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COMPREHENSIVE STUDY OF DRIFT FROM MECHANICAL[a] DRAFT COOLING TOWERS

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by
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COMPREHENSIVE STUDY OF DRIFT FROM
MECHANICAL DRAFT COOLING TOWERS

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ABSTRACT

A comprehensive experiment to study drift from mechanical draft cooling towers was conducted during June 1978 at the PG&E Pittsburg Power Plant. The data from this study are to be used for drift deposition model validation. Results show the effects of tower geometry and orientation with respect to the wind and to single or two tower operation. The effect of relative humidity on droplet evaporation as a function of downwind distance can also be seen.

INTRODUCTION

A comprehensive experiment to study emissions, transport and downwind deposition of drift from a mechanical draft cooling tower was conducted at the PG&E oil-fired Pittsburg Power Plant at Pittsburg, CA during the two week period June 12-26, 1978. The purpose of the study was to develop a data base which can be used for validation of drift deposition models.

The key aspects of the study were to measure the characteristics of the drift droplets emitted from the tower, the ambient meteorological conditions responsible for the transport and dispersion of the drift, and the downwind deposition patterns and near-surface air concentrations of the drift. The source characteristics, including updraft air temperature and velocity profiles, and the meteorological data provide inputs to the models. The measured deposition patterns serve as comparisons to model outputs.

Source characterization measurements were performed by Environmental Systems Corporation (ESC, Knoxville, TN) under Electric Power Research Institute (EPRI) sponsorship. Meteorological and surface deposition measurements were carried out by Pacific Northwest Laboratory (PNL). In addition, other limited comparison tests were also performed by other organizations. Calfran Industries (Springfield, MA) also under EPRI sponsorship, measured drift droplet size distributions using a photographic

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technique; these measurements were to be compared to the ESC derived size distributions and drift emission rates. Xonics (Van Nuys, CA) provided some limited remote wind profile measurements with a doppler acoustic radar system for comparison to the PNL tethered-balloon system used during the experiment.

The site is located on the shore of Suisun Bay near the confluence of the Sacramento and San Joaquin Rivers. The plant consists of seven oil-fired units. Units 1-6 employ once through cooling, while Unit 7 (rated at 720 MWe net) is cooled by two 13-cell Marley rectangular mechanical draft cooling towers located on the center berm in a cooling canal west of the plant. The cooling towers are approximately 0.5 km from Unit 7. The two cooling tower units are identified as Tower 7-1 and Tower 7-2, where Tower 7-2 is about 350 m west of Tower 7-1, measured from center to center. Individual cells are numbered 1-13 from west to east.

The cooling towers have a guaranteed drift rate of 0.004% and a nominal circulating water flow rate of 23.5 m^3/s. During a maintenance outage in December 1977, Marley and the general construction office at the PG&E Pittsburg Plant sealed leaks around the cooling tower drift eliminators. Canal water salt concentration is in the range of 0.4 - 1.2% and has a pH range of 8.0 to 8.7.

EXPERIMENTAL

A total of eight test runs plus a limited near tower test were carried out during the June drift study at Pittsburg, CA. Downwind deposition measurements were coordinated with ESC's source measurements on seven different tests. An eighth test was conducted with no concurrent source measurements. Limited droplet measurements were made on the fan deck of a single tower to examine near field deposition during a ninth and final test. The tests were divided into two-tower operation (three tests), Tower 7-2 alone (two tests), and Tower 7-1 alone (three tests).

Meteorological conditions were not nearly as ideal as previous June climatology would indicate. The winds, though persistently from SW to W to NW, were more intense during the morning hours than usual. Only two or three runs were made where the wind speed could be classified as 5m/s or less. The other tests were carried out under wind speeds ranging from 5 - 10m/s.

It was desirable to have as much information as possible about the operating conditions in the tower at the time the emissions data were recorded in order to assist in applying these results to other towers at other locations.

As mentioned above, the towers at this site are located along the center of an elongated U-shaped canal which was previously used as spray canal for Unit 7 cooling. The cooling water for the Unit 7 condenser is withdrawn from one end of the canal and discharged to the other. The two cooling towers withdraw from the hot leg of the canal and discharge to the cold leg. Hence, there is no direct connection between the condenser cooling water and the tower flow. Furthermore, the inlet water temperature for the two towers may be slightly different if their withdrawal points are not located at the same point on the hot water leg.

Consequently, a complete description of the plant/tower cooling system required:

- Unit 7 generating load
- Unit 7 condenser water flow rate
- Unit 7 condenser inlet and outlet water temperature
- Canal inlet and outlet temperature
- Cooling Tower 1 water flow rate
- Cooling Tower 1 inlet and discharge water temperature
- Cooling Tower 2 water flow rate
- Cooling Tower 2 inlet and discharge water temperature
- Cooling Tower 1 total fan power (air flow)
- Cooling Tower 2 total fan power (air flow)
- Flow rate, inlet/outlet water temperatures, and fan power for individual cell being monitored (if possible).

