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COOLING TOWER DRIFT STUDY AT OAK RIDGE GASEOUS DIFFUSION PLANT

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OAK RIDGE GASEOUS DIFFUSION PLANT
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ABSTRACT

New drift studies on the mechanical draft cooling towers at the Oak Ridge Gaseous Diffusion Plant are being planned to provide data necessary for the building and evaluation of a practical analytical model that will describe drift transport and deposition for existing and new towers. A previous study in 1973 provided the groundwork, but needs to be extended to characterize the effect on drift mechanisms of variations in meteorological and operating conditions, as well as the influence imposed by tower condition, tower type, and terrain. Some inconsistencies in source measurements in the 1973 study also need to be resolved, since errors in this input measurement to existing models are magnified by a factor of seven in the deposition results. It is contended that large droplets (>900 μm) constitute a significant fraction of the total drift and must be accounted for in future measurements. Based on the results of the previous study, a new test plan and measuring method have been formulated and are outlined. It is believed that the extensive measurements of the new study will provide reliable data in quantity for a better statistical analysis that will enhance the formulation of a credible drift model.

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COOLING TOWER DRIFT STUDY AT OAK RIDGE GASEOUS DIFFUSION PLANT

INTRODUCTION

The drift from cooling towers and its environmental impact on surrounding areas has been the subject of several studies in the past. However, at this time there does not appear to be a reliable, general model to describe emanation, transport, or fallout patterns of cooling tower drift. As the demand for cooling towers increases with demand in power, and industrial processes become more reliant on cooling towers to provide cooling water, a better understanding of these mechanisms is necessary to define the interface between the cooling tower drift and the environment. The necessity of better understanding of the behavior of drift is also intensified by the increased use of chemicals in the recirculating water system of various industries and the utilization of different makeup sources, such as sea or brackish water. Since drift carries roughly the same chemicals or contaminant concentration as the recirculating water system, excess deposition of drift on the surrounding area may present a problem. The mechanisms of drift which involve formation of water droplets in the tower, transport processes, and deposition on ground, are very complicated processes which depend on various parameters such as:

1. Physical Condition of Cooling Tower,
2. Water and Air Loadings,
3. Meteorological Conditions,
4. Terrain Effects, and many other factors.

The complexity of the drift problem is further increased by the interaction between these various physical and meteorological conditions.

Numerous analytical models that purport the capability of defining drift problems exist in the literature. Chen[1] (1977) has compared some of the existing models. He found that predicted values for maximum deposition with common input conditions can vary by two orders of magnitude between the existing models; however, he was unable to determine which model was most accurate. The difficulty in judging these models is due to the lack of good field data. Schrecker[2] (1974) analyzed the effect of errors in measurements on the results predicted by these models. He argued that error, δ, in effective release point of droplets results in $(1 + \delta)^2$ on ground deposition error and an error in particle size results in $(1 + \delta)^7$ on deposition result. Therefore, reliable source measurements that provide a reliable particle size density distribution are very critical for model study. It is also important to define and objectively rank various physical processes with respect to their effect on the transport process of drift.

A responsible drift study of cooling towers will need to supply the answers to several fundamental questions. These answers must establish total drift rates from a cooling tower, the particle density distribution, and describe the transfer mechanism of drift to surrounding areas. There is also a need to assess the effect on these parameters of various meteorological effects such as:

1. Relative wind velocity to flux velocity,
2. Stability condition,
3. Humidity, and
4. Turbulence effects.

DRIFT STUDY OF OAK RIDGE COOLING TOWERS - 1973

The first drift study of the Oak Ridge cooling towers was done in 1973 by Environmental Systems Corporation (ESC), Atmospheric Turbulence Diffusion Laboratory (ATDL), and Battelle Northwest Laboratory (BNWL), and the result of these studies were reported by Jallouk.[3] ESC and ATDL measured the source characteristics of cooling towers, as well as the ground deposition, and BNWL measured the ground deposition only. Some of the results of this test were reported in the Cooling Tower Environment Conference in 1974.

The result of the 1973 tests provided a first look at the impact of mechanical draft cooling tower operation on the environment. The chromium deposition results shown in Figure 1 indicate a fairly good agreement between two of the three investigating teams. ESC and ATDL used the sensitive papers (SP), while BNWL directly measured the amount of chromium falling on the ground. It is suspected that the reason for the low BNWL values was that their samplers were not located directly under the plume for most of the test period. The source measurements agree generally, but is believed that there is room for considerable improvement. The result of source characteristic measurements are shown in Figure 2. The measurements were done on Cell 6 of the K-31 tower which is a Marley cross-flow tower that is 25 yr old. The ESC's results were obtained with sensitive papers of 9.6 square centimeters over the droplet range of 50 to 200 μm and with the Particulate Instrumentation by Laser Light Scattering (PILLS) systems on 200 to 900 μm, while ATDL used 8-1/2-in. x 11-in. sensitive papers. Some of the noticable points about the results of this test are the unsymmetrical nature of drift flux in the cell (compare Traverse 1 and 2) and existence of large drops which contribute significantly to the total drift. The importance of large drops is emphasized by Chen (1977) in his study of model comparison. In the study, all models show that the maximum deposition rate and its location are very sensitive to the mass fraction of large drops.

