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ENVIRONMENTAL ASPECTS OF COOLING TOWER OPERATION: SURVEY OF THE EMISSION, TRANSPORT, AND DEPOSITION OF DRIFT FROM THE K-31 AND K-33 COOLING TOWERS AT ORGDP

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February 1974

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ABSTRACT

The results from a program to evaluate the environmental aspects of cooling tower operation at the Oak Ridge Gaseous Diffusion Plant (ORGDP) are presented. The quantities of chemicals being introduced into the atmosphere as well as the deposition of these chemicals on the environs surrounding the cooling towers were measured. Based on the tests performed, the cooling towers, under present operating conditions, are not causing any adverse effect on the native vegetation surrounding ORGDP.

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INTRODUCTION AND SUMMARY

In today's environmentally-conscious society, all systems which introduce detectable quantities of energy and/or material into the surroundings are being intensively studied. Of particular interest to the gaseous diffusion industry, is the study of certain elements such as chromium and zinc which are used in the recirculating water systems for corrosion control. Because these systems involve the use of evaporative cooling towers to reject heat, some traces of these elements are carried into the atmosphere as a result of drift* loss and are finally deposited on the environs surrounding the cooling towers. These elements may also be introduced into surface waters such as rivers by blowdown** from the cooling tower water supply. This latter source is being studied by several groups. One promising method, that essentially eliminates blowdown, has been evaluated by the Power and Utilities Department at the Oak Ridge Gaseous Diffusion Plant (ORGDP). It consists of blending the blowdown stream with the raw makeup water and softening the mixture with lime-soda ash. The details of these studies will not be discussed in this report.

When the Cascade Improvement Program (CIP) and Cascade Uprating Program (CUP) are complete,[2] ORGDP will be operating at a nominal power level of 2080 Mw. To reject this heat load to the atmosphere, mechanical draft cooling towers circulating approximately 300,000 gallons of water per minute will be needed. Two major process buildings are involved; these are designated K-31 and K-33. The enriching equipment in K-33 is larger than that in K-31 and approximately two-thirds of the recirculating water is used in K-33, while K-31 uses the other one-third. The cooling towers were originally constructed in the early 1950's and have been rebuilt since then. The K-31 tower is a Marley cross-flow unit consisting of 16 cells with 264-in. fans, and the K-33 tower is a modified Foster-Wheeler counterflow tower consisting of two banks of 11 cells each, each cell containing two 244-in. fans.[3]

When the towers were purchased, a maximum drift limitation of 0.2% was included in the specifications. Until this series of tests, however, the drift rates from the towers were never measured. The water temperature in the tower ranges from 140°F inlet to 90°F outlet. The relatively high temperatures in the cooling water system create potential corrosion problems in the mild steel piping network, so that there is need for a good corrosion inhibitor in the water. Extensive tests run approximately

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**Drift* is defined as water lost from the tower as liquid droplets entrained in the exhaust air. Units are pounds per hour or percentage of circulating water flow.[1]

***Blowdown* is defined as water deliberately purged from the cooling tower system in order to avoid the accumulation of dissolved solids.

15 years ago demonstrated that a proprietary zinc/chromium inhibitor manufactured by the Betz Corporation provided the protection required. Present practice is to maintain hexavalent chromates at approximately 20 ppm.

Recognizing that operation of the cooling towers at ORGDP introduced significant amounts of both energy and material into the environment, Union Carbide Corporation, Nuclear Division (UCC-ND) acting as contractor to the U. S. Atomic Energy Commission (USAEC) undertook a program to determine the magnitudes of the quantities involved and to evaluate their effect on the surroundings. The primary goals of this study were (1) to measure the quantities of chemicals emitted from the towers in the drift, (2) to determine how these chemicals were transported to and deposited on the environs, and (3) to evaluate their effects on the vegetation around the towers. During the planning phase of this program, it was recognized that the information to be developed could be useful to others concerned with the environmental aspects of large mechanical draft cooling towers, particularly those in the nuclear power field. Consequently, it was decided to expand the scope of the studies beyond the minimum needed for ORGDP's interests and to obtain more extensive data. As the program developed, various groups of people within the USAEC purview were invited to participate in this study in order that the program might benefit from their backgrounds and capabilities and to ensure that a broader range of interests might be served.

Representatives from the USAEC and several of their contractors, as well as other branches of the Federal Government, State governments, and private industry were called on during the several phases of the program to aid in its planning and execution and in disseminating the results obtained. The experimental portion of the study included participants and/or primary observers from the Oak Ridge and Paducah Gaseous Diffusion Plants, the Oak Ridge National Laboratory, and the Oak Ridge Y-12 Plant, all of which are operated by the Nuclear Division of Union Carbide Corporation for the U. S. Atomic Energy Commission; Environmental Systems Corporation; the Atmospheric Turbulence and Diffusion Laboratory, which is a part of the National Oceanographic and Atmospheric Administration; and the Pacific Northwest Laboratory, operated for the USAEC by Battelle Memorial Institute.

The actual study which lasted from December 1972 to July 1973 consisted of experimental work and analysis by four of the groups working in close contact with ORGDP personnel. The results of this program constitute some of the most comprehensive information on the environmental aspects of the operation of large mechanical draft cooling towers that has been obtained thus far. The groups involved were experienced in the measurement of cooling tower drift as it is emitted from the cell as well as its concentration in the air and on the ground surrounding the towers. In addition, one of these groups was capable of mathematically modeling the behavior of the plume. The participants, and a summary of the studies performed, are as follows:

<u>Environment Systems Corporation (ESC)</u>,[4] Knoxville, Tennessee: Extensive studies of the drift emission from two fans, one in the K-31 tower and one in K-33, were undertaken. These included temperature, velocity,

droplet distribution, and total drift emission at the fan mouth. This was done using three methods consisting of a unique laser light scattering instrument, sensitive paper, and an isokinetic sampling probe. In addition, a limited amount of information on the fallout distribution in the vicinity of the K-31 tower was obtained.

Battelle Pacific Northwest Laboratories (BNW),[5] Richland, Washington: Detailed studies of the air concentration and deposition rates of chromates in the vicinity of the K-31 and K-33 cooling towers were made. These studies were more extensive than the fallout studies of ESC in that they covered distances up to 1500 m from the cooling towers.

Atmospheric Turbulence and Diffusion Laboratory (ATDL),[6] Oak Ridge, Tennessee: Velocity and temperature profiles on numerous fans in both K-31 and K-33 were obtained in addition to droplet size data. Information on the relative occurrence of downwash and the atmospheric conditions causing it as well as numerous photographic observations of plume height and length was presented. A small amount of information on the deposition rate in the immediate vicinity of the tower was included. Background meteorological data at the tower site were obtained providing necessary information for use with analytical models of drift transport and fogging probability studies.

Ecological Sciences Division, Oak Ridge National Laboratory (ORNL),[7,8] Oak Ridge, Tennessee: The intake of chromium and zinc in several plant species at varying distances from the cooling towers as well as the effect of these elements on growth rate was investigated.

Information on the physical characteristics of the cooling towers along with a brief discussion of their history is given in a recent report by Uglow.[3]

Although some preliminary scoping measurements were made in April, the majority of measurements of drift emission and deposition were made during a two-week period at the end of June 1973. During most of this time, the weather was unsettled; there were appreciable changes in both wind speed and direction and it rained on several days when data were taken. Fortunately, the drift emission is not significantly affected by weather conditions. Extensive sampling of the vegetation has been previously done for extended periods of time so that the overall results of this study do provide the information needed to make a preliminary evaluation of the effects of cooling tower operation. However, the variations discovered in many of the parameters under study indicate the need for a continuing program to monitor both the tower performance and the deposition patterns.

Generally, it can be seen that the objectives of several of these studies overlap and complement each other. The ESC study[4] forms the basis of the drift emission measurements from the K-31 and K-33 cooling towers. This study is complemented by portions of the ATDL report.[6] The concentration of chromium in the air and the deposition rate in the vicinity of the cooling towers is covered in the BNW study.[5] This information is supplemented by the independent measurements of ESC[4] and ATDL.[6] Finally, the effect of the cooling tower drift on the concentration of chromium and zinc in the vegetation surrounding ORGDP is studied by the ORNL Ecological Sciences Division.[7,8] All studies, as planned, were related to the overall goals cited earlier.

In this report, the findings of the four component studies are combined and summarized. The data obtained have been further analyzed, and an evaluation of the results from the various independent groups has been made. The areas where agreement exists are discussed and the areas where conflicting results are presented have been delineated. This report will not only serve as an up-to-date study of the present status of drift emission from the ORGDP cooling towers, but also will provide a basis for the formulation of plans for future tests to study the effects of other parameters on the drift emission and to develop ways of further decreasing the drift.

The results of this study show that the ORGDP towers are operating within the limits on drift fraction specified when the towers were originally procured even though some of the drift eliminators have deteriorated over the years. The measurements of transport and deposition have provided limited experimental confirmation of analytical models so that these parameters can now be calculated with better confidence for a wider range of operating and meteorological conditions. The studies of vegetation around the towers indicate that plants serve as reliable "instruments" for detecting small quantities of chemicals and that the drift from the towers has little effect on plants at distances over 600 m from the towers.

Consideration is given to a more extensive series of tests on the cooling towers. Such parameters as variations in meteorological conditions may be investigated. In addition, the effect of increased power load corresponding to CUP conditions can be studied to determine the effect on both the drift flux from the towers and the deposition of that drift. Similar tests at the other gaseous diffusion plants are also under consideration.

DESCRIPTION OF EXPERIMENTS

VELOCITY AND TEMPERATURE PROFILES

Velocity and temperature profiles were measured by ESC on Cell 6 of the K-31 tower on June 26 and June 27, 1973. Measurements were also made on Cell 11H, Fan 22 of the K-33 tower on July 2, 1973. A sketch of the location of the two diametral traverses on the K-31 tower and the one diametral traverse on the K-33 tower is given in figure 1. The air velocity was measured by a Gill propeller anemometer. A modified Yellow Springs Model 3314 electronic psychrometer capable of measuring dry-bulb temperature and wet-bulb depression was used for temperature measurement. The instruments were contained in a package mounted on a traverse rail. Readings were taken at each of fifteen stations on each traverse.

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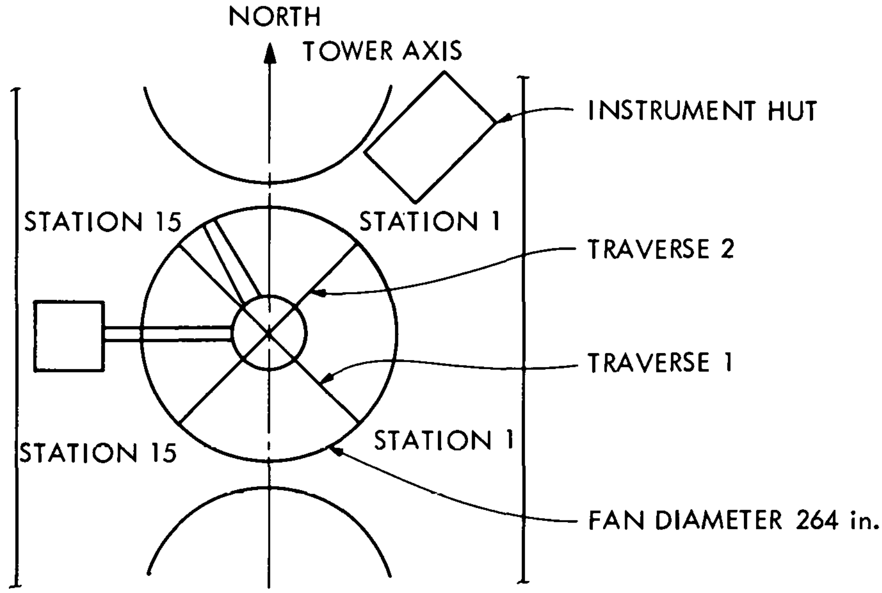
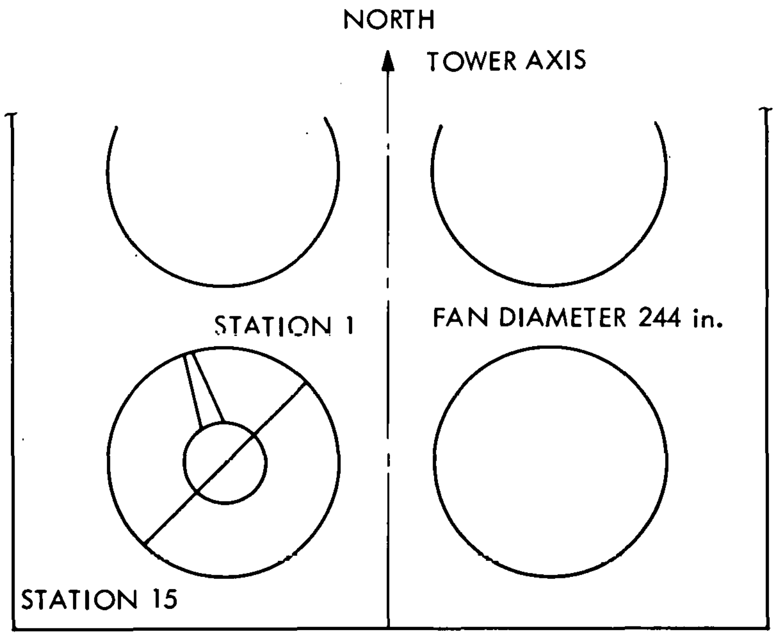


(a) K-31 Tower, Cell 6
(Cross-Flow Design)



(b) K-33 Tower, Cell 11H, Fan 22
(Counterflow Design)

Figure 1

DIAMETRAL TRAVERSE LOCATIONS, ESC DRIFT TESTS

The ATDL tests also utilized a propeller-type anemometer for velocity measurements. For the K-31 tower, data were taken on all seven cells operating during the week June 25 to June 29, 1973. For the K-33 tower, experiments were run on Cell 6G, Fan 12. Temperature measurements by ATDL were made with a Taylor indoor-outdoor thermometer taped to the end of an aluminum pipe. Because of the water droplets in the air, the dry-bulb and wet-bulb temperatures can be assumed to be approximately equal. This was confirmed by the ESC measurements described earlier where the two temperatures were found to differ by a fraction of a degree.

DROPLET SIZE DISTRIBUTION

A knowledge of the droplet size distribution in the drift leaving the cooling tower is important since this, along with various meteorological conditions, will affect the behavior of the plume. Consequently, empirical information on this parameter, when put into mathematical models of plume behavior, will give a more accurate prediction of the drift concentration in the air as well as the distribution of deposits on the ground.

ESC undertook a thorough study of the droplet distribution at the mouth of the fan in Cell 6 of the K-31 tower and a limited study of the distribution from Cell 11H, Fan 22 of the K-33 tower. The measurements on the K-31 tower were made in two ways. For water droplet diameters in the range of a few to 200 μm, sensitive paper was used. In this technique, a piece of chemically-treated paper was oriented so that the surface of the paper was normal to the airflow. Thus, the impingement velocity of the particles was essentially that of the airflow. The sensitive paper was exposed to the airflow for a specified time period and was then analyzed microscopically. The stain sizes on the paper were converted to the true particle size using an impingement velocity calibration curve. A statistical analysis of the particle size distribution was then performed. For the diameter range between 200 and 1000 μm, a Particulate Instrumentation by Laser Light Scattering System (PILLS II) was used. Basically, this instrument produced a voltage output which was related to the size of the particles which entered its sampling volume one at a time. Thus, by counting the number of voltage signals and correlating those with the magnitude of the signal, a droplet size distribution was obtained. No study of droplet size in the diameter range in excess of 1000 μm was performed. Only the sensitive paper technique was used on the K-33 tower.

Another study of droplet size distribution which complemented the tests of ESC was performed by ATDL. Sensitive paper alone was used in these experiments, and only droplets of size larger than 100 μm were discernable. ATDL did, however, detect droplets with diameters as large as 5000 μm. In contrast, the ESC studies were limited to drop diameters of 1000 μm or less. ATDL tests were conducted on eight cells in the K-31 tower which were operating on the day the measurements were taken. Very little difference in droplet distribution was found among the cells. The two tests conducted on Cell 8G, Fan 16 and Cell 9G, Fan 18 of the K-33 tower indicated only the presence of droplets less than 1500 μm in size.