Source characteristics included measurements of those variables required to describe the air/vapor and drift emissions from the fan stack. Cells to be monitored were selected in accordance with the measurement strategy developed in a pre-test phase. Measurements were taken at or near the exit plane. Data were acquired at 12 equal area points along two perpendicular diametral traverses. Variables measured included:

- Updraft air velocity profiles
- Air dry- and wet-bulb temperature profiles
- Drift (water) flux profiles
- Mineral mass flux profiles
- Drift droplet size distribution
- Droplet salinity vs. droplet diameter

Intensive measurements of a single cell during a specific test run were made along with limited measurements of reference cells on each tower. Droplet size distributions and drift flux profiles were determined using sensitive papers (SP) and a light scattering, droplet counting system (PILLS). Additional droplet size distribution data were acquired using a special photographic technique. Mineral mass fluxes were determined with an iso-kinetic (IK) sampler. Updraft velocity profiles were measured with a gill anemometer while the air temperatures were obtained with standard precision thermistors.

Meteorological data were collected at two levels from an instrumented 10 m tower upwind of the cooling towers during the period June 16-25, 1978. Temperature (dry- and wet-bulb), u, v, and w components of the wind were recorded continuously onto a seven track magnetic tape at five minute intervals over the experimental period.

A tethered balloon system provided vertical profiles of temperature, moisture and horizontal wind speed and direction within the vicinity of the cooling towers as well as in the upwind direction. Profiling was performed from the surface up to as high as 400 m on one occasion. The bulk of the profiles extended up to only 100 m. During the experimental period, the tethered balloon system was flown on only seven days (June 15, 16, 17, 21, 23, 24 and 25). Its operation was limited by high winds

(>10 m s^{-1}). The system was interfaced with an HP-97 calculator and provided print-out onto paper tape of time, pressure, height, temperature, relative humidity, mixing ratio, wind speed and direction and potential temperature.

During the last three days of the experiment a Doppler acoustic sounder was employed to determine the wind profile in the boundary layer. A monostatic acoustic sounder also operated continuously during the period June 16-25; data from this device were recorded on a strip chart recorder. Plume photography was also conducted during the experiment using automatic time lapse camera systems. Visible plume lengths were in general very short during the test period, no further reference is made to this phase of the study.

Downwind drift deposition patterns were determined using sensitive papers (SP) and deposition pans distributed in arcs about the cooling towers. In addition, untreated filter papers were also exposed. These latter papers can be examined either as additional deposition receptors for further chemical analysis, or developed for Cl^- ion using Ag NO_3 (the papers treated in this manner should produce stains similar to those found on the SP's). At selected locations a rotating arm sampler with sensitive papers attached was used to determine near surface air concentrations of drift. Canal and basin water samples were collected regularly during test runs.

DATA ANALYSES AND REDUCTIONS

Of the eight test runs, five to six were of sufficient quality to warrant intensive analyses. For the purposes of this paper, only deposition data for the 6-16 (two tower operation) and the 6-17 (Tower 7-1 operation only) tests are presented. The source measurements for all seven test days were reduced and analyzed by ESC, from which a composite emissions inventory with a range of daily deviations was established; these emissions are assumed to be representative for any given day.

The analyses of the deposition samples were of two types:

- Chemical analysis of bulk deposition samples
- Droplet size distribution analysis of sensitive papers.

Mineral ion species, including Na^+, K^+, NH_4^+, Cl^-, NO_3^-, and SO_4^{--}, obtained with the positive and negative ion chromatographs (IC) respectively, while Ca^{++} and Mg^{++} were determined by atomic absorption spectroscopy. Deposition pan samples and canal and basin water samples were analyzed using these techniques. Samples were recovered from the deposition pans using 10 ml of double-distilled, deionized rinse water. Canal and basin water samples were usually diluted by a factor of 100-1000 before analysis on the IC's.

Drift droplet size distributions were obtained from the sensitive papers with an automated scanning and sizing device, the Quantimet 720 system. The system was interfaced with a mini-computer which allowed the measured stain sizes to be converted to droplet sizes, binned according to size category and number and volume size distributions stored on cassette tape for later hard copy retrieval.

The results of the chemical and droplet analyses were then converted to deposition rates. The downwind deposition patterns were obtained by combining data from all of the sampling stations in each arc. It became apparent from preliminary analysis of the 6-16 test that because of the wind and dust conditions at the site during the experiment, larger background values of mineral deposition were present in the data than originally anticipated. Fortunately the sampling procedure allowed for enough outside-the-plume stations such that, with suitable statistical procedures, it was possible to eliminate most of the influence of this variable background component.