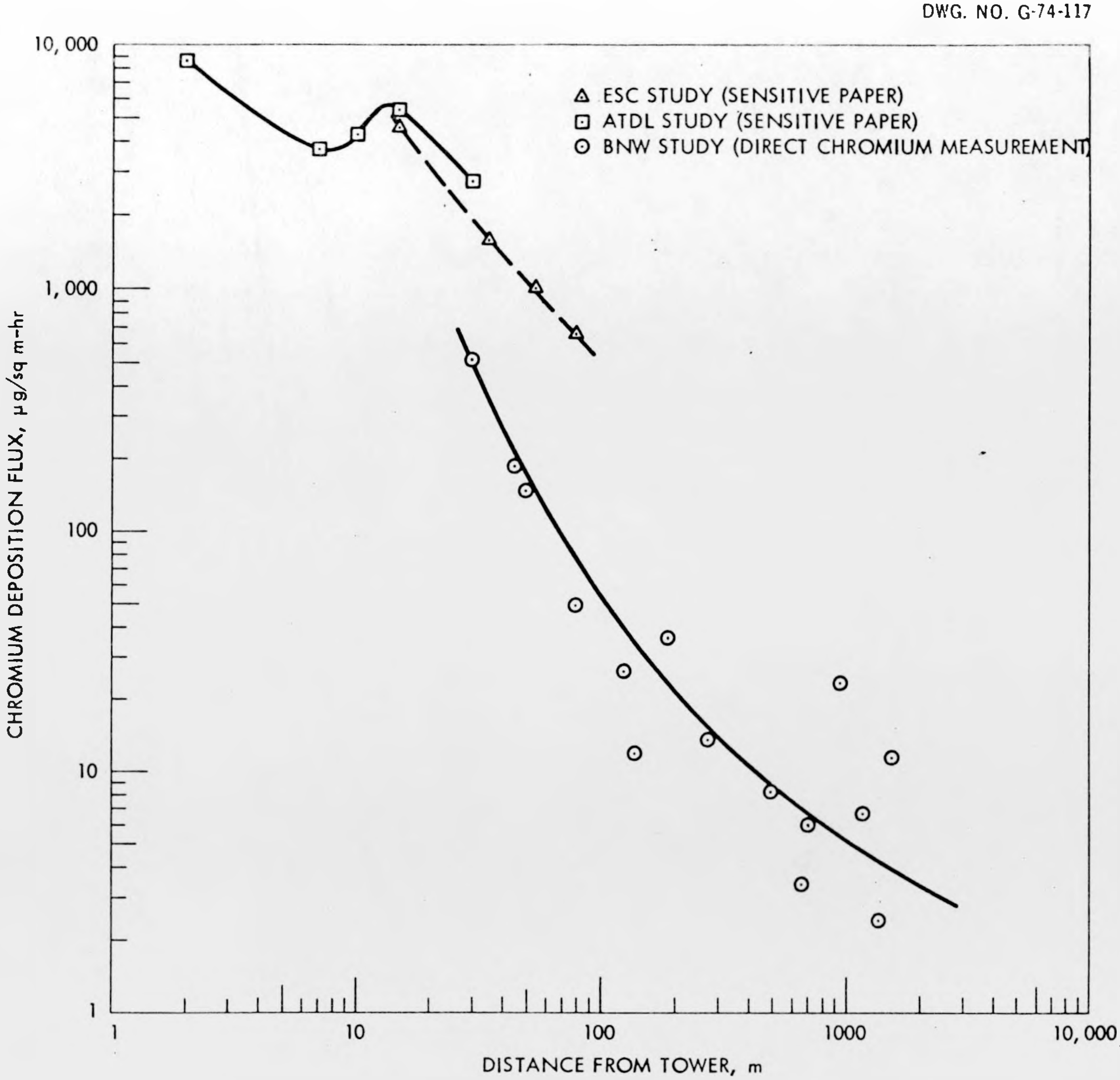

Figure 1

CHROMIUM DEPOSITION FLUX AS
A FUNCTION OF DISTANCE FROM K-31 TOWER

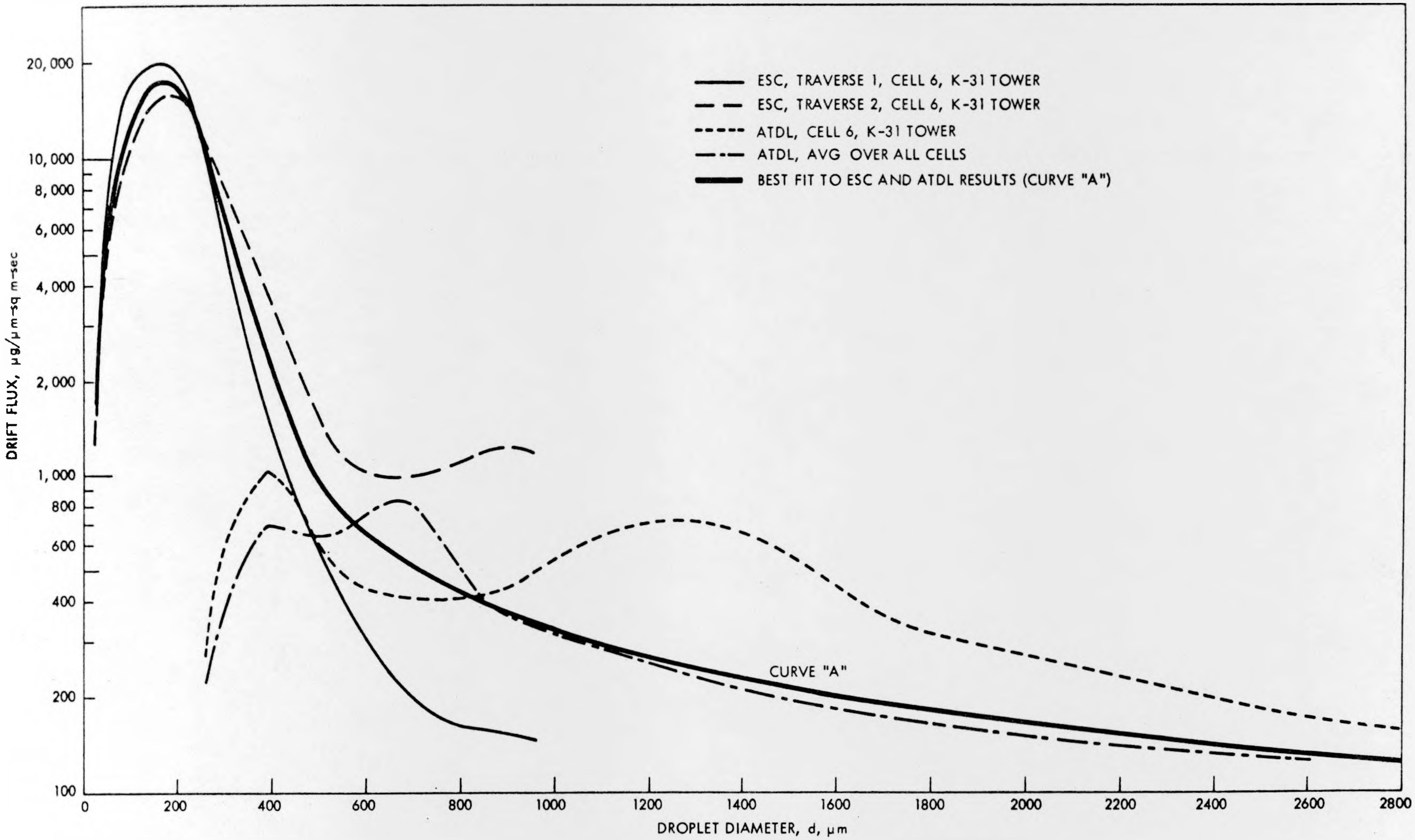

Figure 2

DRIFT FLUX PER UNIT DROPLET DIAMETER

The drift was measured with isokinetic tubes and the results given in Table 1 show that the drift rate calculated from this measurement is lower than the results obtained from the particle density distribution. This is confusing, since the isokinetic sample contains all size particles while the ESC sample was limited to 900 μm and below. A possible explanation is that some of the droplets counted by the PILLS-SP systems may be condensation, or the isokinetic sampling results may not represent true isokinetic sampling conditions.

The drift percentages obtained in K-31 Cell 6 were 0.1% by ESC and 0.028% by ATDL. The difference between these two values was due to the fact that ESC ignored the large drops and ATDL missed the smaller drops of less than 275 μm. The results of the K-31 cooling tower test are also compared with the result of a test at Turkey Point which utilized the same technique. The tower at Turkey Point is a Marley cross-flow tower, but it was constructed in 1974. These results are shown in Figure 3 and indicate the drift fraction, Δ, for Turkey Point tower is 0.00034% with a mass median droplet size, $\bar{d}$, of 100 μm, while the Oak Ridge results are:

$\Delta = 0.1\%$ $\bar{d}$ = 150 μm by ESC.

$\Delta = 0.028\%$ $\bar{d}$ = 1.000 μm by ATDL.

Since the PILLS-SP system by ESC and large sensitive paper by ATDL exhibit different degrees of collection efficiencies with droplet sizes, a third result was generated using the ESC results for small drop sizes up to 400 μm and the ATDL results for larger drop sizes. The results of this interpretation of the data are plotted in Figure 4, and would affect a 20% increase in the drift over the measured value of 0.1% on the K-31 tower which already seemed high.