TOTAL DRIFT FROM THE K-31 AND K-33 TOWERS

ESC obtained the total drift by summing the droplet distributions described earlier over all droplet sizes and over all cell positions. They also used an independent technique involving an isokinetic sampling method. In this experiment, the drift-laden air emanating from the fan mouth entered sampling tubes containing heated glass beads. The water was evaporated from the sampling tubes, leaving its mineral content on the glass beads. These minerals were then stripped from the tubes and analyzed chemically. With a knowledge of the concentration of the elements (chromium, magnesium, and calcium in this case) in the tower basin under study and assuming that the concentration of the elements in question was the same in the droplets as in the basin,* the amount of drift emitted from the cell was back-calculated. This isokinetic sampling technique was used in both the K-31 and K-33 studies.

Based on their droplet size measurements made on sensitive paper, ATDL also obtained drift flux information. Tests were conducted on all eight operating cells in K-31 and Cell 8G, Fan 16 and Cell 9G, Fan 18 of the K-33 tower.

TRANSPORT STUDIES

From the tests described in the preceding three sections, a good estimate was obtained of the amount of drift emanating from the cooling towers as well as characteristics such as droplet size, velocity, and temperature distributions. Coupled with a knowledge of the surrounding atmospheric conditions and environs, one has the necessary parameters to attempt to mathematically model the behavior of the plume, the distribution of the drift in the air, and the distribution of deposits on the ground in the vicinity of the cooling towers. Since any model which one would expect to reasonably predict these parameters is necessarily quite complex, measurement of the drift concentration in the air and the deposition in the vicinity of the cooling towers would serve as a check on the results of such a model.

A limited amount of information was obtained by ESC on the chromium, calcium, and magnesium concentrations in the air near the K-31 tower. Airborne Particle Sampler (APS) Systems were used for these studies. The instruments were electrically-driven horizontal propellers with small pieces of screen or mesh mounted on the APS arms at an elevation of approximately ten feet above the ground. By recording the number of rotations made by the arm and knowing the area of the meshes, the volume swept out by an APS system could be calculated. At the end of the test, the meshes were removed and their chromium, calcium, and magnesium contents were measured. The air concentrations could then be determined in terms of micrograms of material per cubic meter of air. Three APS units were used at approximately the same time with two units downwind and one upwind for ambient background determination. A sketch of all the APS locations is given in

*Additional tests by G. P. Patterson of ORGDP have verified the validity of this assumption.

figure 2. Typically, the locations were 75, 100, 125, and 175 m from the tower. In addition to the above tests, fallout measurements were taken at nine stations of the K-31 tower using sensitive paper. These stations were located at 10-m increments from the north end of the tower. Particle size distributions of the fallout as a function of distance from the cooling tower were thus obtained. From these results, the deposition flux in terms of μg/sq m-hr was computed.

BNW conducted a study of the concentration of chromium in the air and the deposition in the vicinity of the K-31 and K-33 towers. A sketch of the sampling locations is given in figure 3. As can be seen, the distances from the cooling towers that were covered exceeded those of the ESC tests. Air sampling was performed with vacuum pumps which drew ambient air through filters at a controlled flow rate. After each test, the filters were removed and soaked in nitric acid. The chromium content was determined with an atomic absorption spectrophotometer. Deposition sampling was performed using polyethylene jars which had an exposed area of approximately 75 sq cm. After each test, the deposition samples were collected in polyethylene dishes and analyzed in a manner similar to the air sampling filters.

Additional information on deposition rate and mean droplet diameter of the fallout was obtained by ATDL. Using sensitive paper, data were taken both on the walkways of the K-31 and K-33 towers (approximately 2 m from several of the cells) and on the ground under the plume axis at distances of up to 30 m from the towers.

As an extension of the present studies, a Gaussian plume dispersion model was used by ATDL to determine the drift deposition. The calculated values and experimental results were found to agree fairly well.[9]

EFFECT ON VEGETATION

A study of the effect on the environment of chromium and other elements used in corrosion control must, in the final analysis, depend on the quantities of these materials which are absorbed by the vegetation surrounding the cooling towers. Therefore, an inventory was made by ORNL of chromium and zinc concentrations in several plant species located at distances of 15 to 1750 m from the K-33 tower along the axis of predominant winds (NE-SW). Samples of grasses, forbs, coniferous and broadleaf trees, and soil were chemically analyzed. The location of the harvest plots is given in figure 4.

The samples of plant materials obtained were completely burned, and the ashes were treated with nitric acid before being analyzed for chromium and zinc by an atomic absorption spectrophotometer. Soil samples were chemically treated in a different manner before being analyzed by atomic absorption. The original publication[7] should be consulted for the appropriate preparation details.

In addition to measuring the amount of chromium present in plants and soil, it is important to know the effect of the drift on the growth rate of plants. For this purpose, tobacco plants, which are known to be extremely sensitive to chromium, were exposed to cooling tower drift. Three-month-old plants were placed at four locations along the axis of most frequent

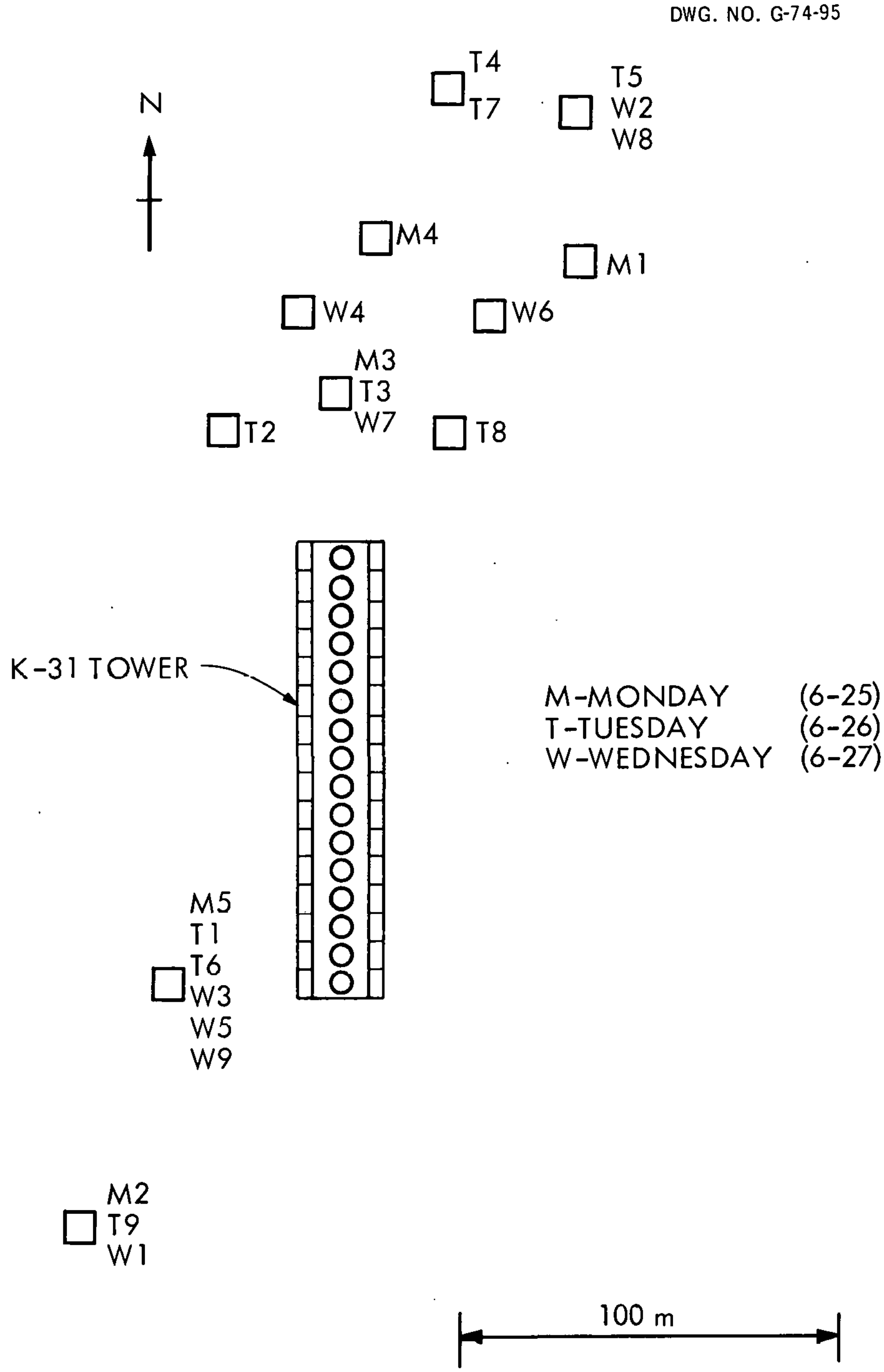


Figure 2

AIRBORNE PARTICLE SAMPLER SYSTEM LOCATIONS, ESC TRANSPORT TESTS

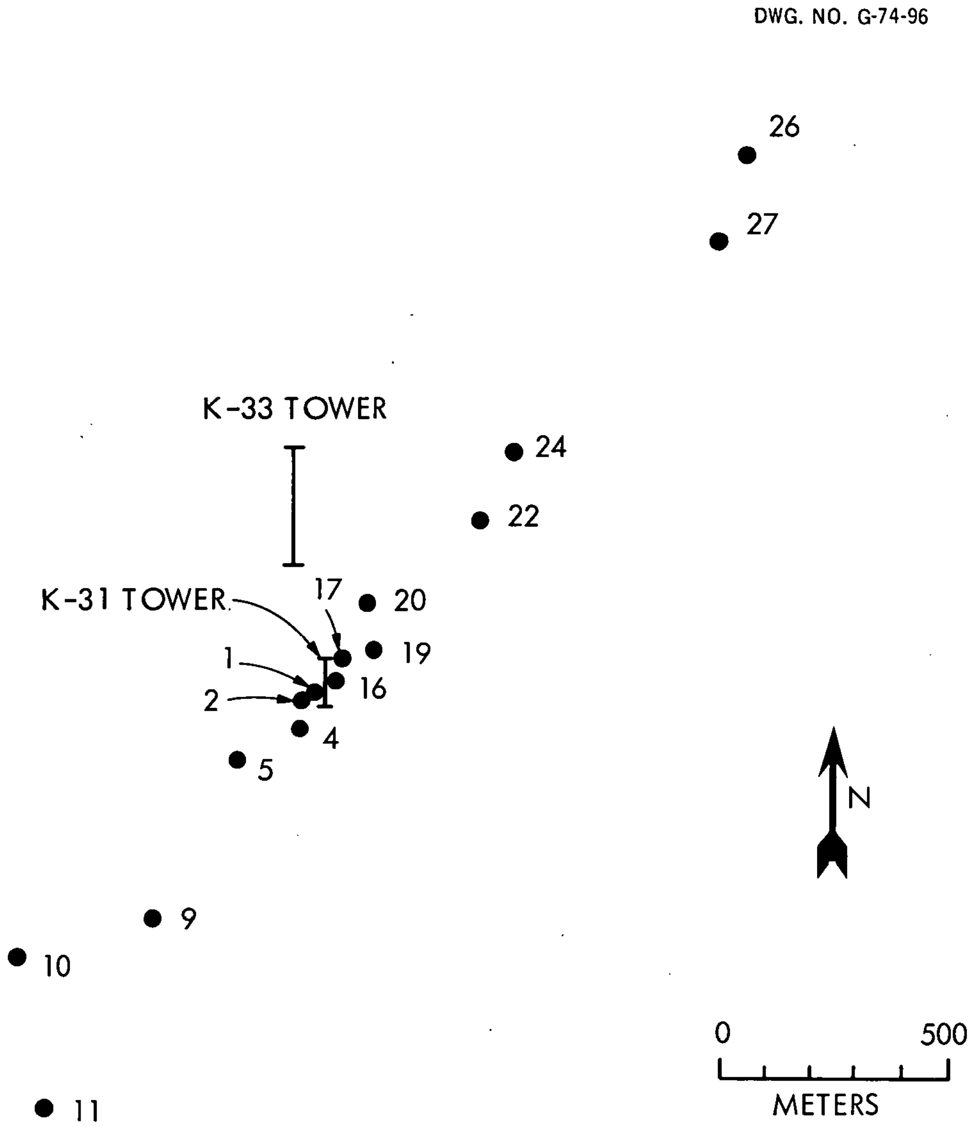


Figure 3
CHROMATE SAMPLING STATIONS, BNW TESTS

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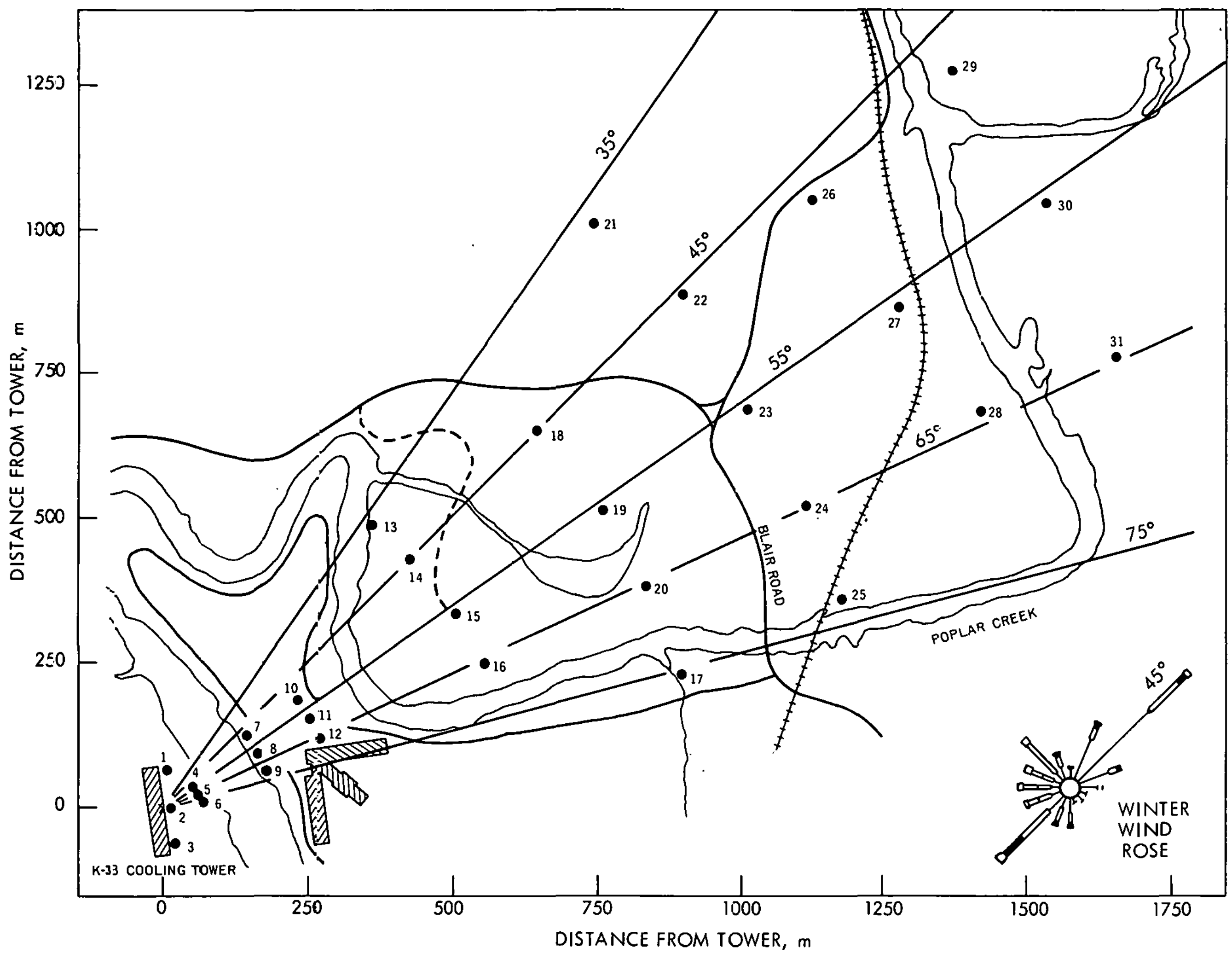

Figure 4

LOCATION OF HARVEST PLOTS NORTHEAST OF THE K-33 COOLING TOWER wind directions. Forty potted plants were placed at each of the following distances from the cooling towers: 15, 200, 600, and 1400 m. Additional plants were located in a control area, remote from the drift. Four plants were harvested at one-week intervals from each location, and leaf size was used as the parameter for assessing effects on growth.

