizes break away from the temperature/water plume.

Proper source measurements are very crucial to model validation. Chen[1] finds that the maximum deposition pattern and its location downwind of the cooling tower are very sensitive to the mass fraction in larger droplets for all present models. Reliable data for this part of the droplet size spectrum is difficult to achieve because of poor counting statistics, i.e., there are very few large droplets but these few can account for an appreciable fraction of the total emitted drift mass. Thus several techniques should be applied to the measurement of the droplet emission spectrum and mineral mass flux to provide a necessary redundancy and to insure that the results are as accurate as possible.

The effective drift droplet emission height is also crucial in determining impact distances and deposition patterns.[1] Cooling tower energetics (temperature, relative humidity and updraft velocity profiles), as mentioned above, are necessary for the prediction of plume rise, droplet evaporation and drift droplet break-away point. Some of the discrepancies between various drift deposition models can be attributed to different assumptions regarding plume centerline height variations, evaporation and effective emission height. Indeed complex circulations within the plume have been observed which very likely have a direct influence on effective height of drift emission.

Since the amount of drift mineral to be measured can be expected to be small, the results of field experiments will be sensitive to the accuracy and precision of the instruments and methods used. Nearly 100% of the drift mass is presumably deposited on the ground within a few kilometers of the tower. Most sampling techniques take advantage of the cooling water minerals (e.g., salt), cooling water additives (e.g., sulfuric acid, chromium), or tracers (e.g., Rhodamine WT dye). Chemical techniques, such as ion chromatography or atomic absorption spectroscopy, can be used to obtain quantitative measurements of various chemical species (e.g., sulfate, Ca^{++}, Na^{+}) from bulk samples. The use of sensitized papers, filters, and/or films as collecting surfaces for individual droplets, although requiring tedious analysis efforts, provides a method of obtaining drift droplet size distributions from which total drift water mass is calculated by simple integration.

When such analysis is applied to the source measurements, the total drift water mass emitted per unit time or drift rate can be estimated. Moreover, by combining the total mineral mass emission with the total drift water emission, a mean drift mineral concentration can be computed and compared to the mineral concentration in the basin waters. In principle these two concentrations should be the same if no evaporation has occurred from the region where the drift droplets are generated to the point where the measurements are made near the exit plane. Discrepancies have been observed but their cause is not yet fully appreciated.

Similarly, by combining downwind mineral mass deposition and drift water drift deposition the mean drift mineral concentration can be also compared to basin water mineral concentration and/or emitted drift mineral concentration. In this manner, the amount of droplet evaporation can be assessed. It is possible that the measured droplet size distributions as a function of downwind distance could be used to calculate the size and position of each droplet when it leaves the plume and thereby provide some additonal information about the break away point as a function of droplet size. Accurate temperature, relative humidity and wind profiles to plume height would be required.

Ideally a series of sampling stations located downwind and along the centerline of the plume would be sufficient to define the drift deposition pattern. Non-ideal wind patterns, non-ideal plume dispersion and the possible downwind obstructions emphasizes the need for a system of downwind arcs with 5 or more sampling stations per arc.[5] Several upwind sampler sites are required to account for ambient background levels of drift chemicals. Sampling periods in excess of one hour are usually required to assure sufficient collection of drift mineral and droplets for analysis. To avoid contamination of the receptors by resuspended surface material or distortion of the measured distribution due to competition from other receptors such as plants and shrubs, the receptor stations could be elevated above the surface by about one meter. Each receptor station should include at least two large water sensitive filter papers and two large plain filter papers for obtaining total water droplet deposition and total mineral droplet deposition, respectively.

Techniques are available or are being developed for obtaining quantitative concentrations of salt (chloride) and fluorescent dye in droplets from the untreated filter papers.[5] A number of water sensitive filter papers are available[6,7] evaluations of sensitive gelative coatings[8], and photographic film, and other filter paper preparation techniques are underway. Each receptor station should also include two bulk deposition sampler, e.g., a large-area plastic pan or buket which can be covered with a tight sealing

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[6]A. Martin and F. R. Barker, "Some Water Droplet Measurements Inside Cooling Towers," Atmospheric Environment, 8, 1977, 325-336.