Ratios of mineral ion mass deposition provided a convenient method to distinguish drift from non-soil, background aerosol since these ratios for drift droplets should be similar to those of the basin and/or canal water. The problem of soil contamination in the deposition pans was not so straightforward. This is because the soil had been exposed to drift deposition, and more importantly, canal water from water trucks as a part of PG&E's

dust abatement efforts. The upwind stations in most cases provided a useful indicator for estimating the non-soil background. Soil samples, collected near many of the sampling stations, were examined to see if any useful method for qualitative estimates of soil/dust contamination could be found. These samples however were too inhomogeneous to help in the evaluation of the soil background.

The meteorological data from the PNL 10m meteorology tower, the tethered balloon system and the PG&E meteorology station were averaged, where practical, over intervals compatible with actual downwind sampling periods. The most important parameters affecting the drift deposition pattern were the wind speed and direction and the ambient relative humidity. At a few stations close to the tower(s) and directly beneath the plume, it was possible to obtain several sequential SP exposures. For these stations the effect of rising temperature and decreasing relative humidity was clearly evident.

RESULTS

In presenting the results for the two test days, 6-16 and 6-17, it is useful to summarize the plant operational data, cooling tower drift emission data, meteorological data and deposition data separately.

Average plant loads for the two days were 682 MWe and 492 MWe, respectively. Condenser water temperatures averaged 25.6°C and 24.6°C at the inlet and 36.5°C and 32.6°C at the outlet, respectively, for the two days. Average canal water temperatures were 35.7°C and 32.0°C at the inlet and 25.5°C and 24.6°C at the outlet, respectively. Cooling tower operational conditions are summarized in Table 1.

Drift emission characteristics are based upon data derived from updraft air speed, temperature, mineral and liquid drift mass emission measurements from four cells of Tower 7-1 and three cells of Tower 7-2. The velocity profile for each cell exhibits the double-lobed structure common to fan driven flows. The highest observed average air speed was 12.7 m/s in one of the lobe regions and the lowest speed was -4.6 m/s in the center region over the hub of the fan (see Figure 1 for a typical example). The air speed profiles were not bilaterally symmetric, due in part to the influence of external crosswinds. Calculated volumetric air flow rates were 557 ± 17 m^3/s which corresponds to an average updraft air velocity of 7.1 ± 0.2 m/s for a cell exit area of 77.8 m^2.

Table 1. Cooling Tower Operational Data

Date	Tower #	Cells Operating	Avg Fan HP/Cell	Water Flow (m^3/min)	Avg T_{hot} (°C)	Avg T_{cold} (°C)
7-16	7-1	12	208	570	35.6	24.5
	7-2	10	206	625	34.6	27.6
7-17	7-1	12	205	570	32.0	23.9
	7-2	0	---	---	---	---

Typical cell temperature profiles are also shown in Figure 1; these profiles were not bilaterally symmetric either, with higher temperatures toward the rim on the downwind side of the cell. As expected for saturated air, wet- and dry-bulb temperatures were the same within sensor accuracy (±0.2°C); dry-bulb temperatures varied by as much as 6°C during a given day's characterization.

Cooling tower circulating water samples and the isokinetic (IK) tube drift mineral sample washes were analyzed for sodium and magnesium ion. Sodium mass emission rates of the seven characterized cells varied in the range 1380 to 3890 μg/s with Mg^{++} emission rate averaging ∿11% of the Na^+ value. If no evaporation of droplets occurs in the fill region, then the mineral mass emission rates coupled with the basin water mineral concentration yield a liquid mass emission rate in the range 6.8 to 18.2 g/s. The corresponding range of values of liquid mass emission from analysis of SP drift droplet spectra were 2.6 - 8.2 g/s. The ratio of IK to SP liquid mass emission values varied from 1.3 to 6.2 with an average value of 2.8, indicating that evaporation effects within the fill are significant.

Because of the variability of drift mass emission from cell to cell, a representative emission rate per cell was calculated using a weighted average of those cells judged during a pre-test survey to have high, medium