RESULTS AND DISCUSSION

VELOCITY AND TEMPERATURE PROFILES

K-31 Tower - Velocity Profiles

The two velocity profiles for Cell 6 of the K-31 tower obtained by ESC are shown in figure 5. As can be seen, the two profiles were very similar and quite symmetric on both sides of the fan hub. On the average, the maximum velocity occurred at a radius of approximately 2 m. On the basis of the measurements made in Traverse 1, the average velocity was 8.04 m/sec and the volumetric flux was 296.4 cu m/sec. From Traverse 2, an average velocity of 7.99 m/sec and a volumetric flux of 294.5 cu m/sec were obtained. In the above calculations, the velocity in the wake of the hub was neglected since it was either very close to zero or slightly negative in all cases - the negative values indicating the effect of downwash. The total area at the mouth of the fan, however, was used in the calculations. On both days of testing seven cells were in operation and, if it is assumed that the other six cells had similar velocity profiles, the total volumetric flux from the K-31 tower was 2068 cu m/sec.

The velocity profile obtained by ATDL for one radius in Cell 6 of the K-31 tower is also given in figure 5. The shape was quite similar to the ESC curves although slightly higher. The maximum velocity occurred at a distance of 1.7 m from the center of the fan. The average velocity was 8.21 m/sec and the volumetric flux was 302.6 cu m/sec. For all seven operating cells, the volumetric flux was 2118 cu m/sec. This was about 2.4% higher than the average value ESC obtained. In table 1, a comparison of some of the velocities obtained on all seven operating cells is presented. As can be seen, at a radius of 1.8 m, which was close to the point of maximum velocity, the agreement was quite good. At a radius of 3.1 m, which was close to the rim, the velocity was much lower, as expected, and the agreement not quite as good. This may be attributed to some degree to interference from the wall.

Table 1

AVERAGE VERTICAL AIR SPEED AT MOUTH OF K-31 COOLING TOWER CELLS, ATDL STUDIES
June 25 - June 29, 1973

Cell		1	2	3	4	5	6	7
Vertical speed, m/sec	1.8-m radius	14.9	15.4	15.0	16.2	15.8	14.2	15.7
	3.1-m radius	4.9	6.2	2.9	3.6	-	-	-

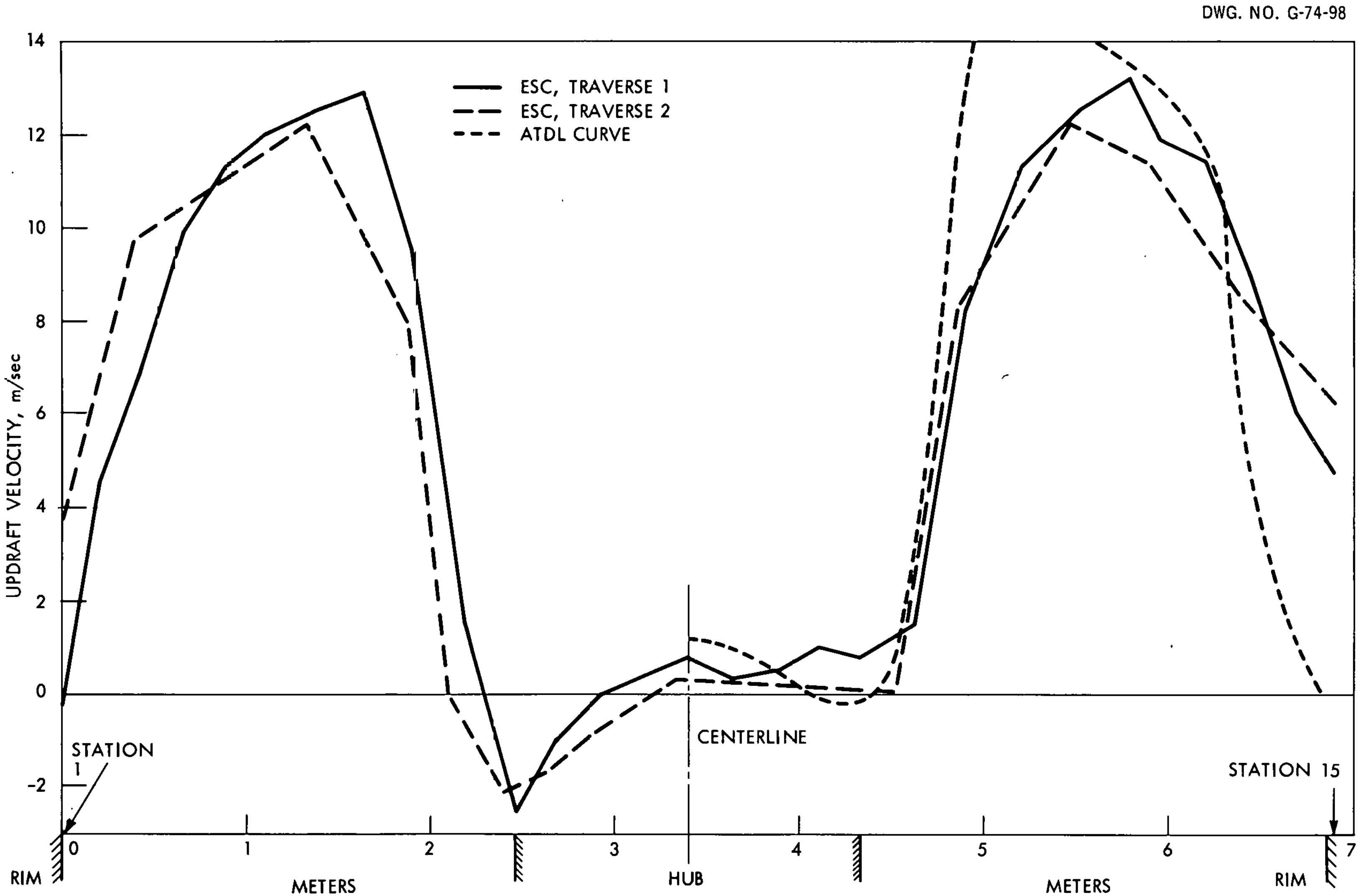

Figure 5

VELOCITY PROFILES, CELL 6, K-31 TOWER

K-31 Tower - Temperature Profiles

The temperature profiles obtained by ESC for Cell 6 of the K-31 tower are given in curves 1, 2, 3, and 4 of figure 6. As can be seen, the temperatures at the edges of the cell were anywhere from 4 to 11°C higher than the temperatures near the hub center, which was approximately 26°C. This could be due to the fact that the velocity in the center region was close to zero and, as a result, there was little or no energy transported. The profiles obtained by the first traverse seem to indicate a higher temperature than those of the second traverse.

ATDL temperature profiles along the south and west radii are shown in curves 5 and 6 of figure 6. Here, the temperature profile from the west radius lay considerably above that of the south radius. This is to be expected since in a cross-flow type of cooling tower the air leaving on the west and east sides of the fan is that air which has entered from the upper portions of the air louvers and had been exposed to the hottest water. From an analysis of the results of ESC and ATDL, the true maximum and minimum axes appear to have been rotated approximately 30° in the same direction as the rotation of the fan. This shift could, quite possibly, be due to the swirling effect of the fan. In general, all seven operating cells gave temperature profiles that were in reasonable agreement with each other. Some comparisons are provided in table 2.

Table 2

TEMPERATURE AT MOUTH OF K-31 COOLING TOWER CELLS
ALONG RADIUS TO THE WEST, ATDL STUDIES
June 25 - June 29, 1973

Cell		1	2	3	4	5	6	7
Temperature, °C	3.1-m radius	36	38	37	35	36	34	35
	1.8-m radius	31	32	33	32	31	29	33

K-33 Tower - Velocity Profiles

Only a few cells on the K-33 tower were operating in the period June 25 to June 29, 1973. ESC obtained only one velocity profile for Cell 11H, Fan 22, and it is shown in figure 7. The average velocity obtained from the integration of this profile was 6.66 m/sec. The volumetric flux was 204.2 cu m/sec.

ATDL also obtained velocity measurements on Cell 6G, Fan 12 of the K-33 tower. These measurements indicated that the velocity profile was within

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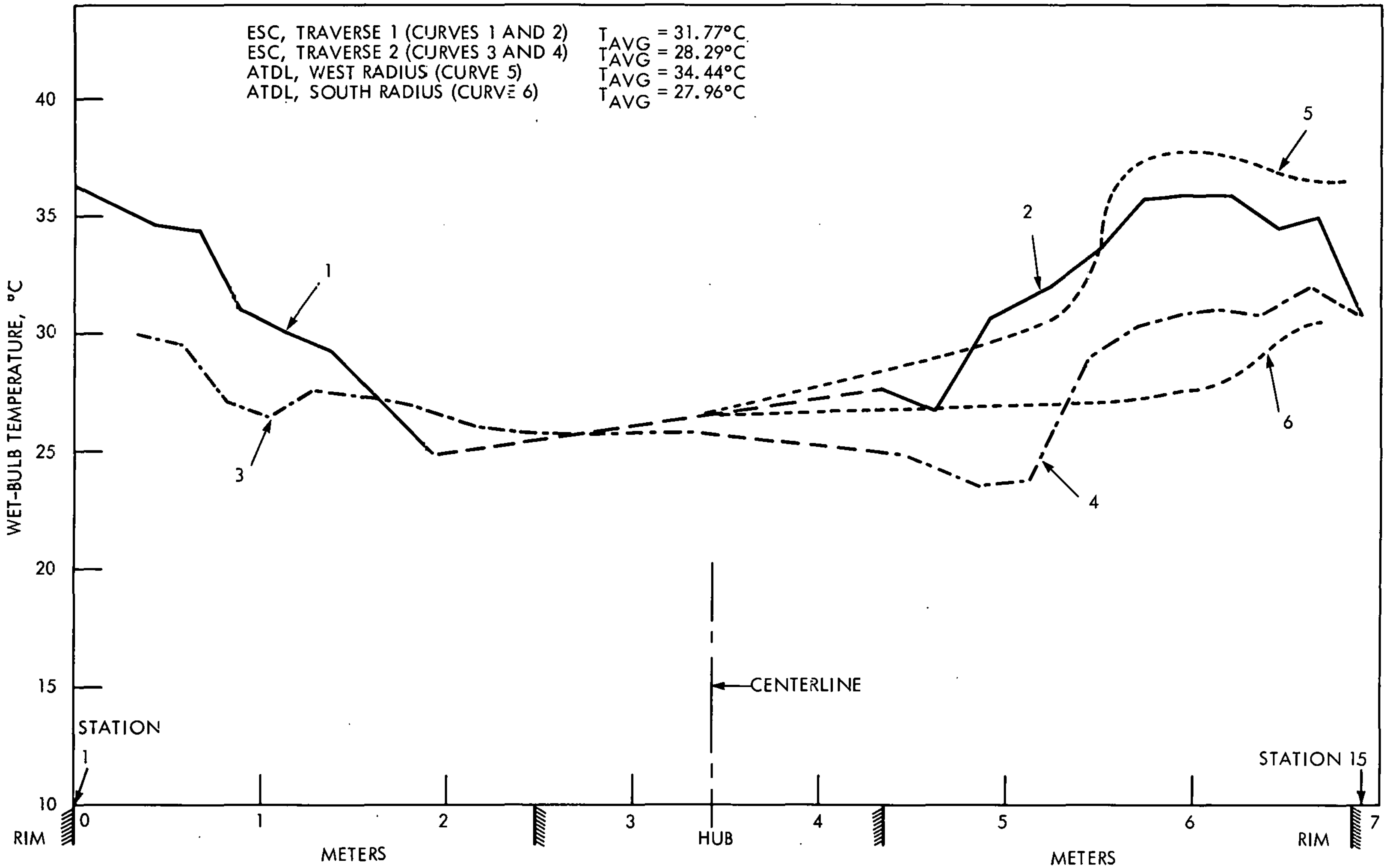

Figure 6

TEMPERATURE PROFILES, CELL 6, K-31 TOWER

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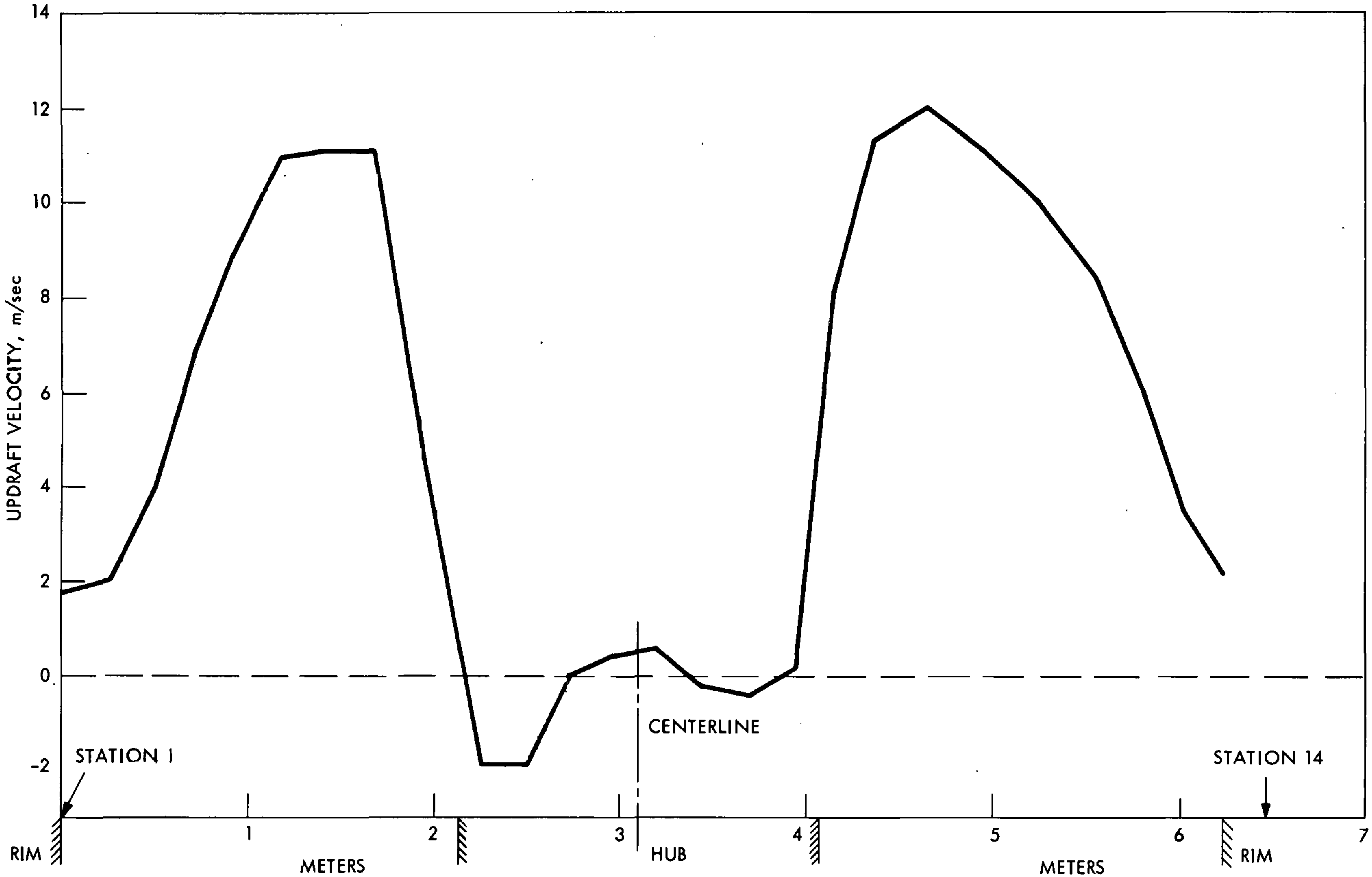

Figure 7

VELOCITY PROFILE, CELL 11H, FAN 22, K-33 TOWER

20% of that measured by ATDL on the K-31 tower. The volumetric flux was about 250 cu m/sec.

K-33 Tower - Temperature Profiles

Figure 8 represents a temperature profile for the K-33 tower as measured by ESC. When comparing figure 8 to figure 6 (the profiles for the K-31 tower), it can be seen that the magnitudes of the profiles for the two types of cells were similar.

ATDL, in their measurements on two fans of the K-33 tower, obtained temperature profiles that were nearly the same as those for the K-31 tower.