[7]H. J. Love, "The Measurement of Precipitation From Water Cooling Towers," Trans. Instn. Chem. Engrs., 30, 1962, 246.

[8]H. F. Liddel and N. W. Wooten, "The Detection and Measurement of Water Droplets," Quart. J. Roy. Meteor. Soc., 83, 1957, 263-266.

lid, for the determination of total mineral mass deposition using standard, high sensitivity analytical chemical methods.

Near surface air concentrations of total drift mineral mass and drift droplet size distributions can be obtained using a rotating arm sampler with sensitive papers and/or films attached.[3]

Determination of droplet size distributions from the sensitive papers and/or films is expected to be the most expensive and time consuming part of the data analyses. Using a Quantimet 720 automatic sizing and counting system, an estimated 2-3 exposed papers can be analyzed per hour at a cost of roughly $40 per hour for equipment and operator time. The system can be programmed to provide hard copy tables and graphs of the measured distributions. Care must be taken, however, to account for droplet overlap and non-normal impingement.

Meteorological observations are extremely important for data interpretation such as distribution pattern, the amount of evaporation the droplets experience and plume rise. Therefore, profile determinations of wind speed and direction, dry- and wet-bulb temperature are required. A monostatic acoustic sounding system and high-quality tethered-balloon system can provide quantitative data to 500 m above ground level. The acoustic sounder provides qualitative data of temperature variability to several hundred meters above ground level and provides a real time display of information related to atmospheric stability and the presence of convection from the surface. Time-lapse photography can also supply valuable information on complex circulations within the plume. It is expected that a synchronized two camera system, viewing the plume from 2 different angles, will be employed; these would provide information on plume geometry and orientation.

Site surveys and pre-experiments at several power plant sites are planned to evaluate a number of factors, including the logistics of setting up suitable surface measurement arcs with respect to surface topography and prevailing meteorological conditions, access to fan stack exits and preliminary measures of the amount of drift deposition which can be expected as a function of downwind distance. Of these latter measurements, the bulk samples are to be used to check the sensitivity of the chemical analysis techniques.

Field Data Applied to Model Validation

Since the data collected in this study are to be used for drift deposition model validation, it is useful to estimate the sensitivity of the models to variations of input data. The Hosler, Pena and Pena model[9], a ballistic trajectory model incorporating evaporation of the drift droplets, provides a suitable starting point because of its relative simplicity.

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[9] C. Hosler, J. Pena and R. Pena, "Determination of Salt Deposition Rates from Drift from Evaporative Cooling Towers," Trans. ASME, Ser A., J. Eng. Power, 96, 1974, 283-291.

In this model particles in the size range d_i to $d_i + \Delta d_i$ released from the plume at height h_r into an ambient wind field having uniform and constant wind speed W are deposited at the ground into a sector having an angular width Θ and radial extremities at x_i and $x_k - \Delta x_i$ determined uniquely by $d_i + \Delta d_i$, respectively. The deposition rate for each size class is given by[13]

$$D_i = \frac{2cQ_i}{\Theta}\left[x_i^2 - (x_i - \Delta x_i)^2\right]^{-1} , \qquad (1)$$

where Q_i is the emitted drift mass in the size range d_i to $d_i + \Delta d_i$ and c is a constant related to the frequency of humidity, wind direction toward the sector.

Changes in mineral concentration are directly proportional to changes in Q_i; similarly the fraction of drift mass emitted in the size range interval is also directly proportional to Q_i[10]. Thus a given uncertainty or variation in mineral concentration and drift mass fraction results in a proportionate change in drift deposition for a given size range interval, e.g., a + 15% error in either of these quantities leads to a +15% error in the predicted deposition.