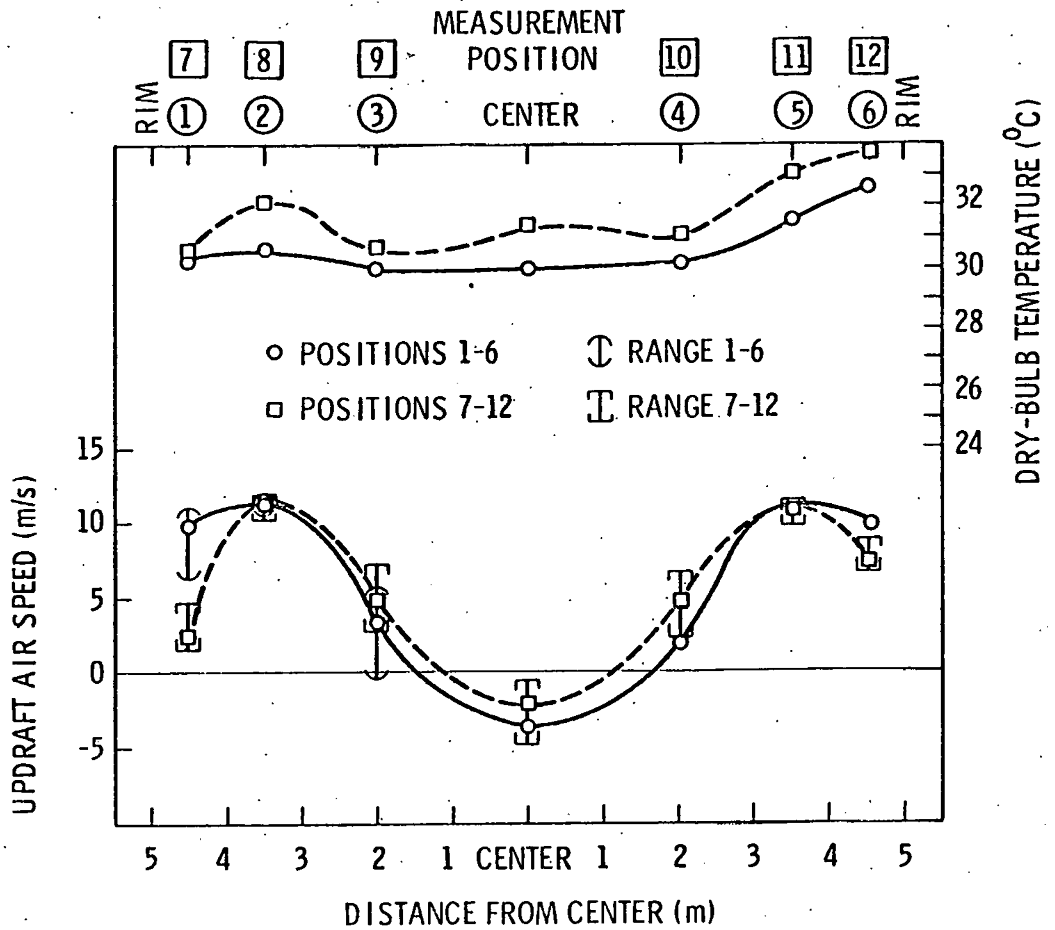


Figure 1. Updraft Air Speed and Dry-Bulb Temperature Profiles PG&E Pittsburg Unit #7, Tower #1, Cell #12. June 16, 1978. 7:30 - 12:00 PDT.

or low emissions. The result was found to be 4.8 g/s per cell or 124 g/s total emission rate if all 26 cells are operating. This corresponds to a drift fraction of 0.0006% for a total circulating water flow rate of 20 m^3/s. A representative drift mass emission spectrum is shown in Figure 2, where the mass peak near 30 μm represents droplets from the fill which have passed through the drift eliminators while the mass peak at 300 μm (and perhaps beyond) is due to large droplets formed by leakage of water into the tower plenum. Half hourly averaged values of dry-bulb temperature, relative humidity, wind speed and direction were computed and synthesized from data obtained from the 10 m meteorological tower, tethered balloon system and PG&E Station.