DROPLET SIZE DISTRIBUTION

K-31 Tower

ESC obtained droplet size distributions at each of the stations where velocity and temperature information was recorded. From this data, it was possible to determine the number of droplets in each diameter range as well as the concentration of drift in the air as a function of droplet size. In figure 9, a plot of the drift particle-density distribution as a function of droplet size is presented for Station 3 of the first diametral traverse. A comparison of the values obtained from ESC's various measurement techniques is shown. In figure 10, the drift particle density distribution averaged over all the positions of each diameter is shown. This figure indicates that there were a large number of very small droplets in the drift, and that as the particle diameter increased, the number of droplets decreased so that at a particle diameter of 1000 μm the number of droplets was about five orders of magnitude smaller than at 50 μm. The areas under the curves for diametral Traverses 1 and 2, when plotted on rectilinear coordinates, gave the number of water particles per cubic meter of air as it was leaving the fan mouth. The results from the second diametral traverse indicated that there were more than ten times as many particles in the 900- to 1000-μm-dia range than measured in the first traverse.

While it is interesting to know the numerical distribution of the drift droplets as a function of diameter, the drift concentration in the air as a function of diameter is a more important parameter. It can be obtained from the drift particle-density distribution by assuming that the droplets are spherical in shape. Using the same density as pure water, the drift concentration in micrograms per cubic meter of air per droplet diameter, shown in figure 11, was obtained. From this curve, it can be seen that the maximum contribution to drift was made by droplets in the 140- to 180-μm range. Also according to the second diametral traverse, there exists the possibility that droplets with diameters greater than 1000 μm may have contributed appreciably to the total drift.

Another way of plotting the distribution of drift as a function of droplet diameter is in the form of the drift flux. This parameter was obtained by multiplying the drift concentration by the velocity of the water droplets.

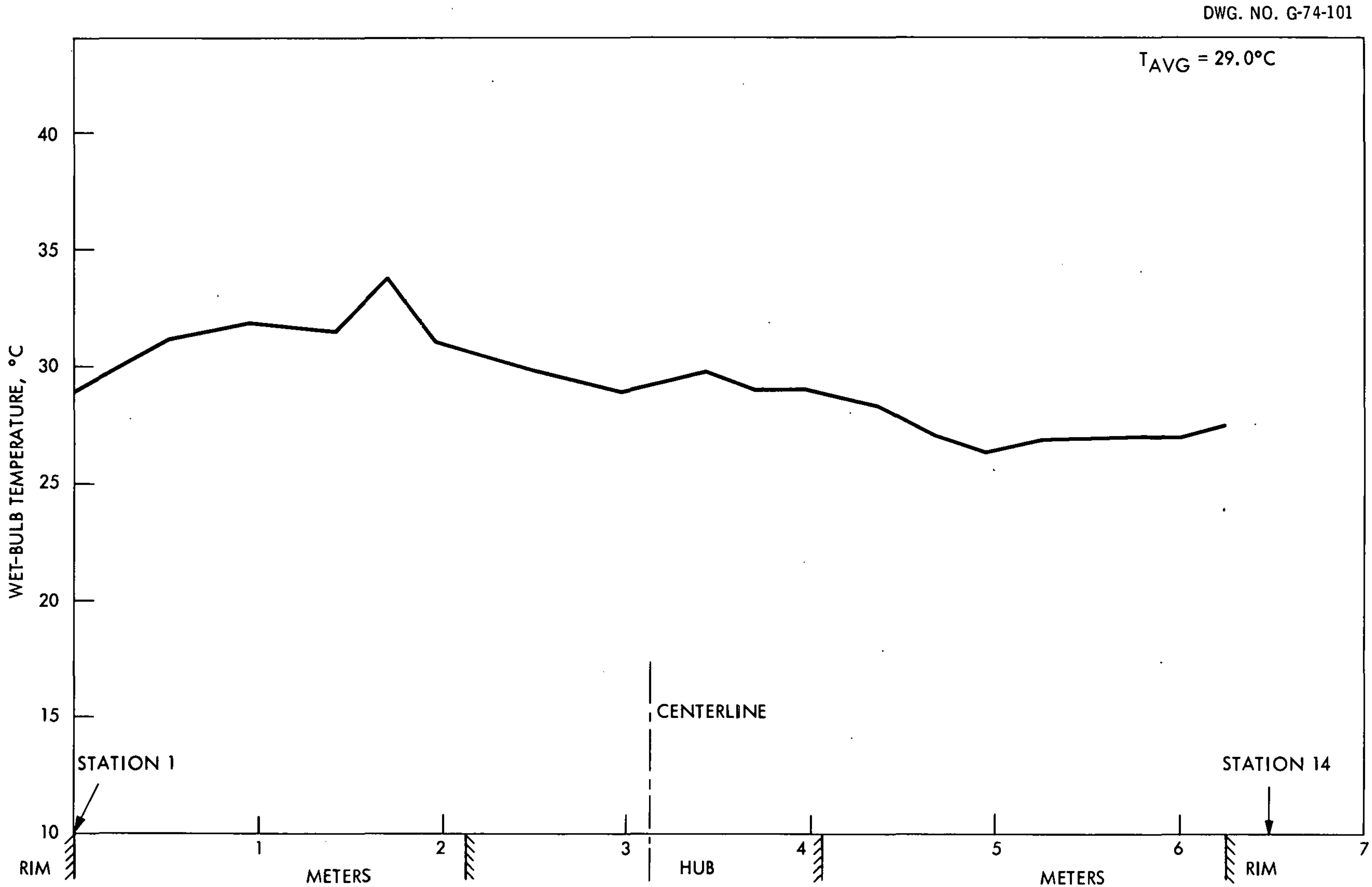

Figure 8

TEMPERATURE PROFILE, CELL 11H, FAN 22, K-33 TOWER

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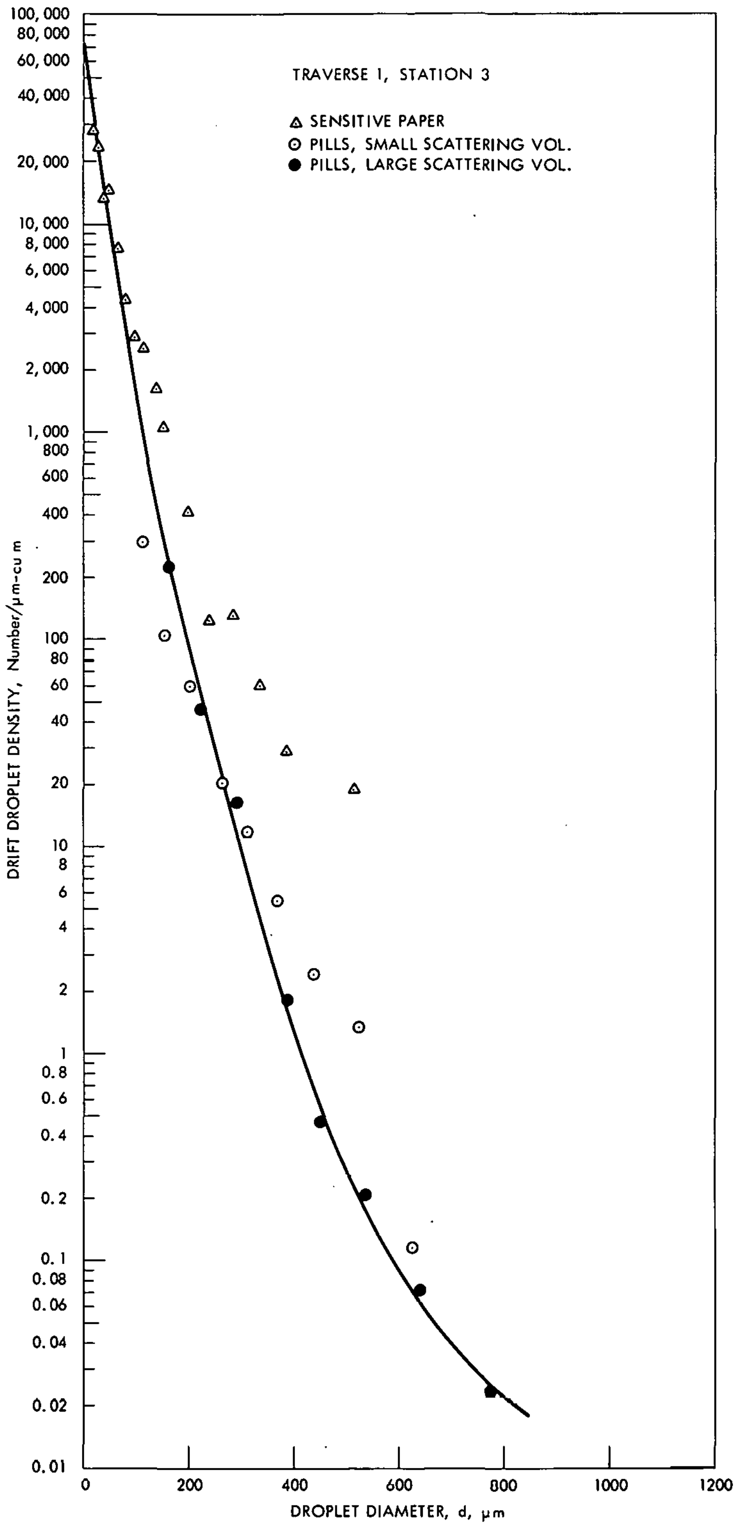


Figure 9

DRIFT DROPLET DENSITY DISTRIBUTION

DWG. NO. G-74-103

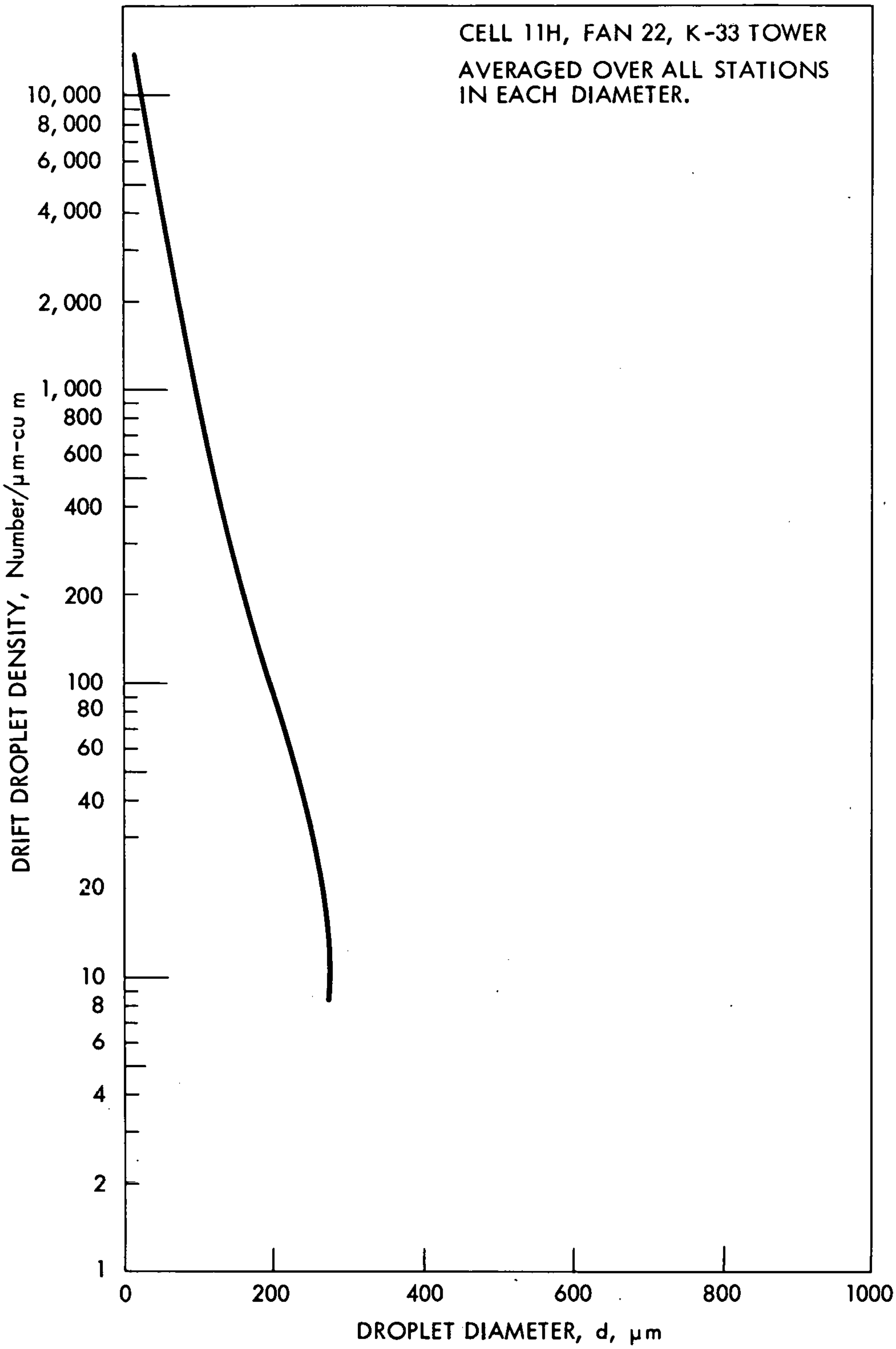


Figure 10

DRIFT DROPLET DENSITY DISTRIBUTION

DWG. NO. G-74-104

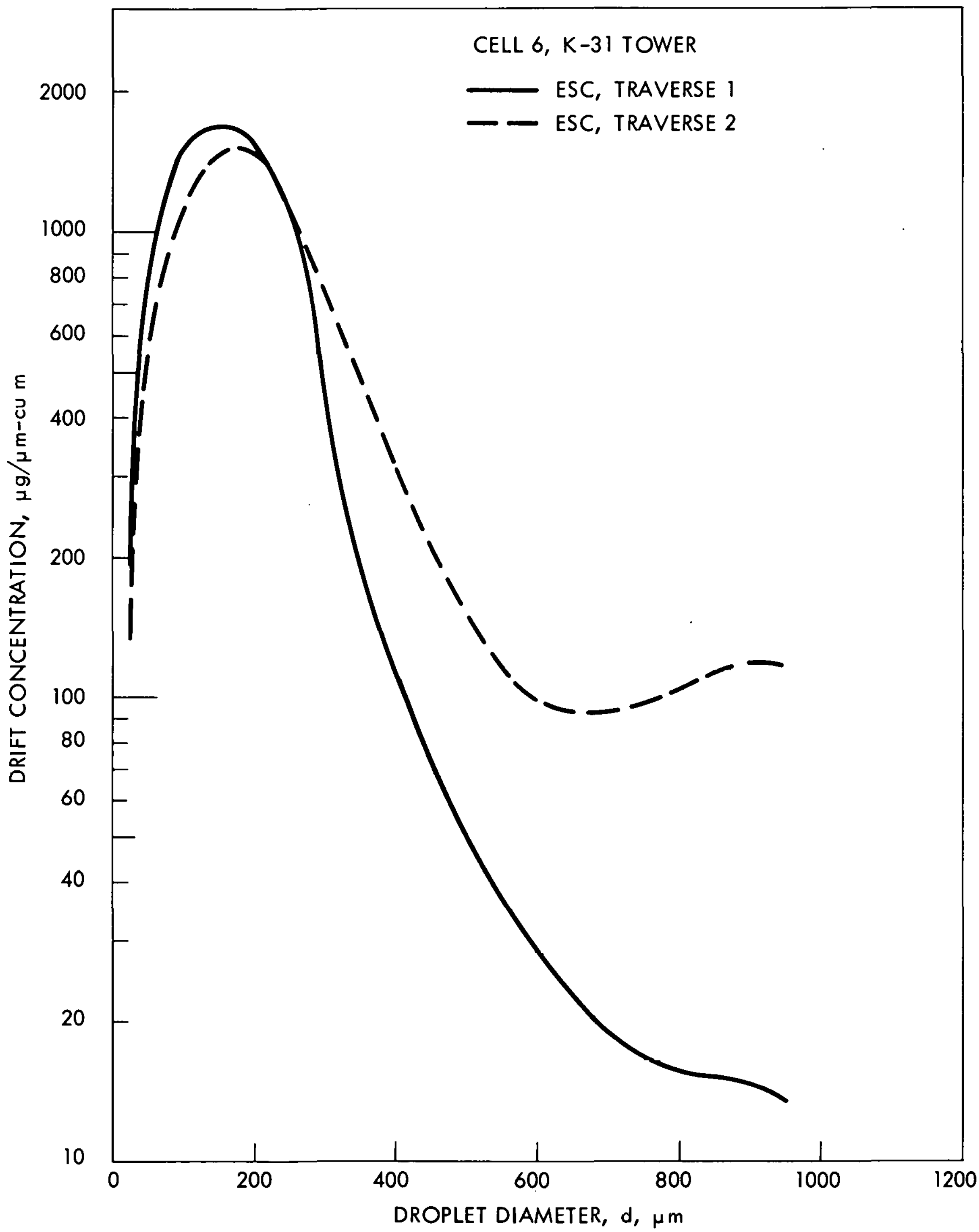


Figure 11

DRIFT CONCENTRATION PER
CUBIC METER OF AIR PER DROPLET DIAMETER

It was assumed that this velocity was the same as the air velocity. Since in reality it was slightly lower, the curve given in figure 12 can be thought of as an upper limit on the drift flux.