Other sources of uncertainity in model output include error in the effective release height h_r, error in the effective terminal settling speed $\bar{V}_r$, and error in the measured particle size, d_i. Pena and Hosler[11] have discussed the errors in estimating the settling velocity of drift droplets because of droplet evaporation and have suggested approximations to minimize these errors. Schrecker, et al.[12] have discussed the errors in effective release height and particle size and have concluded that errors in particle-size determinations, especially for trajectory-type models, have the greatest impact on the transport calculations. To illustrate this results further, a summary of the discussion by Schrecker, et al. is given. Subscripts are dropped for simplicity.

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[10] J. H. Meyer and W. D. Stanbro, "Chalk Point Cooling Tower Project Final Report Fy 1977, Col. 1, Salt Loading, Modeling and Aircraft Hazard Studies," JHU P PSP-CPCTP-16, John Hopkins University, Applied Physics Laboratory, Laurel, MD, August 1977.

[11] J. Pena and C. Hosler, "Influence of the Choice of the Plume Diffusion Formula on the Salt-Deposition-Rate-Calculation," Cooling Tower Environment-1974, CONF-74303, 1975, 573-584.

[12] G. O. Schrecker, K. R. Wilber and F. M. Shofner, "Prediction and Measurement of Airborne Particulate Concentrations from Cooling Device Sources and in the Ambient Atmosphere," Cooling Tower Environment-1974, CONF-740303, 1975, 455-482.

[13] F. M. Shofner, G. O. Schrecker, T. B. Carlson and R. O. Webb, Measurement and Interpretation of Drift-Particle Characteristics, Cooling Tower Environment-1974, CONF-740303, 1975, 427-454.

The error in ground-level deposition due to error in effective release height can be calculated by noting in Eq. 1 that

$$X = W\, h_r/\bar{V}_r \tag{2}$$

and that

$$A = \left[\frac{\Theta}{2}\, x^2 - (x-\Delta x)^2\right] \tag{3}$$

is the area of the sector into which the emitted mass is deposited. Consequently, a fractional error of δ in h_r, i.e., $h_r \rightarrow h_r(1+\delta)$, results in an fractional error in the deposition rate D of

$$\frac{D'}{D} = \frac{A}{A'} = \frac{x^2 - (x-\Delta x)^2}{x'^2 - (x' - \Delta x')^2} = \frac{1}{(1+\delta)^2} \tag{4}$$

where the primes indicate the perturbed parameters. For δ=+0.15, $D'/D \simeq 0.76$, a 24% decrease in ground-level deposition.

The error estimate for errors in the particle size measurements is more complicated and requires the additional assumptions that the equilibrium particle size (after evaporation) is a constant fraction of the original size, i.e., $d_e = \beta d$ and that the number of droplets per unit volume of air sampled is the same in the size intervals $[d,\ d+\Delta d = d(1+\Delta)]$ and $[d' = d(1+\delta),\ d'+\Delta d' = d(1+\Delta)(1+\delta)]$. For particles in the range $0<d<100\mu m$, $V_r = K_1 d_e = K_2 d^2$, while for large droplets $V_r = Kd$. Because of the size change, there is also a mass change to account for in Q of Eq. 1. Thus, the fractional error in the deposition rate is, from Eq. 1 and 2,

$$\frac{D'}{D} = \frac{Q'}{A'} \cdot \frac{A}{Q} = \frac{m'}{m}\, \frac{x^2 - (x-\Delta x)^2}{x'^2 - (x'-\Delta x')^2} = \left(\frac{d'}{d}\right)^3 \left(\frac{(d)^{-4} - (d(1+\Delta))^{-4}}{(d')^{-4} - (d'(1+\Delta))^{-4}}\right)$$

$$= (1+\delta)^3\, (1+\delta)^4 = (1+\delta)^7 \quad . \tag{5}$$

for particles in the range of $0<d<100\mu m$ and

$$\frac{D'}{D} = (1+\delta)^5 \tag{6}$$

for large particles. Thus with δ = +0.15, Eq. 5 gives D'/D - 2.66 and Eq. 6 gives D'/D = 2.01. These errors are substantial and clearly point out the need for precise size distribution measurements of the source. Meyer and Stranbro[10] have also carried out sensitivity analyses of several drift deposition models and have made similar conclusions regarding size distribution measurements of the source, ambient relative humidity and effective drift release height.