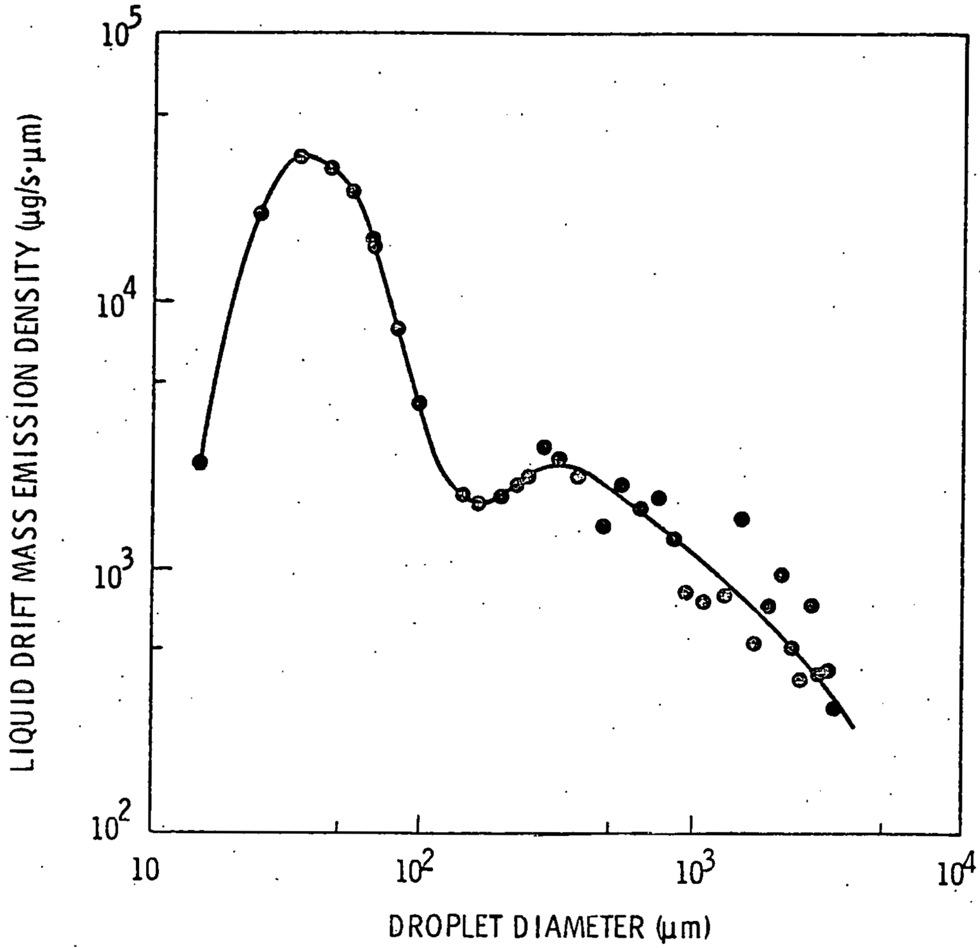


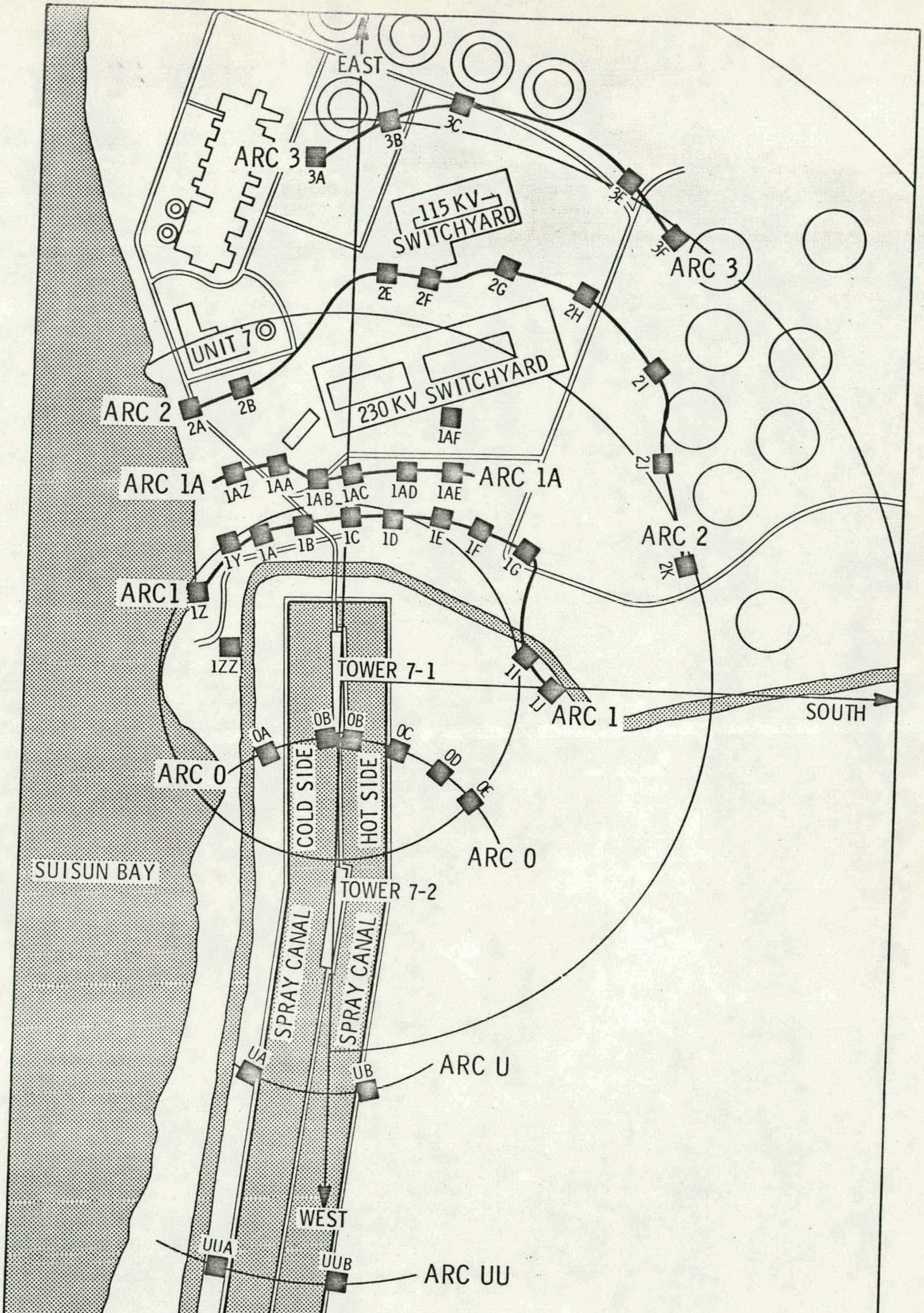
Figure 2. Composite Drift Droplet Emission Spectrum