In addition to the ESC data, figure 12 presents the results obtained by ATDL. ATDL obtained drift flux measurements on all operating cells of the K-31 tower, including Cell 6. While the results for small droplet diameters (less than about 300 μm) were difficult to discern on the sensitive paper and thus not very reliable, the droplets with diameters greater than 500 μm could be measured with confidence. Generally, ATDL showed that a sizable portion of the drift occurred at droplet diameters greater than 1000 μm. The shape of the curve from the second diametral traverse also tended to indicate that drift at droplet diameters greater than 1000 μm could quite readily exist. Curve A, which was chosen as the average of the ESC and ATDL results, is recommended as the drift flux curve. Based on this curve, 7.5% of the drift was located in the diameter range in excess of 1000 μm.

In addition to Cell 6 studies, ATDL ran tests on the seven other operating cells of the K-31 tower. Little difference in droplet size distribution was observed.

The drift flux curve based on the average of all the cells as measured by ATDL was, however, found to lie below the curve for Cell 6. The condition of the drift eliminators in Cell 6, which will be discussed later, is believed to account for the large amount of the drift emanating from that cell.

K-33 Tower

The drift particle density distribution for Cell 11H, Fan 22, obtained by ESC using sensitive paper only, is shown in figure 13. When compared to the curve for Cell 6 of the K-31 tower, the two curves are seen to be of the same shape in the range where data were taken.

In figure 14, the drift concentration in the air is given. Data were taken by ESC in the limited droplet range from 0 to 300 μm. In that range, the drift concentration was about 12% lower than that in the K-31 tower. The maximum concentration of drift occurred at a droplet diameter of approximately 130 μm. When examined on the basis of the drift flux, as in figure 15, the values obtained for Cell 11H, Fan 22 of the K-33 tower were approximately one-half those obtained on the K-31 tower. This was due to the combined effect of both a lower drift concentration in the air and a lower air velocity at the fan mouth in the K-33 tower.

ATDL also ran tests on the droplet distribution of the drift flux for two fans in the K-33 tower. The drift flux was found to be only about one-third that of the K-31 tower. Droplets with diameters greater than 1500 μm were not present. Consequently, the dashed curve in figure 15 may be used as a reasonable representation of the drift flux curve for the K-33 tower.