It is instructive to estimate the downwind mineral deposition rates with the ballistic trajectory model of Hosler, Pena, and Pena.[9] Chen[1] has carried out calculations for a natural draft cooling tower using a drift rate of 2×10^{-5}, an ambient relative humidity of 70%, a wind speed and tower exit

speed of 4.3 m/s. The tower is 100 m high with a plume rise of 500 m. Source emission parameters are shown in Table 1, along with the downwind drift mass and droplet deposition rates. The mineral mass and droplet numbers in each size category were assumed to be conserved and deposited into a sector bounded by impact distances of those droplets whose sizes were at the extrema of each size category. A maximum deposition case was also calculated by Chen[1], where the droplets are emitted from the top of the tower and do not evaporate. Results of these calculations are shown in Table 2.

Since the results in Table 1 are rather conservative while those of Table 2 represent an upper limit, actual deposition patterns from a mechanical draft tower can be expected to be somewhere between these two cases. It is clear that evaporation is extremely important in predicting drift droplet deposition.

From an experimental standpoint, a one hour sample with a 1 dm^2 receptor area, using the deposition rates of Table 1, would be close to the sensitivity limit of the various detection methods. For example a 25 μg sample when diluted with 10 mℓ of rinse water results in a 2.5 ppm salt concentration. The ion chromatograph is sensitive to 0.5 ppm, but operates best in the range 5-50 ppm. For droplet size distribution measurements several hundred droplet stains are necessary for good statistics. Thus an experiment run of 5-10 hrs would be required to reasonably characterize drift deposition with the rate given in Table 1. On the other hand only 10-20 minutes would be required for similar accuracy with the rates given in Table 2.

Data Interpretation and Accuracy

Before the measurements can be used in the various models, they must be cast into a more suitable form such as total mass emission rates or total mass deposition fluxes. Thus it is necessary to examine how accurately these quantities can be specified from a number of point measurement locations, i.e., from equal area traverse measurements in the tower for source characterization or from a series of measurements along an arc downwind from the tower for establishing deposition patterns. In practice this usually means integrating the data over the entire traverse or deposition pattern or, alternatively, by fitting an analytical function, such as a Gaussian, to the data in a way which minimizes the variance between the measured and fitted values. The data may be smoothed by various averaging techniques before fitting. Source and deposition measurements are examined separately.

The source measurements which are required to specify the total mineral and droplet mass emission rates are the updraft velocity, the mineral mass flux and droplet mass concentration at each point along a kiametralequal area traverse. For mechanical draft towers a 10-12 point traverse along a single diameter per cell is usually adequate, although two traverses along crossed diameters is preferable. Typically, mechanical draft cells have a double lobe velocity profile, with a minimum at the center, which may have negative or even slightly positive values. Mineral and droplet flux measurements are not usually made in the center area. Because of the geometry of linear mechanical draft arrays, the emission pattern at the exit plane can be expected to be azimuthally asymmetric, which clearly indicates the need for several traverses of a given cell.