On June 16 the wind was relatively strong and steady from the west. The average direction was 267° with a standard deviation of 4°. During the test period (0730 - 1300 PDT), the greatest half hourly change in wind direction was only 7°. Mean wind speed and standard deviation were 4.7 ms^{-1} and 0.4 ms^{-1}, respectively. The maximum half hourly wind speed was 9.0 ms^{-1}. The temperature reflected the normal heating trend on a clear day. During the measurement period, the low and high temperatures were 15.1°C and 25°C respectively. The average temperature was 20.2°C with a standard deviation of 5.6°C. The maximum half hourly relative humidity was 73% at the beginning of the test decreasing to a minimum of 35%. The average relative humidity was 46% with a standard deviation of 14%.

Meteorological conditions on June 17 were quite similar to that of the previous day except during the beginning of the measurement period when the average winds were out of the south at approximately 1.8 ms^{-1}. The average wind direction was 273° with a standard deviation of approximately 42°. Wind speed increased steadily during the morning reaching a half hourly maximum of 6.5 ms^{-1} near noon. Mean wind speed and standard deviation were 4.1 ms^{-1} and 2.7 ms^{-1}, respectively. The average temperature was 22.0°C with a standard deviation of 4.3°C. The maximum and minimum half hourly relative humidities were 66% and 38% respectively. The average relative humidity was 52% with a standard deviation of 9%.

Figure 3 shows the sampling network with respect to the two cooling towers. The intent was to establish arcs at radii of 1/4, 1/2 and 3/4 km from Tower 7-1 with sampling stations located about every 10° along a given arc. An additional arc was set up during the test which was to be mid-way between the 1/4 and 1/2 km arcs. A separate arc at ∿1/4 km was set up for Tower 7-2. The two upwind arcs were located 1/4 and 1/2 km west of Tower 7-2, assuming persistent westerly winds. Spacings of individual stations, both radially and azimuthally, were irregular due to physical constraints of obstructions, roadways, etc. on the plant site. This irregularity, of course, made interpretations of the downwind deposition patterns somewhat more difficult than for an ideal layout; uncertainties in the measured mineral and water mass deposition rates were found to be sufficiently large such that high precision in the actual station locations was not necessary.

The drift deposition pattern was determined by first establishing a background pattern from stations outside the plume and subtracting this background component from the uncorrected pattern. An example of the pattern for Na^+ for the 6-16 test is shown in Figure 4. The error bars represent the uncertainty in the mineral mass deposition when the two deposition pans



EAST
ARC 3
3A
3B
3C
3E
3F
ARC 3
115 KV
SWITCHYARD
UNIT 7
2E
2F
2G
2H
2I
2J
ARC 2
2A
2B
230 KV SWITCHYARD
1AF
ARC 1A
1AZ
1AA
1AB
1AC
1AD
1AE
ARC 1A
ARC 2
2K
1Y
1A
1B
1C
1D
1E
1F
1G
ARC1
1Z
1ZZ
TOWER 7-1
1I
1J
ARC 1
SOUTH
0A
0B
0B
0C
0D
0E
ARC 0
COLD SIDE
HOT SIDE
ARC 0
SUISUN BAY
TOWER 7-2
SPRAY CANAL
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Figure 3. Sampling Station and Plant Layout for the PG&E Pittsburg Power Plant Cooling Tower Drift Study