DWG. NO. G-74-105

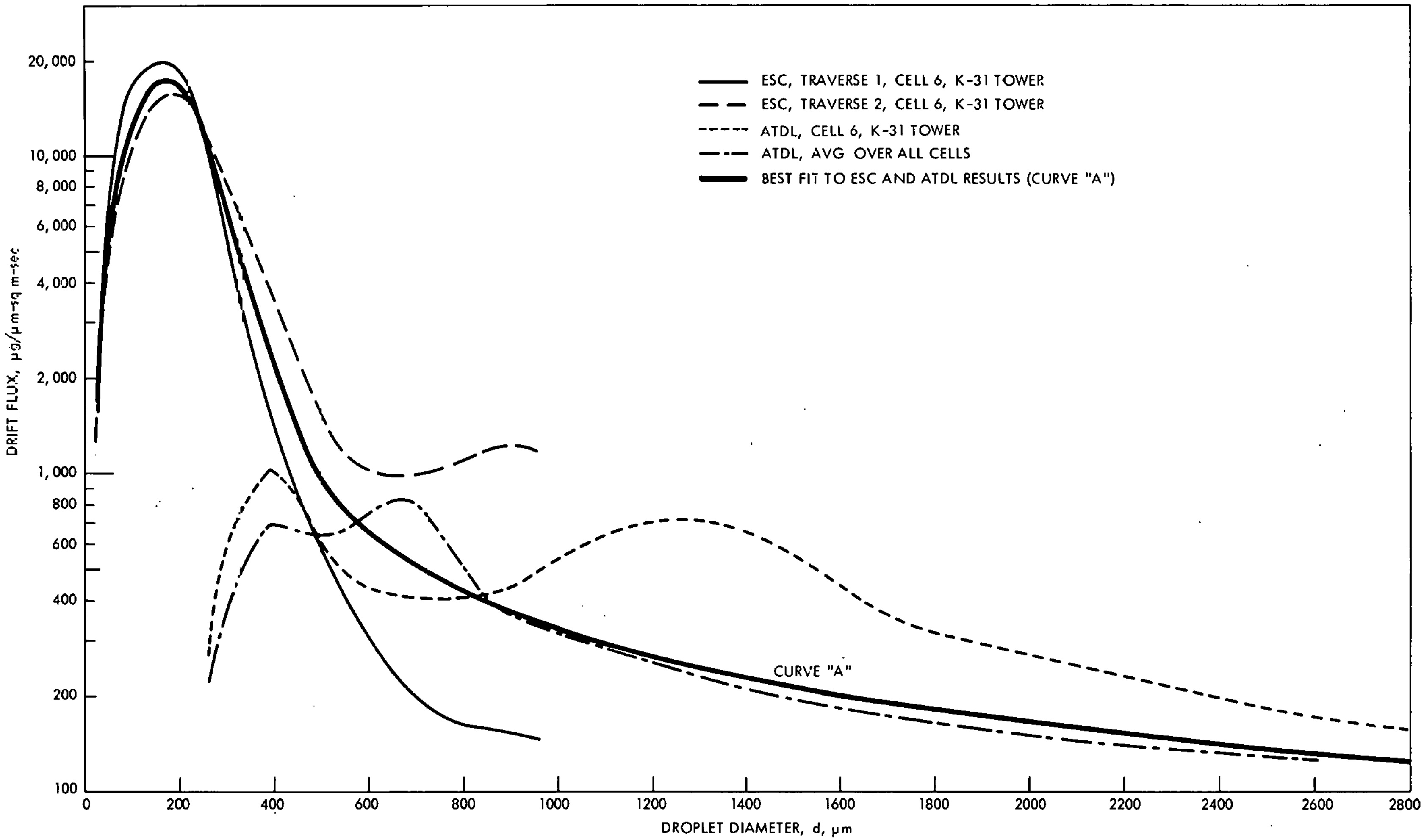


Figure 12

DRIFT FLUX PER UNIT DROPLET DIAMETER

DWG. NO. G-74-106

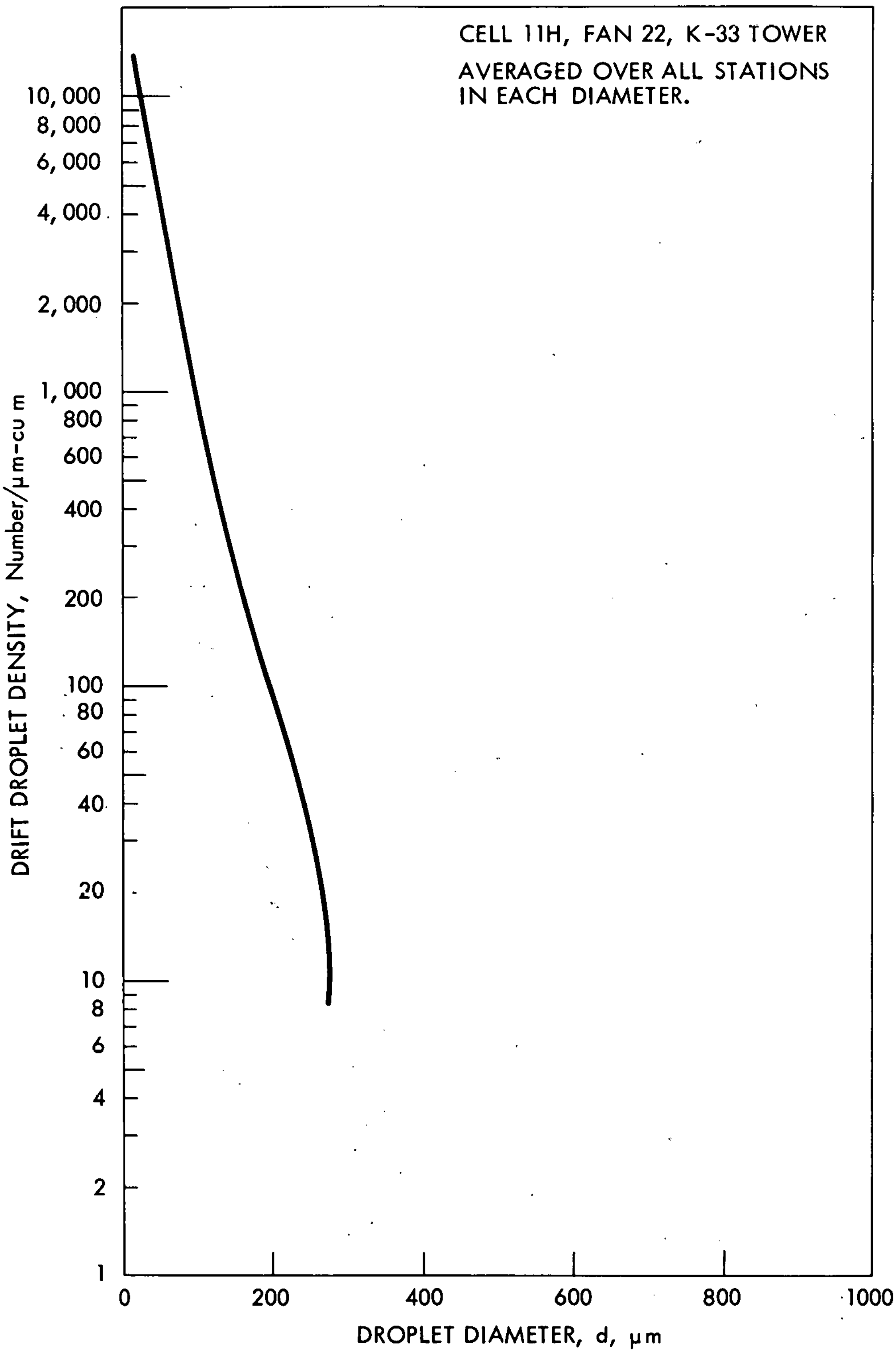


Figure 13

DRIFT DROPLET DENSITY DISTRIBUTION

DWG. NO. G-74-107

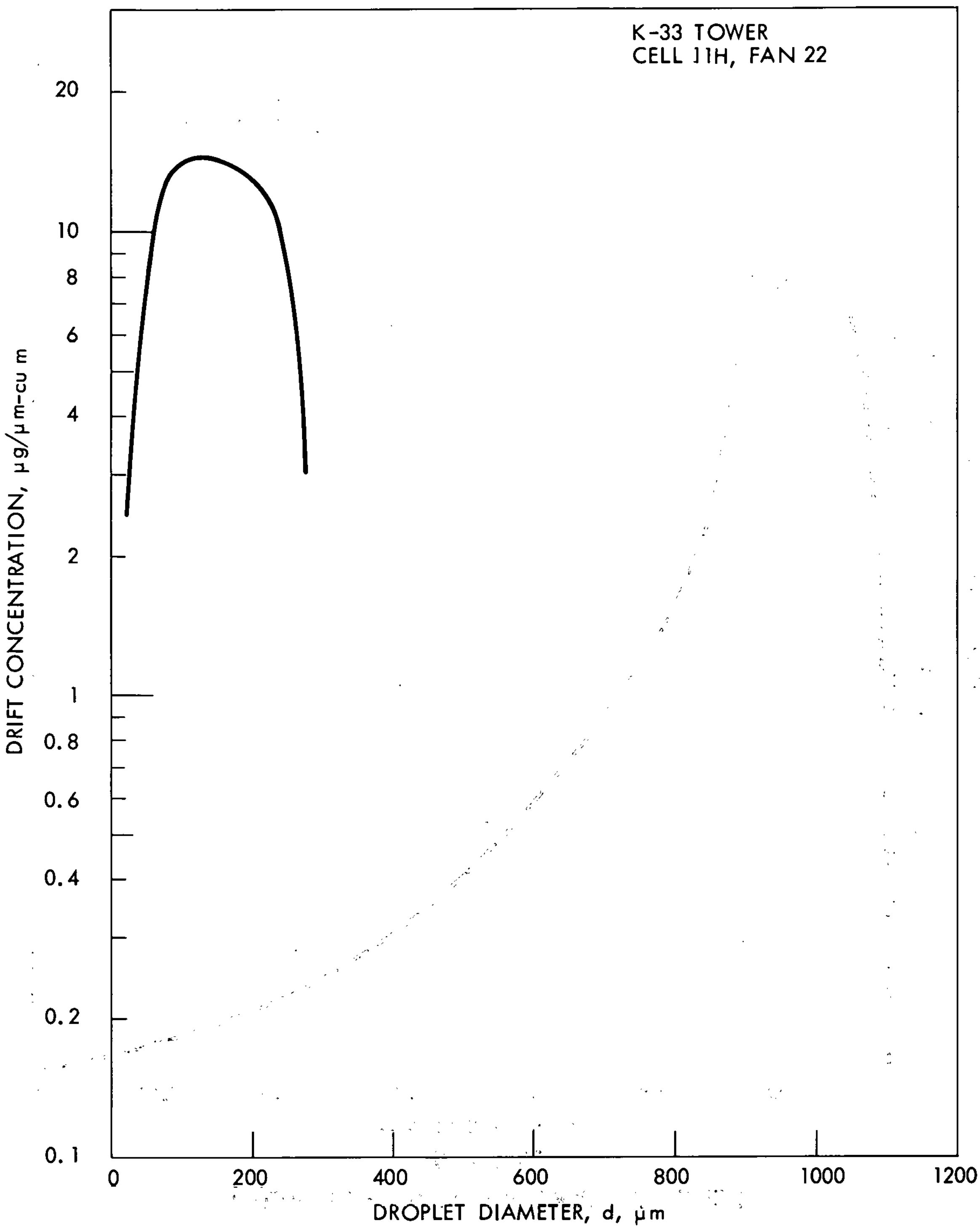


Figure 14

DRIFT CONCENTRATION PER
CUBIC METER OF AIR PER DROPLET DIAMETER

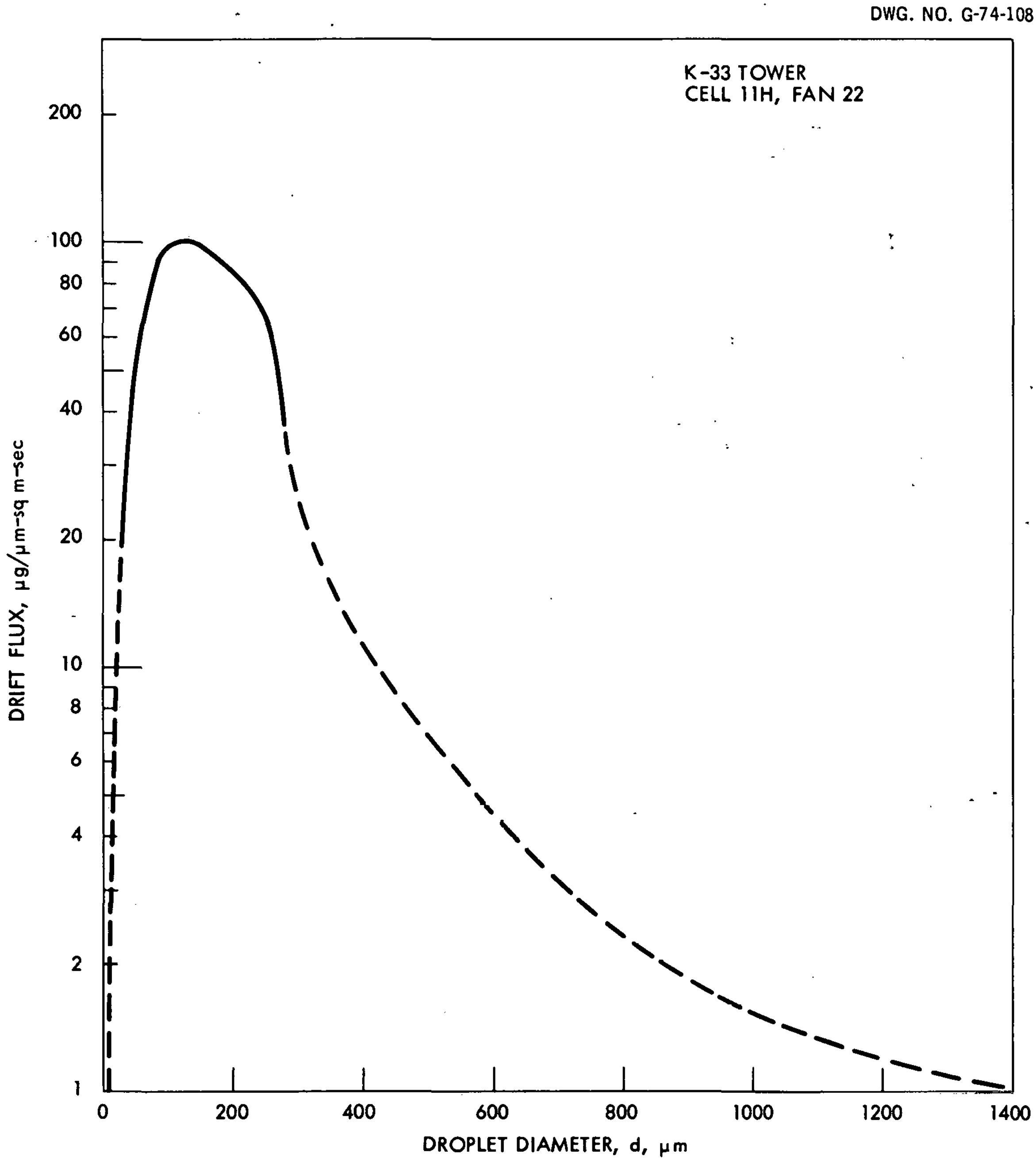


Figure 15

DRIFT FLUX PER UNIT DROPLET DIAMETER

TOTAL DRIFT FROM THE K-31 AND K-33 TOWERS

Having investigated the droplet size distribution of the drift leaving the cooling towers, the total drift, regardless of the droplet size, will now be studied. The drift as a function of the cell position was examined. Observations were made by the PILLS and sensitive paper techniques as well as by the isokinetic probe technique.

K-31 Tower

One method used by ESC to measure the drift emanating from the cooling tower consisted of the sensitive paper technique for droplet diameters of less than 200 μm and the PILLS instrument for droplet diameters between 200 and 1000 μm. These results were analyzed in the previous section with regard to the droplet distribution. By summing the drift contributions from all droplet sizes at a given position of the cell mouth, the total drift at that position was obtained. The isokinetic sampling technique, while incapable of measuring the droplet size distribution of the drift, does provide a reliable measurement of the total drift at each position over the complete droplet size spectrum.

A comparison of the drift flux as a function of position as measured by sensitive paper and PILLS versus isokinetic sampling is shown in figures 16 and 17 for the first and second diametral traverses, respectively. As can be seen, the drift flux profile as measured by the isokinetic probe was usually below that obtained by PILLS and sensitive paper. This result is unexpected, and one would have expected that the opposite would have been true. As previously mentioned, one of the major differences between the ESC and ATDL studies concerned the droplet size distribution. The PILLS system used by ESC measured only droplets up to a size of 1000 μm. The isokinetic sampling technique, on the other hand, collected droplets of all sizes. Thus, if droplets of greater than 1000 μm were present in the drift, they would have gone undetected by the PILLS system and the answers obtained by that technique would have underestimated the true drift flux. Since it was previously found that approximately 7.5% of the drift flux was in the droplet diameter range greater than 1000 μm, one would have expected the isokinetic sampling results to have been consistently higher than the PILLS - sensitive paper data by approximately 7.5%. This does not seem to be the case, and reasons for the discrepancy are not known although the possibility of the existence of condensed vapor indicating higher values in the PILLS and sensitive paper measurements is acknowledged. In addition, inaccuracies in the droplet calibration curve used may have been a contributing factor.

Pictures were taken of the drift eliminators in Cell 6 as shown in figures 18a and b. As can be seen, large pieces of the drift eliminators on the east and west sides of the tower seem to have been broken off. This could account for a sizable fraction of the drift leaving the tower at Station 12 of the first traverse (figure 16) and Station 3 of the second traverse (figure 17).

DWG. NO. G-74-109

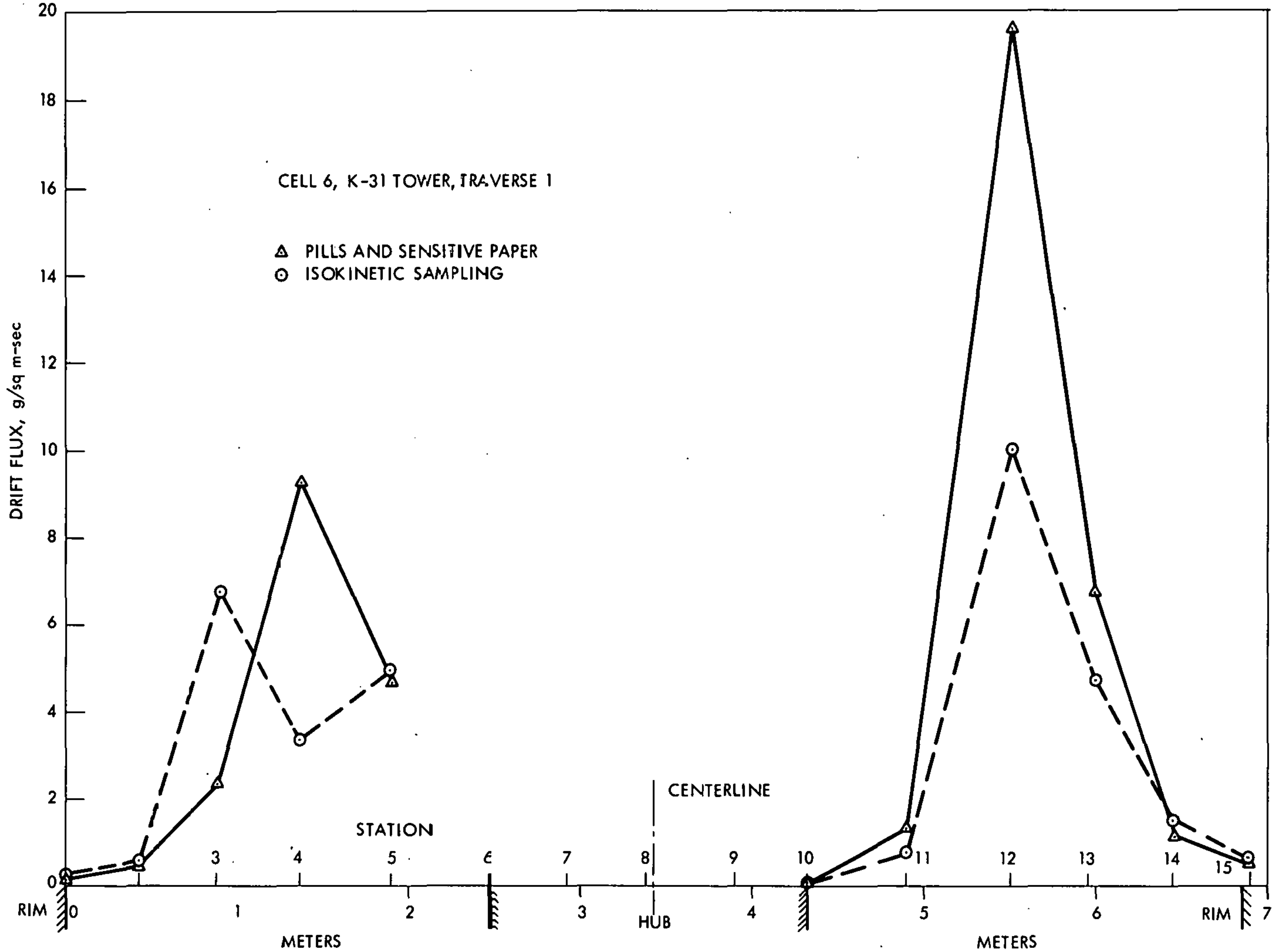


Figure 16

DRIFT FLUX VS. STATION NUMBER

DWG. NO. G-74-110

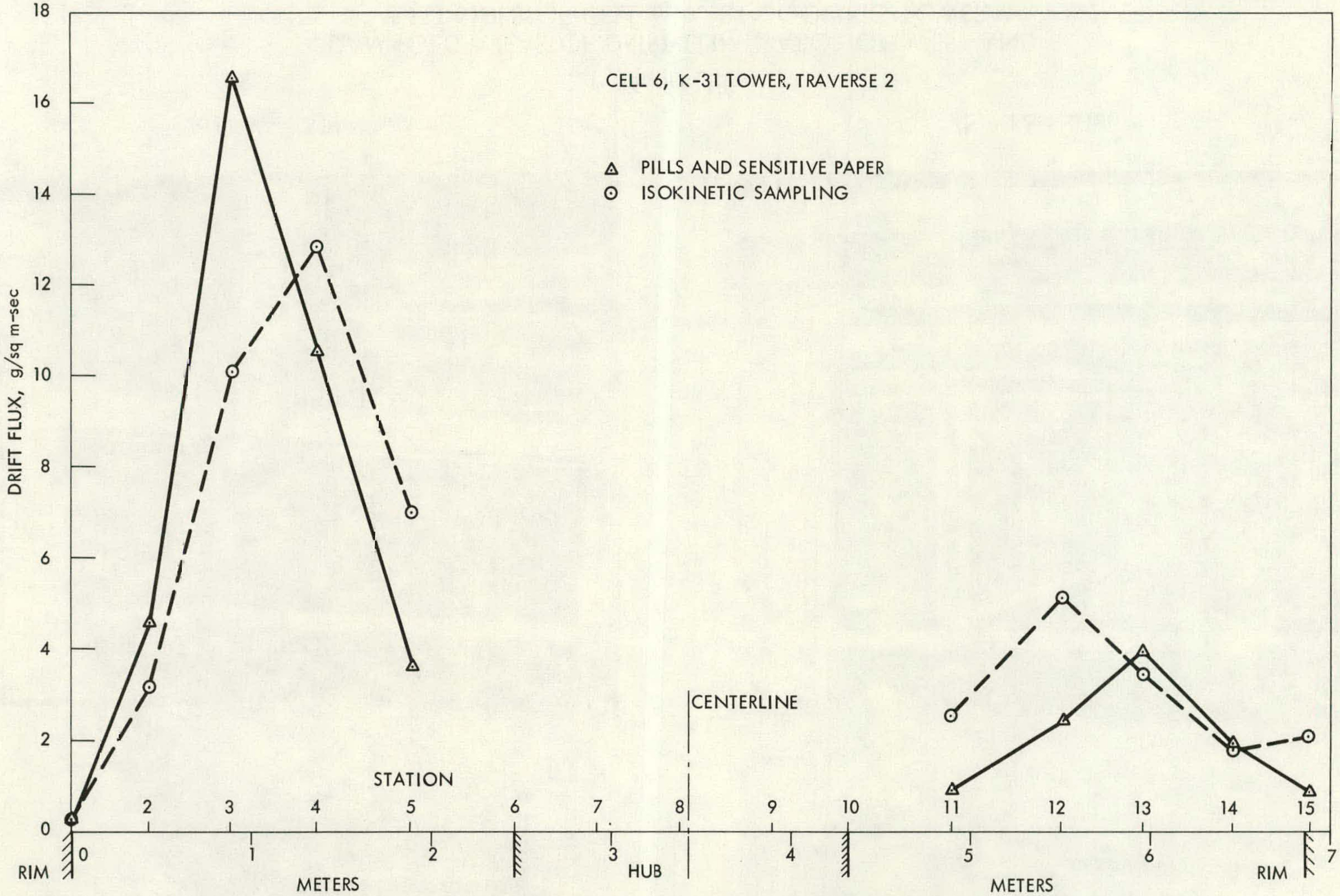
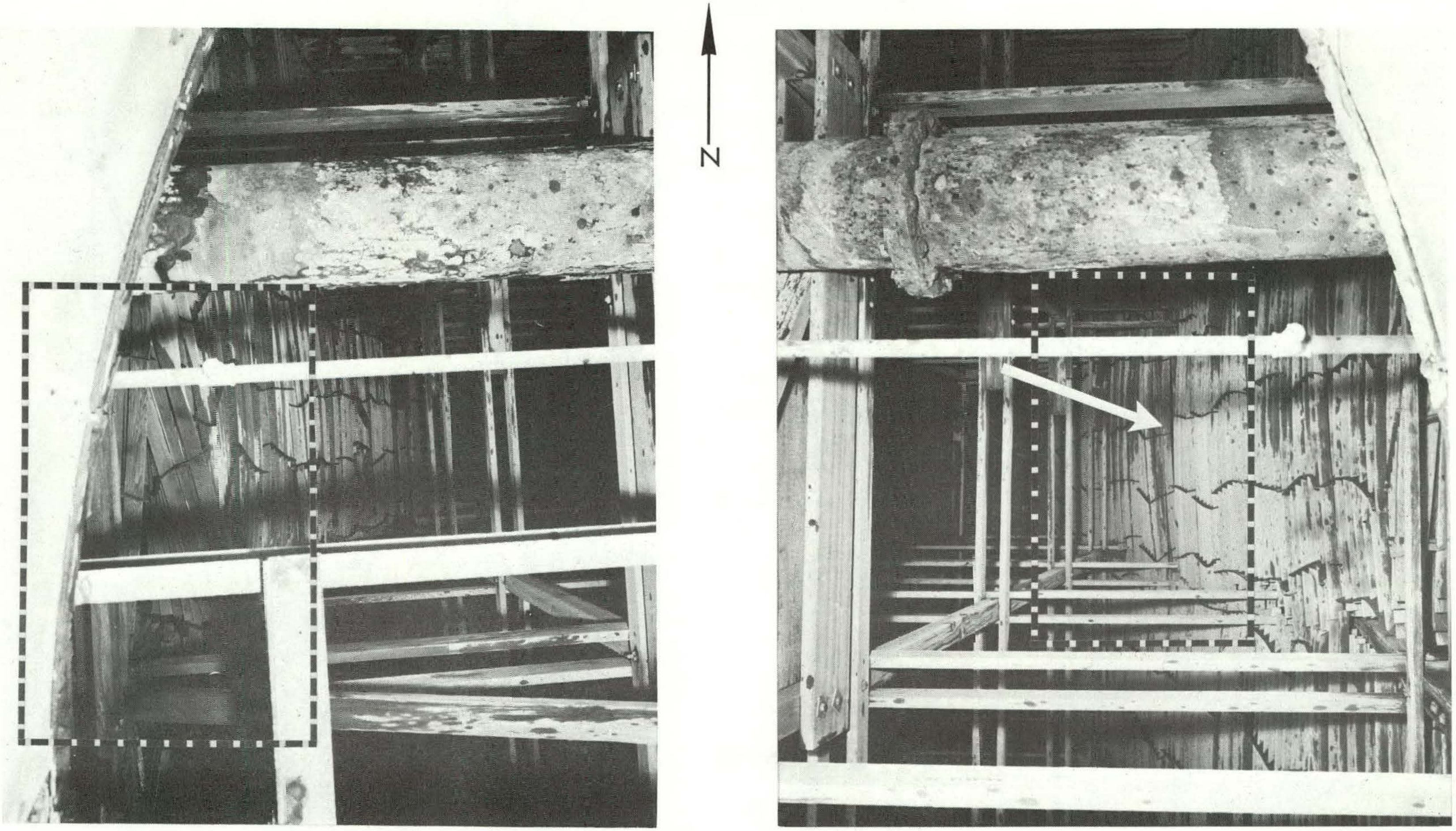


Figure 17

DRIFT FLUX VS. STATION NUMBER

PHOTO NO. PH-73-3619

PHOTO NO. PH-73-3620



(a) West Side

(b) East Side

Figure 18

DAMAGED AREAS OF DRIFT ELIMINATOR ON WEST AND EAST SIDES OF CELL 6, K-31 COOLING TOWER

The drift flux profiles in figures 16 and 17 can be integrated to yield average drift fluxes over the whole cell mouth. The results obtained are shown in table 3.