One of the instruments to be used in future investigations of drift is the isokinetic tubes which in theory collect the whole spectrum of drops. The quantity of drift is then calculated from the total amount of chemical collected and the concentration of that chemical in the drift. To obtain a true drift rate, the chemical concentration in each droplet would need to be known. The general practice now is to use the same chemical concentration as in the recirculating water system, but there is a general feeling that there is a concentration variation with drop sizes. Shofner [5] (1971) compared drift rates as measured by PILLS and isokinetic tubes. The isokinetic tube has a collection efficiency of 90% or better for droplets greater than 0.3 μm, while the PILLS system counts droplets above 80 and below 900 μm. The results for various droplet size ranges are shown in Table 2, and indicate a 39% higher drift rate by the isokinetic method. Recalculating the drift rate with inclusion of smaller droplets will reduce the difference in drift rate between isokinetic tubes and PILLS to 28%. This 28% difference, therefore, may be attributed to the large droplets which PILLS has failed to measure. In the source characteristic results shown in Figure 2, the combined result of ESC and ATDL is about 24% higher than ESC's result. This may confirm that the existence of larger drops beyond 900 μm would be 20 to 30% of the whole spectrum of droplets.

Table 1

TOTAL DRIFT VALUES MEASURED AT THE K-31 COOLING TOWER
June 25 - June 29, 1973

Tower Cell	Investigator	Drift, g/sec
K-31-1	ATDL	20.0
K-31-2	ATDL	18.0
K-31-3	ATDL	25.0
K-31-4	ATDL	17.0
K-31-5	ATDL	28.0
K-31-6	ATDL	36.0
K-31-7	ATDL	31.3
K-31-8	ATDL	23.1
K-31-6	ESC (First Diametral Traverse - PILLS and Sensitive Paper)	156
K-31-6	ESC (First Diametral Traverse - Isokinetic Sampling)	105
K-31-6	ESC (Second Diametral Traverse - PILLS and Sensitive Paper)	150
K-31-6	ESC (Second Diametral Traverse - Isokinetic Sampling)	147