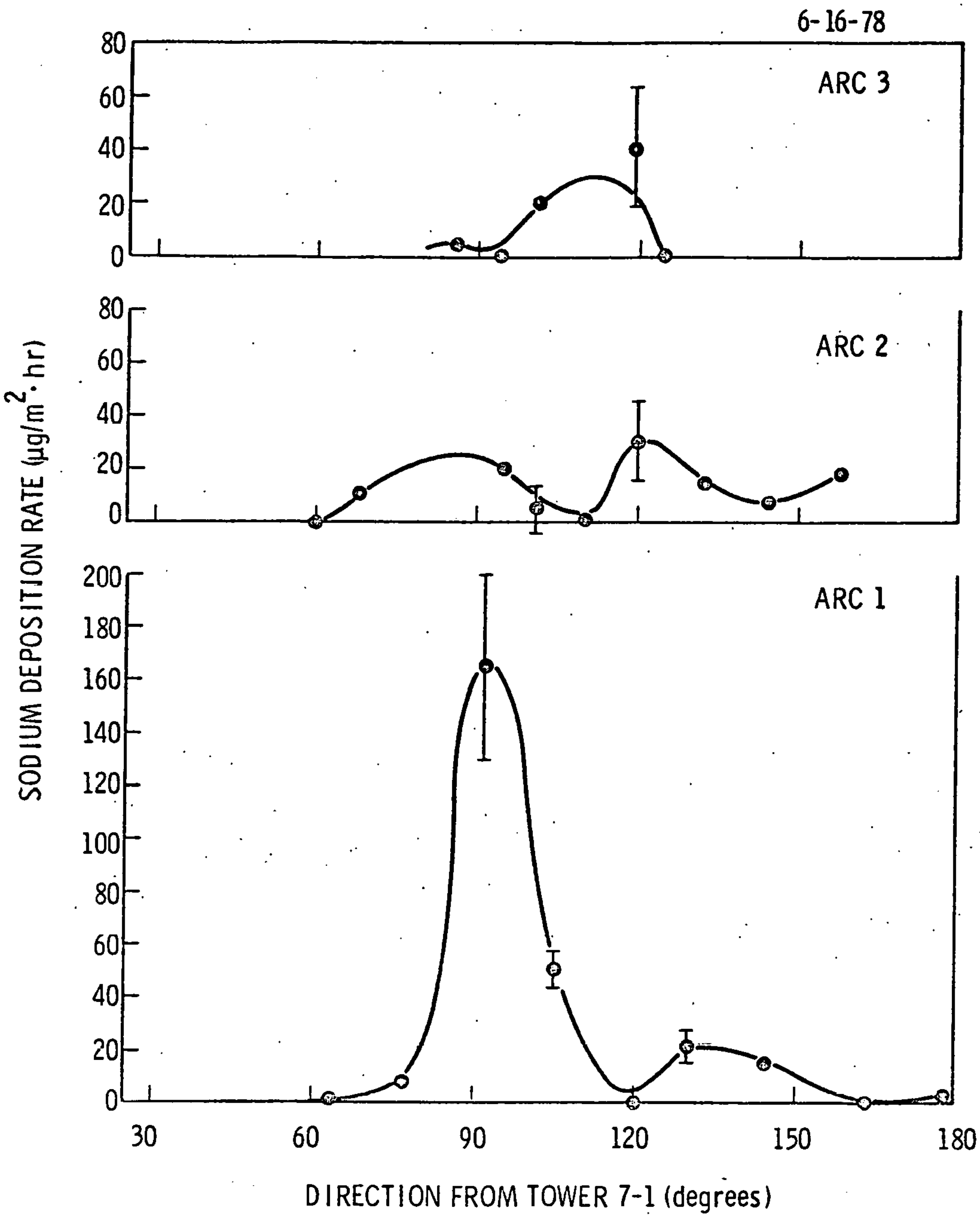

Figure 4. Downwind Surface Drift Deposition Pattern for Na^+ Ion

per station were analyzed separately rather than the two pans added together before analysis. The data points should also show the uncertainties in determining the background component. Along the plume center line the ratio of drift to background depositions varied from about 1 to 6, depending on the distance from the towers. Outside the plume these ratios were generally less than 1.

Peak or plume centerline deposition rates as a function of distance are shown in Figure 5 for Na^+. Also shown are predictions made by ESC with the ESC/Schrecker drift deposition model for two values of the droplet salinity and the measured drift flux from the cooling towers. The salinity value of 250 ppm is an average basin water value found by ESC while the 750 ppm value is one determined by ESC using the IK and SP methods for the droplets leaving the tower.

Similar deposition patterns were found for the other mineral ions, including Cl^-, SO_4^{--}, and Ca^{++}. Peak deposition rates had a distance dependence similar to the Na^+. Water droplet mass deposition rate had a much steeper falloff with distance than the mineral mass; this is a reasonable expectation because of evaporation of the droplets as they travel downwind. Deposition droplets were found to have salinities of 0.26%, 2.9%, and 2.5% at 1/4, 1/2 and 3/4 km from Tower 7-1, respectively. These salinity values are based upon the measured peak sodium mass and water mass deposition rates for each arc.

Several other observations are also apparent from an examination of Figures 4 and 5 (as well as the other data not shown). The effect of a shift in wind direction from 270° to around 300-310° during the last hour of the test is seen in Figure 4. It is not clear from these data what effect the switchyard structures had on the interception of drift material before its deposition onto the receptors.

From a comparison of the experimental values at 1/2 and 3/4 km alone it would appear that the switchyards could have reduced the drift deposition by as much as a factor of two. Referenced to the ESC/Schrecker model the value at 3/4 km would appear to be too high. The deposition values (Figure 5)