Table 3

AVERAGE DRIFT FLUX, CELL 6, K-31 TOWER, ESC RESULTS

First Diametral Traverse	- PILLS and Sensitive Paper:	4.22 g/sq m-sec
First Diametral Traverse	- Isokinetic Sampling:	2.85 g/sq m-sec
Second Diametral Traverse	- PILLS and Sensitive Paper:	4.07 g/sq m-sec
Second Diametral Traverse	- Isokinetic Sampling:	4.00 g/sq m-sec

A sizable portion of the discrepancy in the average drift flux in the first diametral traverse between the two techniques was due to the readings at Station 12. A sharp rise in drift flux occurred at that point and numerous factors, including an uncertainty in the exact location of the two instruments, could have contributed to the differences.

ATDL data were obtained on all eight operating cells in the K-31 tower. These results, along with the ESC findings, are shown in table 4. One reason for the discrepancy is due to the fact that the ATDL results do not include the very small droplet sizes (0 μm ≤ d ≤ 250 μm at least) which, according to figure 12, constituted a sizable portion of the drift; ESC predicted a total drift from the eight cells of 1115.8 g/sec. The ATDL measurement yielded a total drift of 198.4 g/sec for the eight cells.

The above information can also be used to predict the drift fraction - that is the fraction of the water, circulating through the cooling tower, which is emitted as drift from the cell mouths. The various values of drift fraction for Cell 6 are given in table 5.

K-33 Tower

In figure 19, a profile of the drift flux as a function of position is shown for one radial traverse of Cell 11H. These measurements were made by ESC using the sensitive paper and the isokinetic probe techniques. Agreement between the two methods was fair, with the isokinetic sampling fluxes being consistently higher.

Integration of the drift flux velocity profile shown in figure 19 yielded an average drift flux of 0.0188 g/sq m-sec from the sensitive paper results and an average drift flux of 0.0700 g/sq m-sec from the isokinetic sampling curve. It was the measurement at Station 4 that contributed the most to

DWG. NO. G-74-111

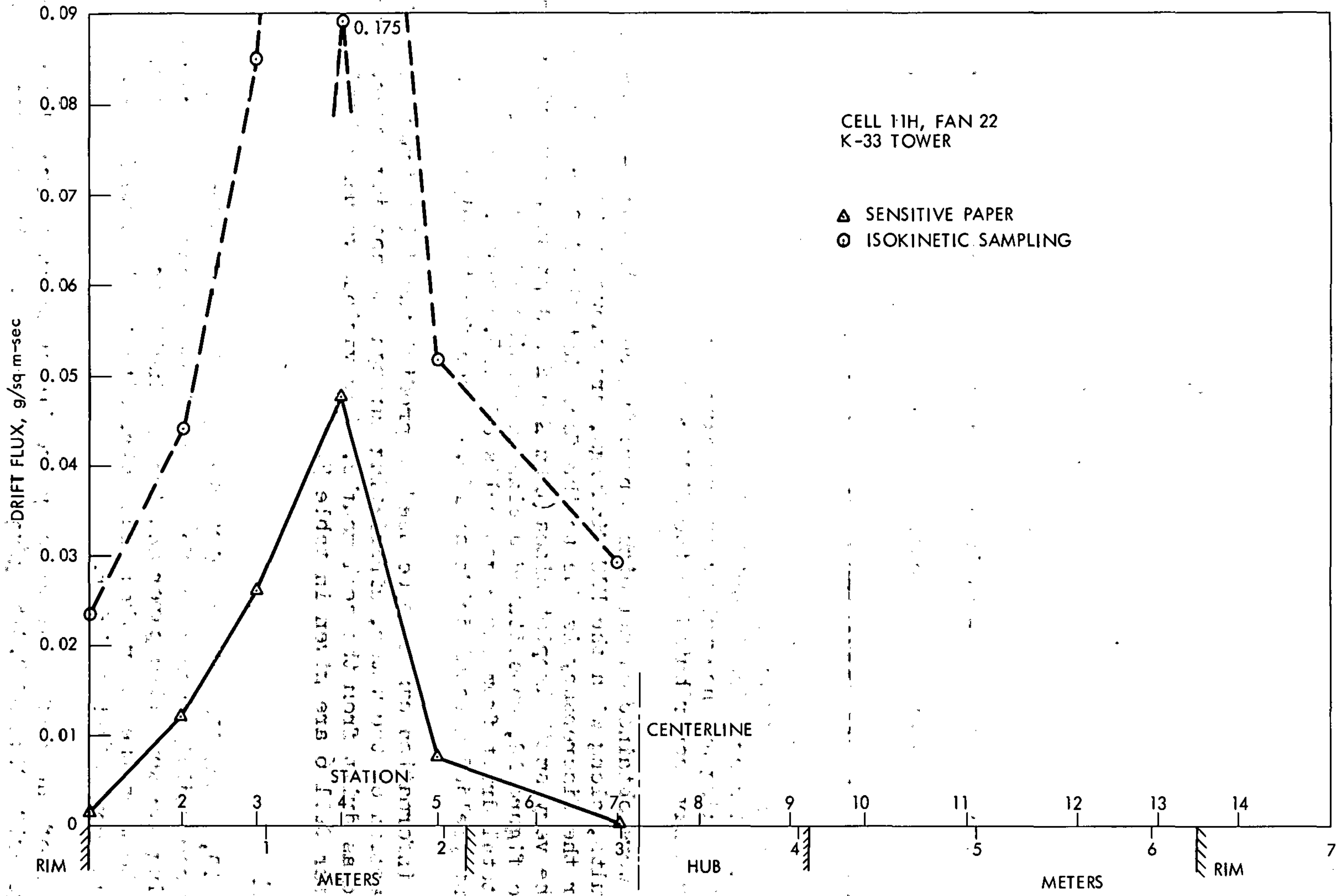


Figure 19
DRIFT FLUX VS. STATION NUMBER

Table 4

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

the discrepancy. Since droplets existed in the entire range of 0 to 1500 μm in diameter, and since the sensitive paper used by ESC was limited to droplets no larger in diameter than 300 μm, one would have expected the drift flux curve based on isokinetic sampling to be above the curve obtained by sensitive paper. This was found to be true. By replotting the curve in figure 15 on rectangular coordinates, it was observed that 83% of the total area under the curve lay in the droplet range from 0 to 300 μm. Based on this, one would have expected the average drift flux from the sensitive paper method to be 83% of the value obtained by isokinetic sampling. In reality, the value was found to be 27%. Uncertainties in the data, especially at Station 4, could account for this discrepancy.

ATDL data were obtained on Cell 8G, Fan 16 and Cell 9G, Fan 18. These results along with the ESC findings on the total drift from each cell are given in table 6. Again, as in the case of the K-31 tower, agreement was

Table 5

DRIFT FRACTION VALUES, Δ, FOR CELL 6 OF THE K-31 TOWER
June 25 - June 29, 1973

ESC Values:

Δ (First Diametral Traverse - PILLS and Sensitive Paper) = 0.121%

Δ (First Diametral Traverse - Isokinetic Sampling) = 0.081%

Δ (Second Diametral Traverse - PILLS and Sensitive Paper) = 0.115%

Δ (Second Diametral Traverse - Isokinetic Sampling) = 0.114%

ATDL Value:

Δ = 0.028%

Table 6

TOTAL DRIFT VALUES MEASURED AT THE K-33 COOLING TOWER
June 25 - June 29, 1973

Tower-Cell	Investigator	Drift, g/sec
K-33 - 8G, Fan 16	ATDL	6.0
K-33 - 9G, Fan 18	ATDL	7.0
K-33 - 11H, Fan 22	ESC (Sensitive Paper)	0.577
K-33 - 11H, Fan 22	ESC (Isokinetic Sampling)	2.15

not very good. The situation here was, however, reversed. The ATDL values were in all cases higher than the ESC results. This result is surprising because the physical condition of the distribution and drift eliminator sections of Cell 11H were in worse need of repair than any of the other cells. Since these tests have been made, the H-tower has received considerable general upgrading. It should be pointed out that ESC and ATDL took data on different cells. Also, the whole operation of the K-33 tower was such that only a few fans were on and some cells were dissipating heat without the benefit of fans. However, even if one used the higher ATDL values, the drift fluxes were still considerably lower than those from the K-31 tower.

The ATDL and ESC values can also be used to predict the drift fraction. The results are shown in table 7. The values were much lower than those for the K-31 tower.

Table 7

DRIFT FRACTION VALUES, Δ, FOR THE K-33 TOWER
June 25 - June 29, 1973

ESC Values (11H)	
Δ (PILLS and Sensitive Paper)	= 0.000148%
Δ (Isokinetic Sampling)	= 0.000549%
ATDL (8G, Fan 16 and 9G, Fan 18)	
8G, Fan 16: Δ = 0.00153%	
9G, Fan 18: Δ = 0.00179%	

TRANSPORT STUDIES

Having obtained a good estimate of the amount of drift emitted from the cooling towers, it is now necessary to determine how this drift was distributed in the air and on the ground in the vicinity of the cooling towers.

Concentration In Air

ESC, using their Airborne Particle Samplers, measured the drift emitted from the K-31 tower at distances of 75, 100, 125, and 175 m upwind and downwind of the K-31 tower. While approximately 20 data points were taken, it was most meaningful to combine these points into 85- and 175-m locations upwind of the cooling tower and 80- and 175-m locations downwind of the cooling tower in order to minimize scatter in the data. The results are shown in figures 20 and 21. As one would expect, the concentration of chromium upstream of the cooling tower, as shown in figure 20, is about an order of magnitude less than downstream of the cooling tower. Similar trends are noted for calcium and magnesium in figure 21. The existence of drift upwind of the cooling tower may be attributed to both the possibility that it came from the nearby K-33 tower and because of varying wind direction. Shifts in wind direction were common during all test runs.

BNW ran a very extensive series of tests, obtaining data at 14 sampling stations on each of four different days. The stations varied in distance from 30 to 1500 m from the cooling tower. The results from all four days were averaged and the chromium concentration as a function of distance from the cooling tower is presented in figure 20. Because of the variability of the wind direction, shown in figure 22, no attempt was made to differentiate between upwind and downwind sampling positions. As can be seen in figure 20, the concentration of chromium in the air as measured by BNW was below the downwind values ESC obtained, but considerably above ESC's upwind results.

Deposition on Ground

The drift which was carried away from the cooling towers eventually fell out on the ground surrounding the towers. ESC measured this fallout rate by placing sheets of sensitive paper with areas of 9.6 sq cm at 10-m intervals from the north end of the K-31 tower. The stain sizes on the sensitive paper not only gave an estimate of the amount of drift that fell at each of these locations, but also yielded information on the distribution of that drift according to droplet size. It was again generally found most meaningful to combine the results into 15-, 35-, 55-, and 80-m distances from the K-31 cooling tower. The fallout particle size distribution is given in figure 23. The behavior of the 15-m curve and to some degree the 35-m curve was unexpected. Large numbers of particles seemed to fall out in the very small droplet diameter range ($0\ \mu m \le d \le 80\ \mu m$) and in the large droplet diameter range ($200\ \mu m \le d \le 700\ \mu m$). In the intermediate diameter range, a trough existed in the fallout droplet distribution. When the results were analyzed in terms of the actual number of micrograms of drift per unit area per unit of time, as in figure 24, the curves appeared considerably smoother. In all other respects, ESC's results appearing in figures 23 and 24 were in reasonable agreement with what one would have expected.

At the smaller distances from the K-31 cooling tower, a significant portion of the drift was composed of the larger sized droplets which were the heavies and therefore were expected to fall out the soonest. As the distance increased, the fraction of the drift which was composed of the larger sized droplets, while still considerable, was progressively decreasing. The anomaly in the 55-m curve may be explained to some degree by noting that gusting winds occurred during the run. Such high-velocity winds are known to cause downwash and an attendant increase in contact between the plume and the ground very close to the cooling tower.