Table 1 Estimated salt deposition rates from a ballistic drift model (see Chen[1]) at ambient relative humidity of 70%

Emitted droplet diameter interval (μm)	Emitted drift mass (g/s)	Downwind distance (km)	Salt deposition rate ($\mu g/hr/dm^2$)	Final droplet diameter interval (μm)	Droplet deposition rate ($\#/hr/dm^2$)
600-500	0.6	1.2-2.3	25	360-220	∿9
500-400	1.7	2.3-3.4	56	170-110	29
400-300	3.4	3.4-6.5	21	170-110	25
300-200	9.0	6.5-14	12	110-70	37
200-100	6.7	14-32	1.4	70-50	25
100-0	1.1	32-180	<.01	50-0	∿3

Table 2 Estimated maximum salt deposition rates from a ballistic trajectory model (see Chen[1]) with no evaporation and the droplets are emitted from the top of the tower

Emitted droplet diameter interval (μm)	Emitted drift mass (g/s)	Downwind distance (km)	Salt deposition rate ($\mu g/hr/dm^2$)	Droplet deposition rate ($\#/hr/dm^2$)
600-500	0.6	0.18-0.22	6900	2100
500-400	1.7	0.22-0.27	11,000	7400
400-300	3.4	0.27-0.38	8,300	11,000
300-200	9.0	0.38-0.61	6,900	24,000
200-100	6.7	0.61-1.6	.490	9,000
100-0	1.1	1.6-150	0.01	∿2

Mineral mass flux is usually determined using an isokinetic (IK) sampling technique[13]. The toal mineral mass flux is obtained by summing the average flux measured at each equal area traverse point. Alternatively, the same IK sampling tube can be used at each traverse point so that the total flux is automatically obtained. The accuracy of this method depends upon the collection using backup filters. The IK system is presumed to have a collection efficiency of 95% or better. The overall accuracy and reproducibility of this technique under field conditions is specified to be ±15%. Consequently, the total mineral mass may be uncertain by at least this amount.

Two different systems[13] are employed to measure droplet size distribution concentrations at the tower exit; these include a light scattering device (e.g., PILLS), which measured concentrations directly, and a sensitive paper (SP) device, which usually measured droplet fluxes but can be employed to measure concentrations too. The PILLS and SP data are combined to find an average volume concentration of droplets in each size range for each traverse point. Since the mean exit velocity is the difference between the tower updraft velocity and the droplet settling velocity, a droplet mass flux for each size range can be calculated. To obtain the total droplet mass flux it is necessary to sum over each size range and over each traverse point. The PILLS and SP systems can be calibrated in the laboratory to within ±5%; however, in the field, intercomparison between the two techniques indicates that the accuracy of these systems can be specified to only ±15%. Hence, total droplet mass is probably accurate to no better than ±15%. The question of evaporative effects within the cooling tower, which preferentially operate on smaller droplets ($d \gtrsim 100$ μm), have not been factoried into this accuracy specification.

Source measurements are also dependent upon the ambient meteorology. This is especially true for natural draft towers, but of lesser importance for mechanical draft towers. Consequently, the ideal experiment plan is to conduct source characterization measurements on many cells of the tower while the downwind measurements are being made. The next best plan, is to characterize the source by making measurements of only a few representative cells (i.e., select cells which appear to have high, low and average emission rates) while downwind measurements are being made.

The deposition pattern on an arc downwind from a natural draft cooling tower is roughly Gaussian with respect to the plume centerline according to data of Meyer and Stanbro[5]. Rectangular bank mechanical draft towers may produce a deposition pattern which lies between Gaussian and top hat distributions. In any case, the actual deposition pattern on a given arc can be used to specify the parameters of whatever analytical distribution function appears appropriate. An example of fitting the data of Meyer and Stanbro[5] to a Gaussian follows.

Two cases are examined: a) unaveraged data and b) data from 3 adjacent stations are averaged together. The data are summarized in Table 3 and Figure 1. The data are fit to a Gaussian of the form