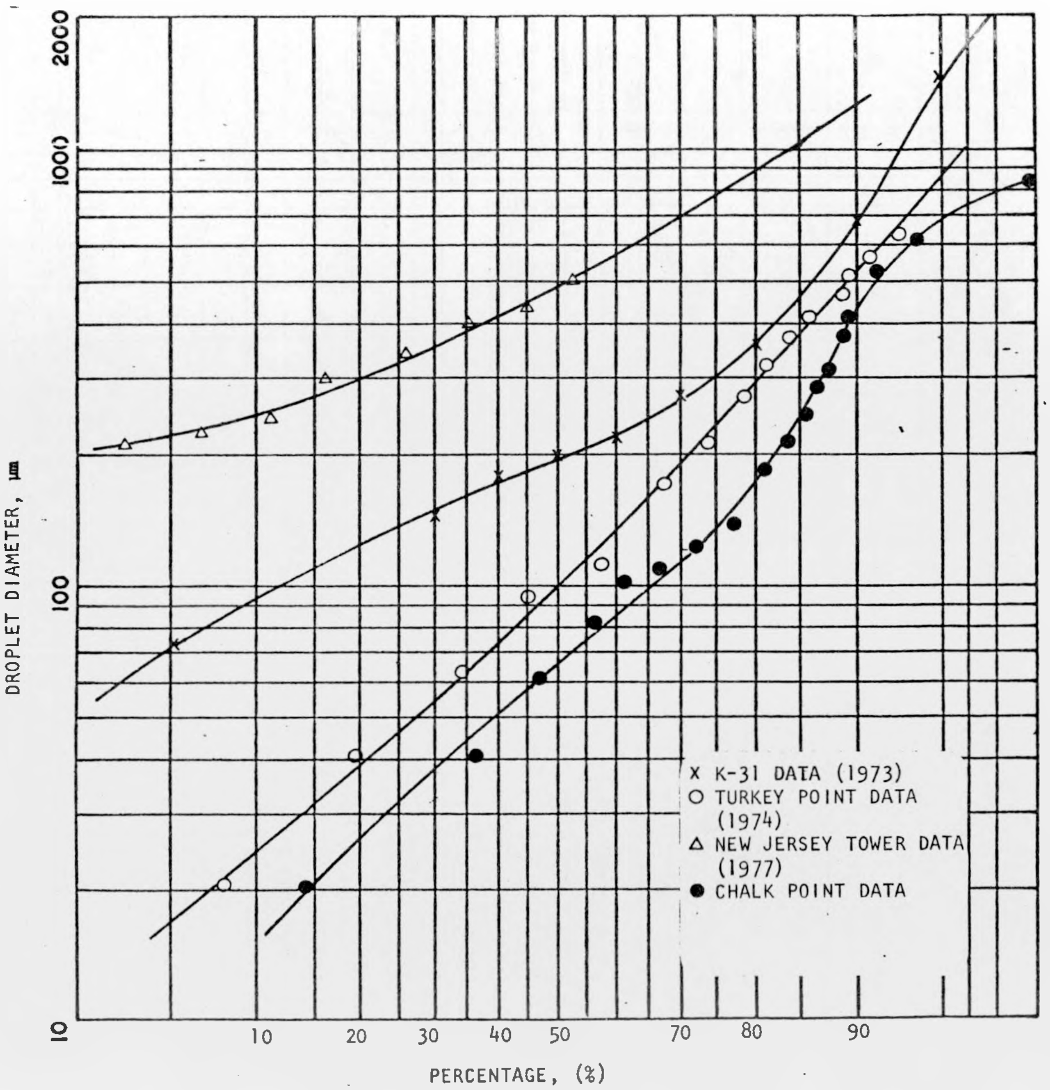

Figure 3

DRIFT MASS EMISSION

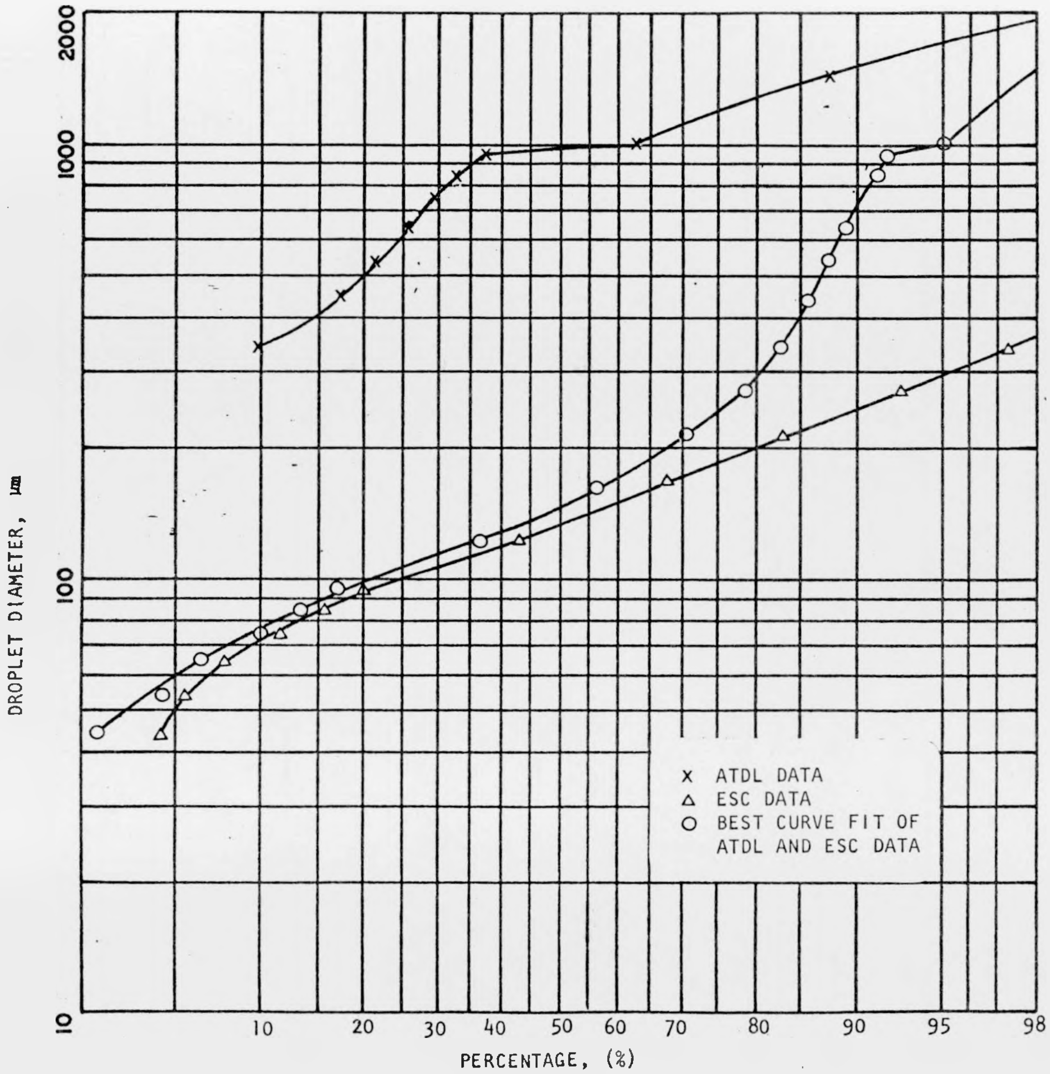

Figure 4

DRIFT MASS EMISSION 1973 OAK RIDGE COOLING TOWER RESULT

TABLE 2

OAK RIDGE COOLING TOWER DATA SUMMARY

Station	V_j	gms/sec ft^2		gms/sec	
j	ft/sec	D/A/IK	D/A/PILLS	D_j/IK	D_j/PILLS
1	20	0.029	.012, d>80 m	0.79	0.33
2	35	0.119	.047, d>120	7.67	3.03
3	18.3	0.025	.017, d>100	0.95	0.65
5	18.3	0.026	.0046, d>80	1.01	0.18
6	34.2	0.100	.13, d>140	6.55	8.36
7	29	0.074	.037, d>120	2.04	1.02

$$D = \sum_j D_j = 19 \qquad 13.6 \text{ gm/sec}$$

$$\text{drift percentage} = \delta = \begin{cases} \dfrac{19 \times 100\%}{25 \times 10^4} = 0.0076\%, \text{ IK} \\[2ex] \dfrac{13.6 \times 100\%}{25 \times 10^4} = 0.0055\%, \text{ PILLS} \end{cases}$$

The evidence of these large drops are shown on the sensitive paper test of ground deposition by ESC and ATDL. Again the size of sensitive papers used are 9.6 square centimeters for ESC and 8-1/2 in. x 11 in. for ATDL. The results are shown in Tables 3 and 4 and in Figure 5. Figure 5 and Table 3 show the variation of the mass median drop sizes fo ground deposition with distance from the tower. ATDL also reported observing a few drops in the 2,000- to 3,000-μm size range on the fan deck, as shown in Table 4.