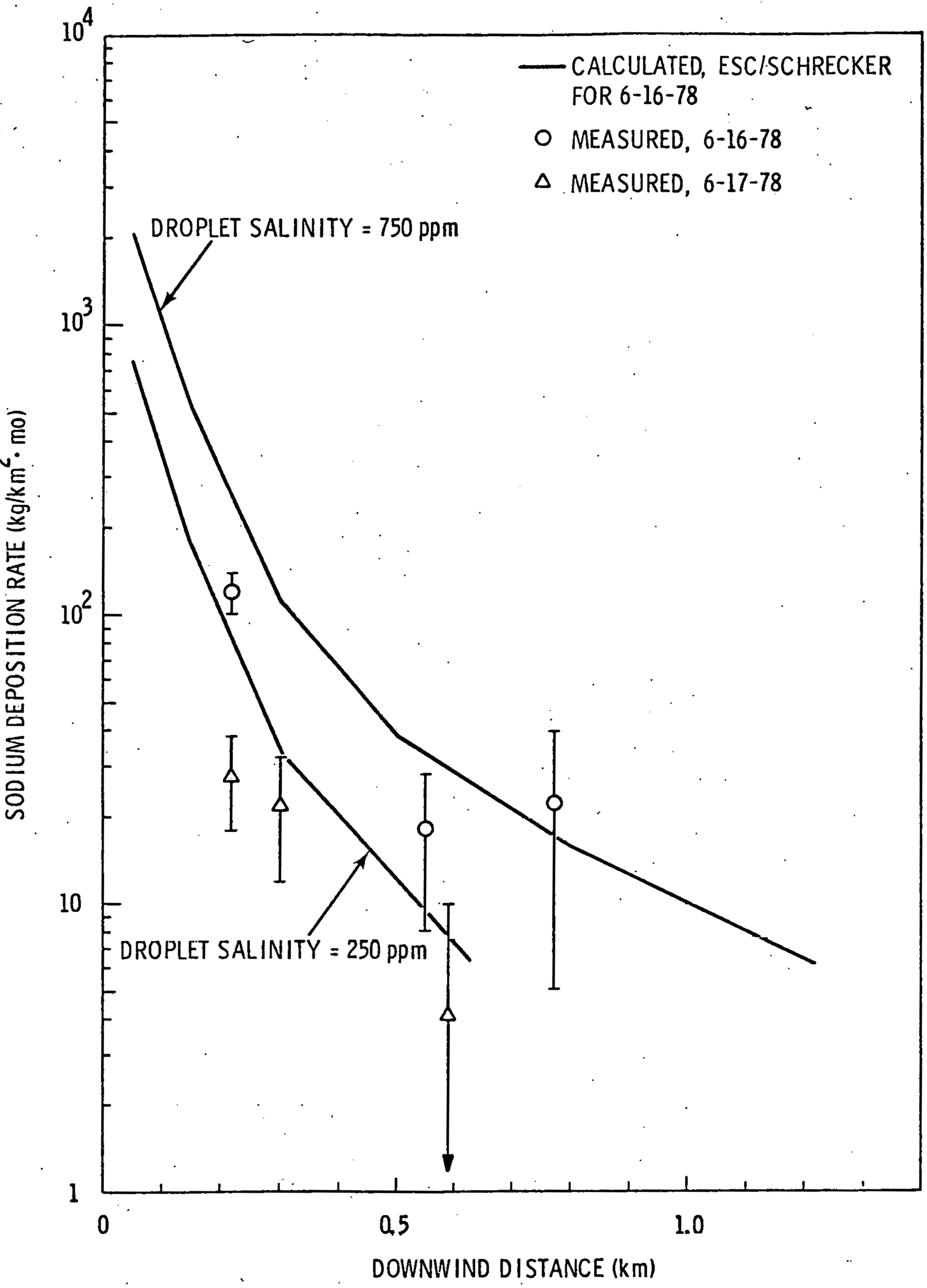

Figure 5. Peak Drift Deposition Rate as a Function of Downwind Distance

for the 6-17 test are lower than the 6-16 test values primarily because of a reduced power load; otherwise wind conditions were similar for both days. Consequently, additional test days where the wind did not blow the drift plume through the switchyard, will be required to examine the effect of these structures on the drift.

The effect of decreasing relative humidity during the course of a test run was also observed on the sensitive papers. The peak droplet mass deposition rate for the 6-16 test changed from a value of 1070 mg/m^2 hr during the first 1 1/4 hr of the test to a value of 310 mg/m^2 hr during the next 1 3/4 hr, although a value of 280 mg/m^2 hr was also measured at an adjacent station corresponding to the wind shift which had occurred during the final hour of the test. Similarly for the 6-17 test, the droplet mass deposition rate changed from 530 mg/m^2 hr during the first 1 1/4 hr to 145 mg/m^2 hr during the final 2 1/2 hrs.

CONCLUSIONS

A comprehensive experiment to study drift from mechanical draft cooling towers was conducted during June 1978 at the PG&E Pittsburg Power Plant to establish a data base for use in drift deposition model validation. Results from two test runs have been discussed. It was found that using the source measurements obtained by ESC and the ESC-Schrecker drift model that the predicted downwind depositions are in reasonable agreement with the observed values. Background mineral depositions arising mainly from blowing dust produced substantial interference with the downwind deposition patterns, especially at the larger downwind distances where drift deposition rates were small.

The effects of wind direction changes and relative humidity changes during the course of an experiment were easily seen in the results. The effect of structures such as the electrical switchyards, in sweeping out drift material before it arrives at the surface was examined. With the limited data which has been presently analyzed, no definite conclusion can be established.

ACKNOWLEDGEMENTS

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