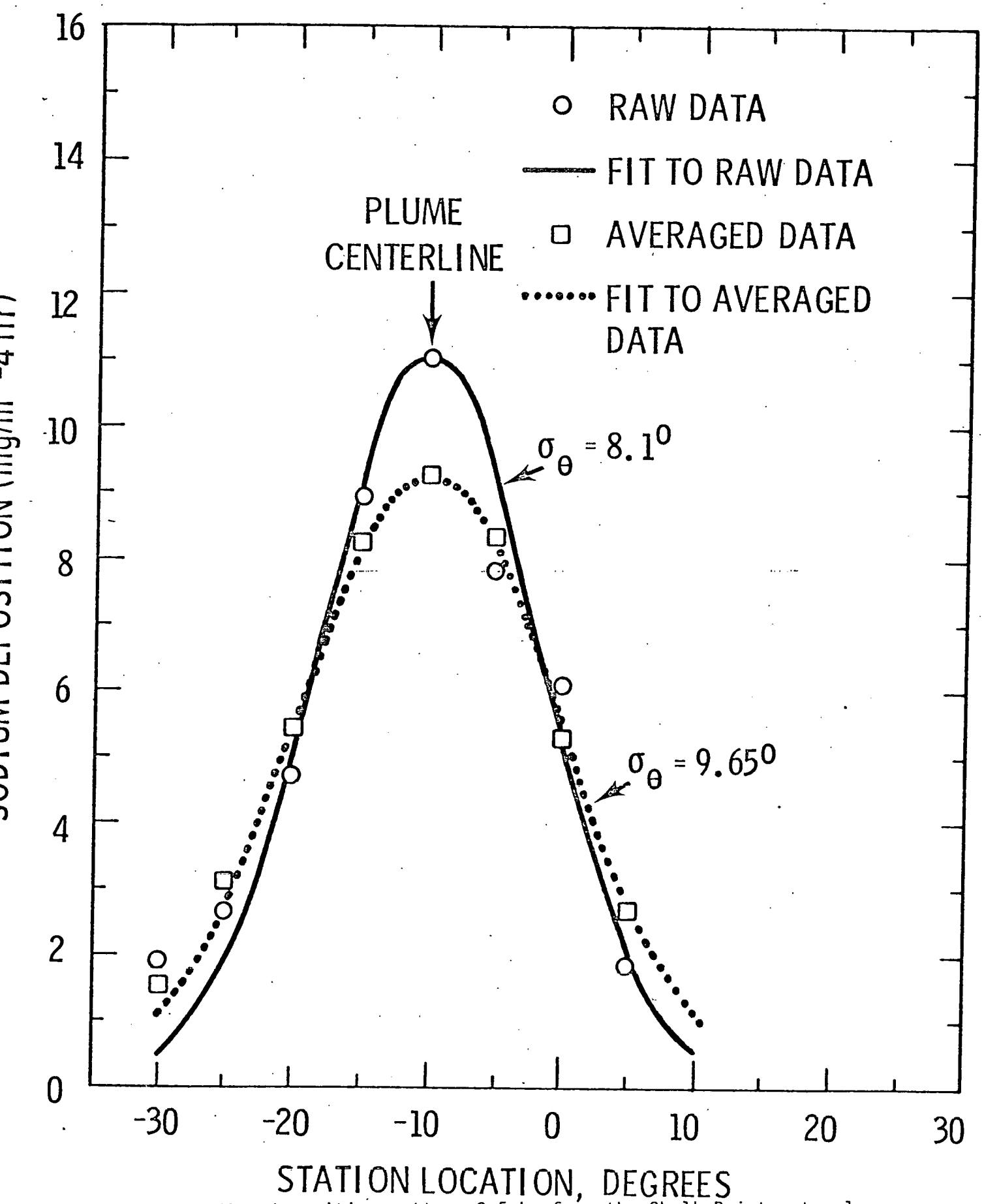

Figure 1. Sodium deposition pattern 0.5 km from the Chalk Point natural draft cooling tower.

$$D_\theta = \frac{D_t}{\sqrt{2\pi}\ \sigma_\theta} \exp\left[-\frac{(\theta - \theta_o)^2}{2\sigma_o^2}\right] , \qquad (7)$$

where D_θ is the deposition rate at station location θ,

D_t is the total deposition rate,

σ_θ is a measure of the width of the deposition pattern, and

θ_o is the location of deposition centerline.