PROPOSED STUDY OF COOLING TOWER AT ORGDP

The justification for continuing cooling tower drift studies is the need for better and additional field data in order to provide a significant statistical set of data that has been obtained during continuous testing of a cell under various meteorological conditions. The proposed cooling tower drift study in Oak Ridge has been planned to answer some of the fundamental questions which are directly connected with Oak Ridge Plant Operations. To answer the questions, information must be obtained in the areas that follow.

RELIABLE INFORMATION ON DRIFT RATE

As an operator of large cooling towers, we have a responsibility to assess the environmental impact of drift from these units. This will require a determination of mineral effluent flux from the cooling towers which can be obtained from a determination of the total drift rate and the average concentration of chemicals in the drift.

CORRELATING DRIFT RATE WITH COOLING TOWER OPERATING CONDITIONS

A cooling tower may exhibit an unique drift rate that depends on the type of cooling tower, operating conditions (L/G), mist eliminator type, and meteorological condition of the area. It is, therefore, the intention of this investigation to correlate the drift rate with parameters connected with cooling tower operation. This will be based on data obtained from measurement of:

1. Cross-flow - counterflow towers,

2. Old and new towers (1954 and 1977),

3. Various water and air flow rates (L/G), and

4. Towers tested under various meteorological conditions.

PARTICLE SIZE DENSITY DISTRIBUTION

The spectrum of drop sizes existing in the drift is an essential parameter that must be measured. This information is particularly important to the transport model study. Models have typically treated the transport process

Table 3

DRIFT DEPOSITION RATES AND MASS MEDIAN DROP SIZES AT GROUND DOWNWIND OF K-31 TOWER

Distance From Tower, M	Mass Median Drop Diameter, μm	Drift Deposition Rate, μg/sq m-hr	Chromium Deposition* Rate, μg/sq m-hr	Calcium Deposition* Rate, μg/sq m-hr	Magnesium Deposition* Rate, μg/sq m-hr
7	750	256×10^6	4,040	44,900	11,200
7	750	220×10^6	3,480	38,600	9,630
10	1,000	266×10^6	4,220	46,800	11,700
15	1,000	238×10^6	3,760	41,800	10,400
15	600	745×10^6	11,800	131,000	32,700
15	750	72×10^6	1,140	12,700	3,160
30	450	79×10^6	1,250	13,900	3,470
30	450	277×10^6	4,390	48,700	12,200

*Computed from Drift Deposition rate using average basin concentrations of the elements in question.

Table 4

DRIFT DEPOSITION RATE TWO METERS DOWNWIND OF CELL

Tower Cell No.	Mass Median Drop Diameter, μm	Drift Deposition Rate, μg/sq m-hr	Chromium Deposition* Rate, μg/sq m-hr	Calcium Deposition* Rate, μg/sq m-hr	Magnesium Deposition* Rate, μg/sq m-hr
K-31-3	2,500	468×10^6	7,410	82,300	20,500
K-31-6	2,500	972×10^6	15,400	171,000	42,600
K-31-4	2,000	205×10^6	3,250	36,100	9,000
K-33-8G, Fan 16	900	25.6×10^6	203	3,720	808
K-33-9G, Fan 18	600	10.4×10^6	83.1	1,520	330

*Computed from Drift Deposition rate using average basin concentrations of the elements in question.

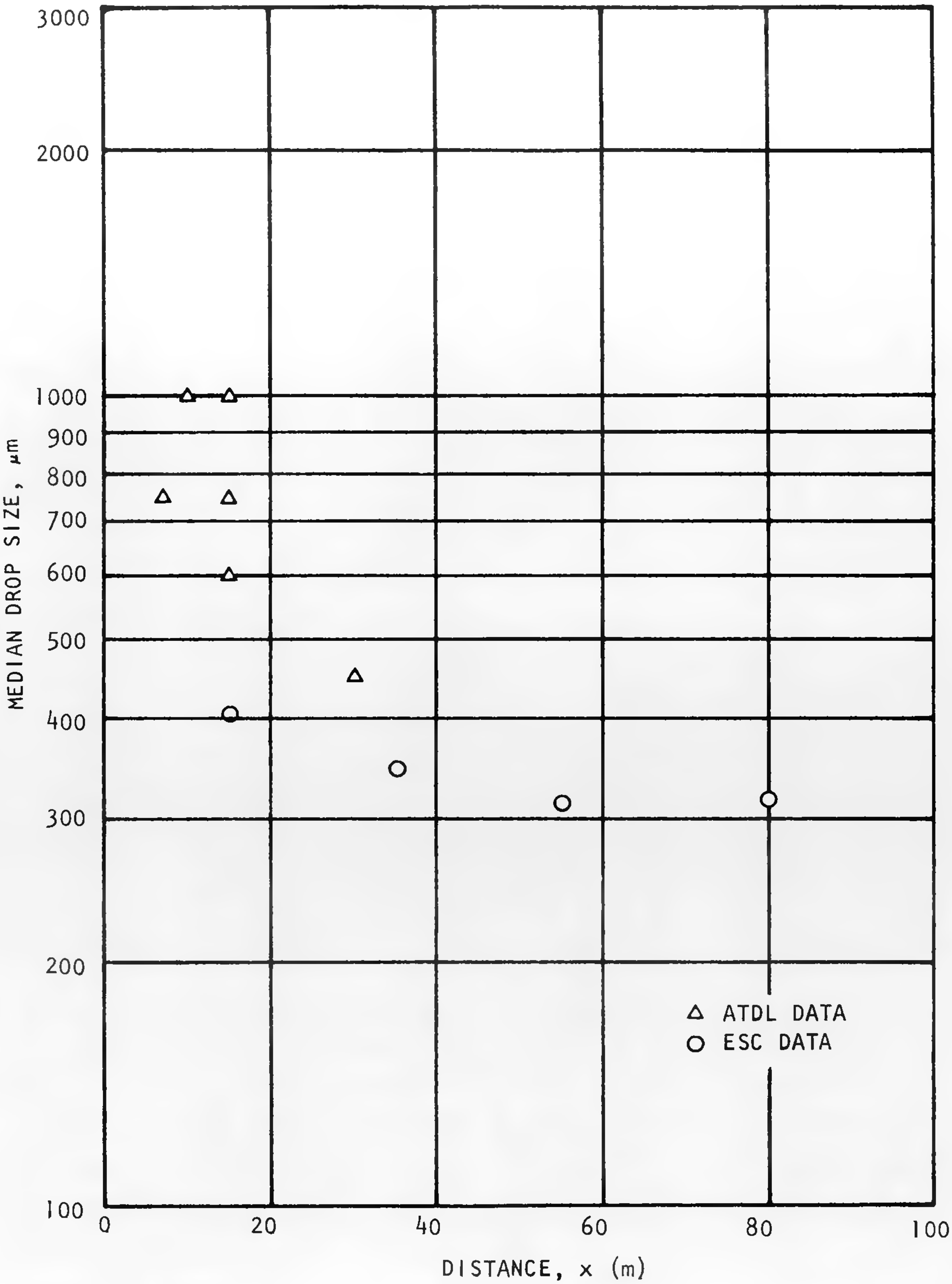

Figure 5

GROUND DEPOSITION RESULTS

of drops from the tower to the surroundings with either the Gaussian plume method, the ballistic method, or a combination of both. The particle size density distribution constitutes an input condition to the various models, and inaccuracies can result in two or three orders of magnitude difference on ground deposition as calculated by Schrecker[2] (1974). The particle size density distribution information may also provide insight to the origin of the drops and effectiveness of the mist eliminator.

UNDERSTAND THE TRANSPORT MECHANISM

The transport mechanisms of droplets would be studied. The physical processes that could influence drop transport will be investigated and a study conducted on the influence of other factors, such as large buildings surrounding the cooling towers.

UNDERSTAND THE EFFECTS OF METEOROLOGICAL AND GEOGRAPHICAL CONDITION

The flight of drops from the cooling tower exit to ground are greatly influenced by various meteorological and geographical conditions. The ground deposition of drift depends on:

1. Wind velocity and direction,

2. Relative humidity,

3. Turbulence,

4. Stability condition,

5. Terrain effect, and

6. Recirculation effect.

The relative influence of these factors on ground deposition of drops and mineral flux are not fully understood. With acquisition of field data, the various models would be compared to determine their relative importance. A transport model would then be developed or selected from the existing models in order to predict the drift deposition of future cooling towers.

ASSESSMENT OF THE IMPACT OF CHROMIUM

A long-term study of deposition of chromium is being carried out by the Oak Ridge National Laboratory. The environmental impact of chromium on vegetation, animal life, and the food chain, in general, is being determined.

The measurements of source characteristics would include:

1. Velocity profiles,

2. Temperature profiles,

3. Particle size density distributions,

4. Drift rates, and

5. Mineral fluxes.

The drift rate determination of the cooling tower can be accomplished by two methods:

1. Determining the particle size density distribution, and

2. Measuring the total mineral flux.

Obtaining the droplet size spectrum is by far the most difficult to achieve, due to poor counting procedures and limitation of measuring methods. The difficulty of counting large drops which occur in low frequency, but contribute significantly to the drift rate exists with certain instruments. Table 5 summarizes some of the capabilities of the measuring instruments currently available.

The ground deposition of drift will be measured simultaneously with the source characteristics measurements. The predominant wind direction at the Oak Ridge Plant is from SW to NE. The sampling will be done along three radii in this direction and there will be 5 to 6 sampling points on each radii extending up to 1 km distance from the cooling tower. The measurements at each sampling point would include:

1. Drop size deposition,

2. Chromium deposition, and

3. Airborne concentration measurement of chromium.

Tables 6 and 7 summarize the measuring techniques available. Besides these measurements, there is a continuing effort to assess the intake and retention of chromium in plant and animal life.