The width of the deposition pattern σ_θ and the total deposition rate are determined from the data according to

$$\sigma_\theta = (\theta_{1/2} - \theta_o) \Big/ \sqrt{2 \ \ln \ 2} \qquad (8)$$

and

$$D_t = D_{\theta_o} \cdot \sqrt{2\pi} \ \cdot \ \sigma_\theta . \qquad (9)$$

where $\theta_{1/2}$ is the location of the half maximum point, i.e., $D_{\theta_{1/2}} \ D_{\theta_o} = 1/2$. The centerline was chosen to be at $\theta_o = -10°$ and the total deposition rate $D_t = 223$ deg . mg/m^2 - 4hr was used in both cases. The fitted data are also shown in Table 3 and Figure 1. The effect of averaging the data before fitting was to decrease the maximum deposition at the centerline and to increase the wodith of the distribution slightly. The average deposition rate over a 40 degree sector at 0.5 km is 5.6 mg/m^2 - 4hr.

Table 3. Distribution of sodium deposition rate at Chalk Point Cooling Tower on an arc 0.5 km downwind (see Meyer and Stanbro[5])

Station Location θ (deg)	Sodium deposition rate, D_θ (mg/m^2-4hr)			
	raw data		averaged data	
	measured	fitted	measured	fitted
+10	--	0.5	--	1.1
+ 5	1.8	2.0	2.6	2.8
0	6.1	5.1	5.2	5.4
- 5	7.8	9.1	8.3	8.1
-10	11.0	11.-	9.2	9.2
-15	8.9	9.1	8.2	8.1
-20	4.7	5.1	5.5	5.4
-25	2.7	2.0	2.8	2.8
-30	1.9	0.5	1.1	1.1

Since the deposition measurements use techniques which are similar to those used for source characterization, the accuracy of the individual downwind measurements ought to be similar also. Consequently, it is necessary to examine what effect the measurement errors have on specifying the total deposition rates. It is straight-forward to derive the following error estimates from Eqs. 8 and 9:

$$\frac{\delta\sigma_\theta}{\sigma_\theta} = \frac{1}{2\ n2} \cdot \frac{\sigma D_\theta}{D_\theta} \quad , \tag{10}$$

and

$$\frac{\delta D_t}{D_t} = 1 + 1/2\ell n2 \cdot \frac{\delta D_\theta}{D_\theta} \quad , \tag{11}$$

where the assumption that $\delta D_\theta/D_\theta \approx \delta D_{\theta_o}/D_{\theta_o} \simeq \delta D_{\theta_{1/2}}/\delta D_{\theta_{1/2}}$ has been used. If $\delta D_\theta/D_\theta = 0.15$, then $\delta\sigma_\theta/\sigma_\theta = 0.11$ and $\delta D_t/D_t = 0.26$. This result indicates that a measurement error no better than 15% would produce an uncertainty in the total deposition no better than 26%.

Finally, there are some uncertainties which are difficult to address prior to actual field measurements. It is important to know that all the droplets contain basin water mineral, since there may be other sources of droplets which impinge on the surface. Appreciable variations of dyes and salt concentration in individual downwind droplets has been found which suggests that a variety of processes may include fragmentation or coalescence through collisions with other droplets, evaporation, and coagulation with plume water.

It would appear that the overall accuracy of specifying total source emission and downwind deposition rates is in the range 15-30% using techniques which are presently available. From the point of view of model validation, it would seem that any model which can reasonably determine the effective release height and the effective settling speed (dependent on evaporative effects) of drift droplets, given the droplet emission flux as a function of droplet size, would be satisfactory.

Conclusions

A drift experiment program to develop a data base which can be used for validation of drift deposition models has been formulated. The first field effort is designed for a suitable mechanical draft cooling tower to be selected after site visits have been conducted. The discussion in this paper demonstrates the importance of characterizing the droplet size spectrum emitted from the tower and to accurately account for droplet evaporation, as the downwind droplet deposition patterns and near surface airborne concentrations are extremely sensitive to these parameters.