With good reliable field data on both source and deposition, it is hoped to find relationships of efflux deposition with:

1. Distance from tower,

2. Meteorological conditions, and

3. Evaporation of water droplets.

The effect of recirculation of the cooling tower plume on drift deposition, as well as heat transfer efficiency is under investigation. Hanna[6] (1974) observed that downwash occurs about 50% of the time at the Oak Ridge induced draft cooling towers when wind speed exceeds about 3 m/sec. The study will be based on the model that simulates two-dimensional steady state flow over a bluff body with recirculation and droplets being investigated by a trajectory model. The model would provide us the relative importance of the recirculation on the drift deposition pattern around the cooling towers.

Table 5

DRIFT EMISSION MEASUREMENT AT TOWER MOUTH (See Chen)[7]

Technique	Measurement Capability: Droplet Size Distribution	Size Range Measured	Mineral Mass Flux	Accuracy
Sensitive Paper	Yes	1-50 μm (ESC)* 50 μm up (ATDL)**	No	Fair
Coated Slides	Yes		No	Fair
Isokinetic Sampling Tube	No		Yes	Very Good
Cyclone Separator	No		Yes	Good
Laser Scattering	Yes	50-1000 μm (ESC)	No	Good
Chemical Balance	No		Yes	Poor
Calorimetry	No		No***	Poor

*ESC (Environmental Systems Corporation), a company in Knoxville, Tennessee.

**ATDL (Atmospheric Turbulence and Diffusion Laboratory), a NOAA laboratory in Oak Ridge, Tennessee.

***Measures total water content, neither droplet-size distribution nor mineral mass flux.

Table 6

DEPOSITION MEASUREMENT ON THE GROUND (See Chen)[7]

Technique	Principle of Operation	Measurement Capability: Droplet Size Distribution	Measurement Capability: Size Range Measured	Measurement Capability: Mineral Mass Flux	Accuracy
Sensitive Paper	Collection	Yes	1 µm up	Yes	Fair (Israel & Overcamp)
Deposition Pans	Collection	No	N/A*	Yes	Fair (U. of Maryland)
Neutron Activation	Collection	No	N/A	Yes	Unknown (ORNL)**
Grass Interception	Collection	No	N/A	Yes	Fair (ORNL)

*Not applicable.

**A measuring technique proposed by Oak Ridge National Laboratory.

Table 7

AIRBORNE MONITORING - BACKGROUND AND TOWER CONTRIBUTION (See Chen)[7]

Technique	Principle of Operation	Measurement Capability: Droplet Size Distribution	Measurement Capability: Mineral Mass Concentration	Accuracy
High-Volume Sampler	Collection	No	Yes	Fair
Airborne Particulate Sampler	Collection	No	Yes	Good

CONCLUSIONS

A previous investigation of cooling tower drift and the ramifications of its fallout pattern on the environs was conducted in Oak Ridge in 1973. That landmark study has been used in many subsequent treatments of drift from mechanical draft cooling towers and constitutes some of the best data available today. The study, however, was a highly intensive study of a limited number of cooling tower cells conducted over a few days interval. This precluded a determination of the influence of meteorological, operating, and geometrical variations on drift characteristics and did not permit a determination of cooling tower cell interaction in large cooling tower complexes. There are also some inconsistencies in the data which need to be resolved.

To provide information necessary for environmental impact assessments of cooling tower operation, it is necessary to obtain a mathematical model of the drift process which will duplicate mechanisms accurately enough to predict the drift fallout patterns from existing, as well as new installations. There are several models available today, but they differ by two or three orders of magnitude in their assessment of identical installations. Due to the lack of experimental data, these models cannot be evaluated to determine which is most accurate. In order to fill this data void, it is necessary to conduct a more extensive investigation of the cooling towers which will provide input to establish correlations between pertinent parameters and drift fallout patterns. These data will permit the fashioning of a new model or selection of an existing code as a practical working tool for cooling tower environmental studies.

There are three areas which need to be investigated to provide the desired data for our program:

1. Source,
2. Transport, and
3. Deposition.

A measurement of particle size distribution will be a prime experimental goal, since this will provide input to the transport model, as well as determining the drift rate. An independent measurement of drift rate will be obtained to provide confidence in the measurements of the drift source.

The influence of variables on the transport of the drift particles will be established for inclusion in the transport model. The experimental determination will require multiple cell testing to provide a base definition and long-term testing of a few cells to provide correlation with variables.

The deposition data will consist of airborne and ground collection of drift to establish fallout patterns. The ground collection will provide quantitative determination of drift fallout, as well as particle size distribution with distance from the tower.

The problem is complex and will require incorporation and treatment of complex mechanisms in the model such as turbulence of the air stream flow, temperature inversions, recirculation, and evaporation of the drift droplets. The problem will probably be accomplished in steps with the first providing a base model and each succeeding step incorporating necessary improvements.

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