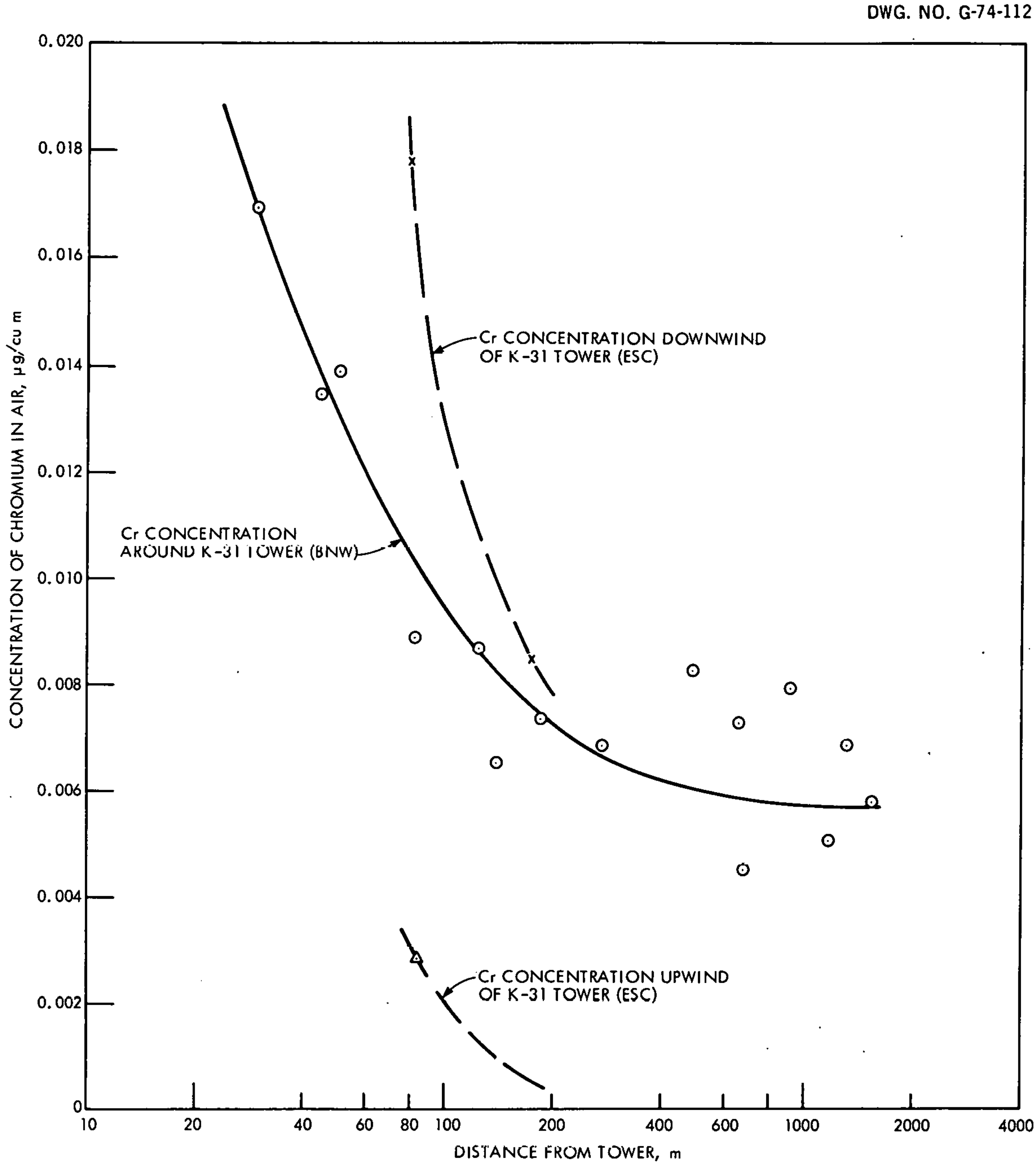


Figure 20

CONCENTRATION OF CHROMIUM IN AIR AS A FUNCTION OF DISTANCE FROM K-31 COOLING TOWER

DWG. NO. G-74-113

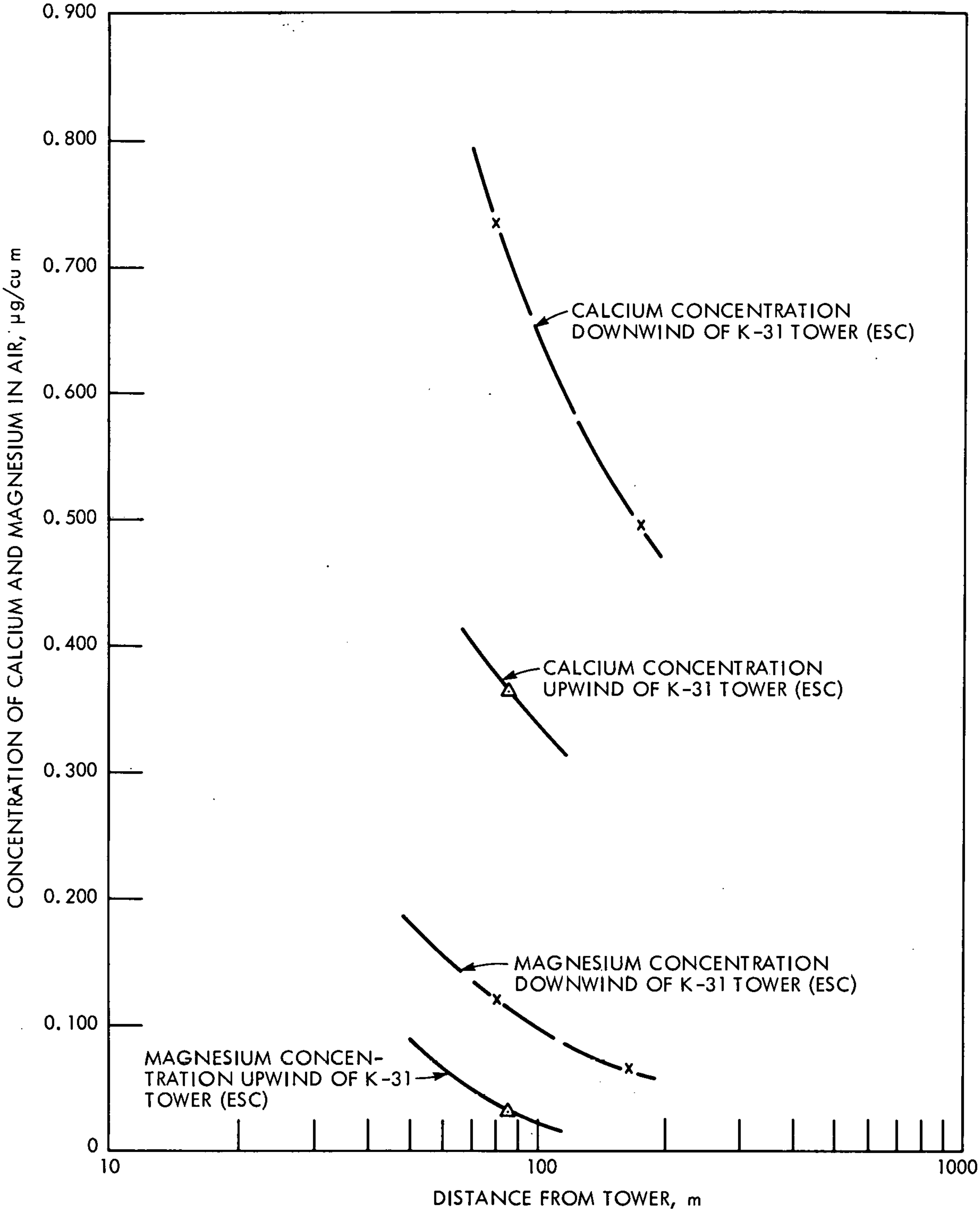
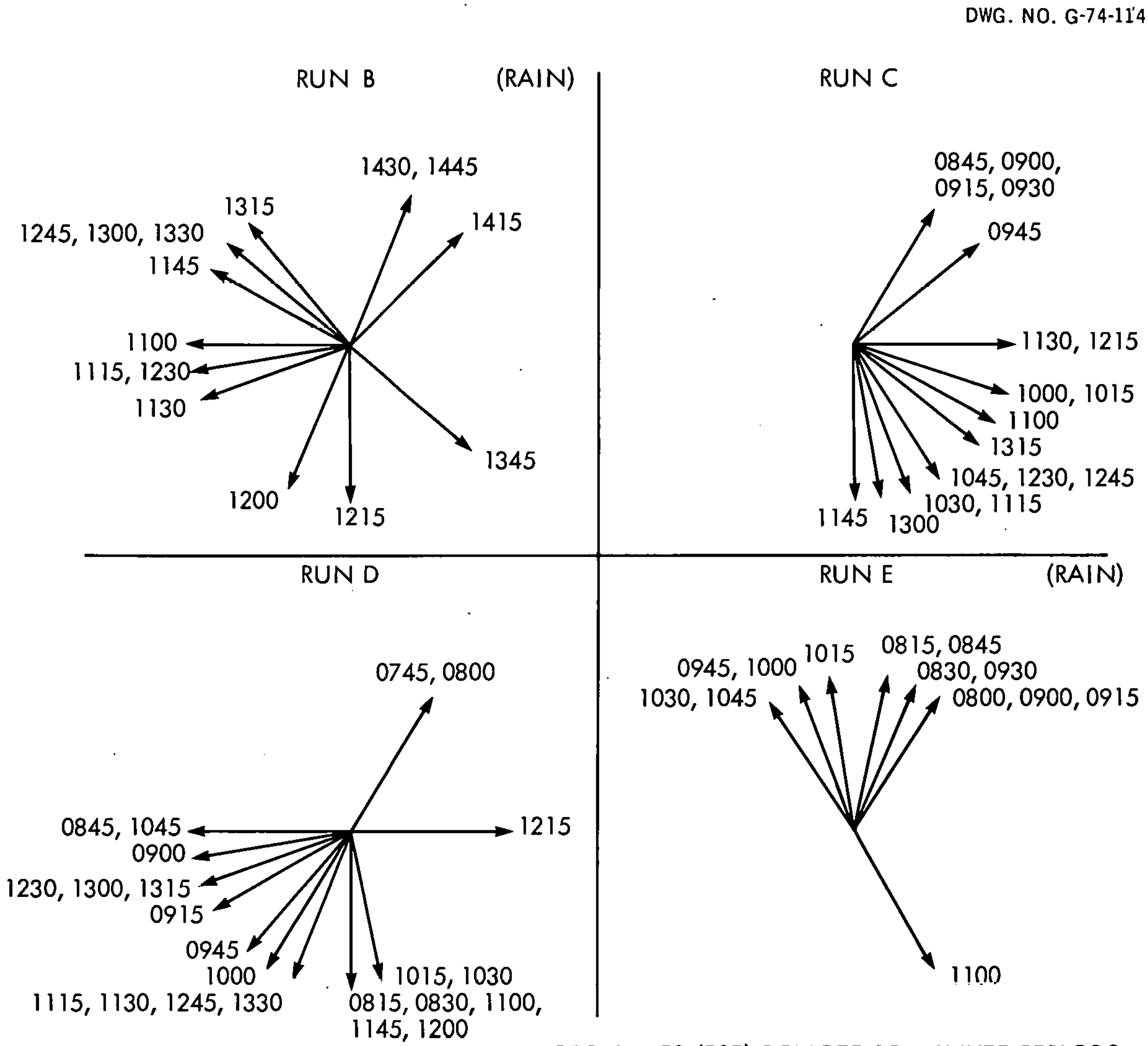


Figure 21

CONCENTRATION OF CALCIUM AND MAGNESIUM IN AIR AS A FUNCTION OF DISTANCE FROM K-31 COOLING TOWER



NOTE: TIMES (EST) DENOTE 15-MINUTE PERIODS FOR WHICH AVERAGE WIND DIRECTIONS WERE DETERMINED.

Figure 22

WIND DIRECTION VARIABILITY, BNW STUDIES

DWG. NO. G-74-115

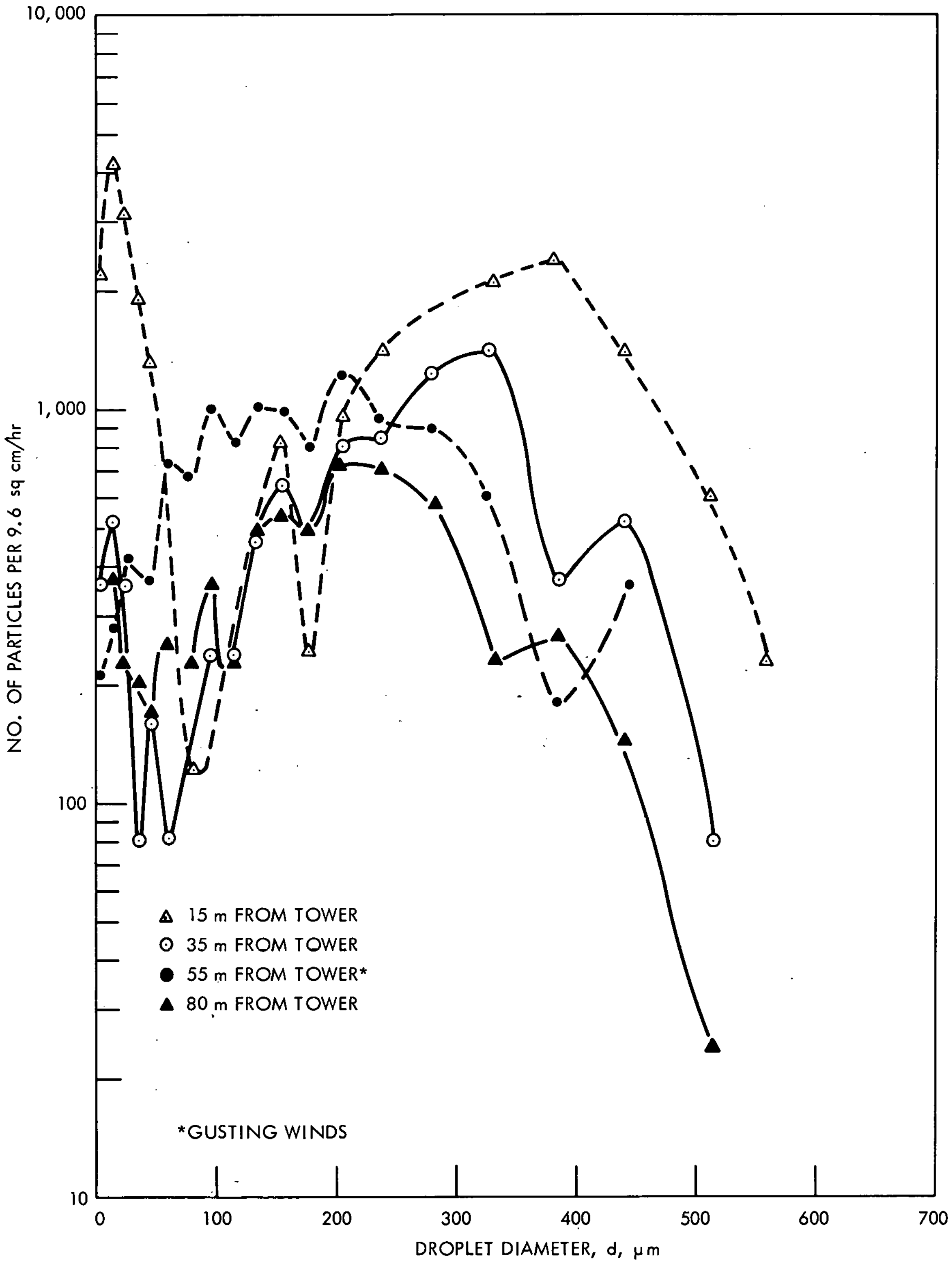


Figure 23

FALLOUT PARTICLE SIZE DISTRIBUTION FOR VARIOUS DISTANCES FROM K-31 TOWER, ESC STUDY

DWG. NO. G-74-116

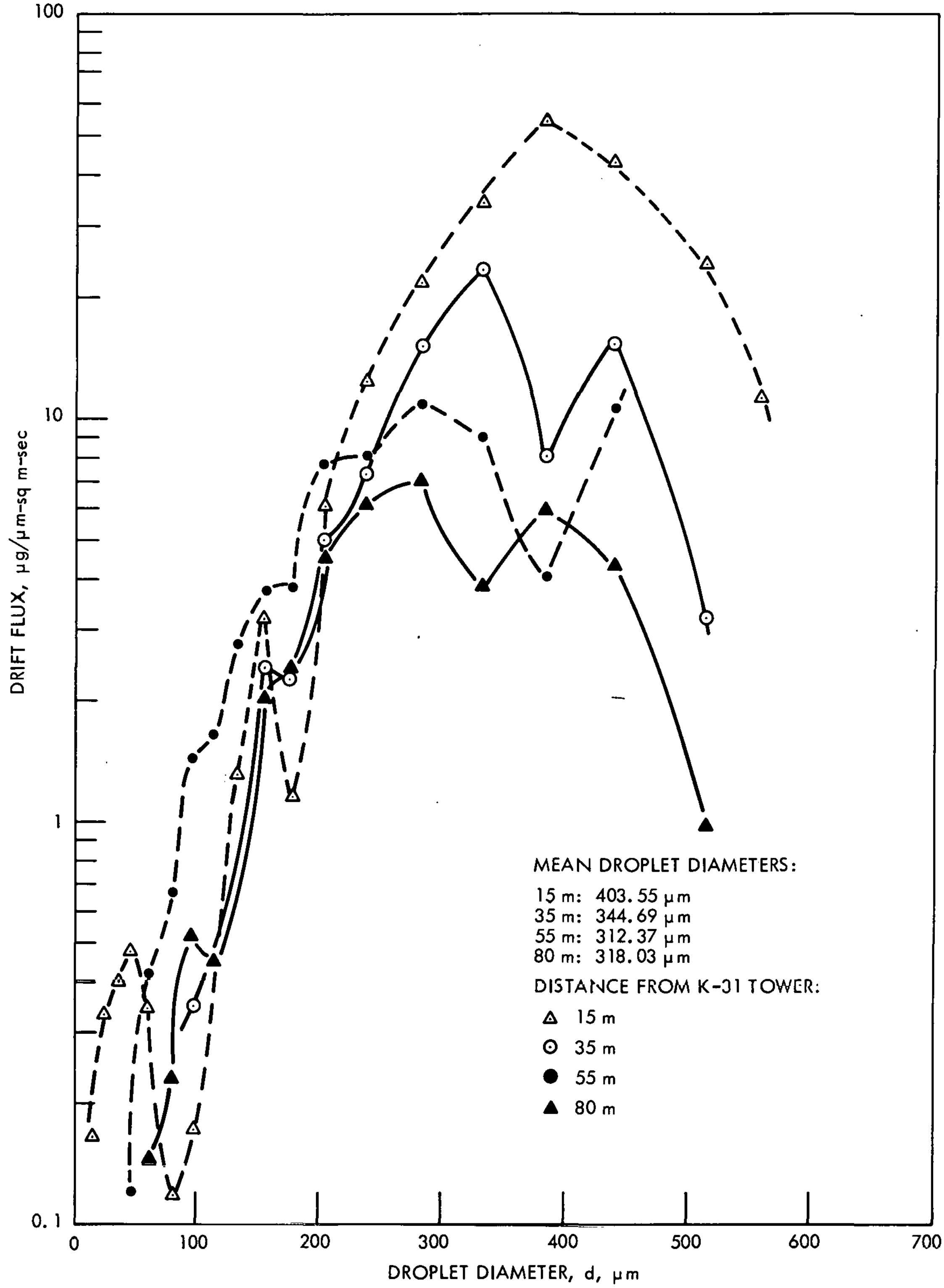


Figure 24

DRIFT FLUX PER UNIT DROPLET DIAMETER FOR VARIOUS DISTANCES FROM K-31 TOWER, ESC STUDY

By knowing the concentration of chromium, calcium, and magnesium in the water in the basin of the cooling tower and assuming the same concentration existed in the drift, the deposition flux of these elements can be computed. The results for chromium are shown in figure 25 and those for calcium and magnesium in figure 26.

ATDL also ran deposition flux studies using sensitive paper at distances ranging from 2 to 30 m away from the cooling towers. The results are given in tables 8 and 9. The mass median droplet diameters were considerably higher than those obtained in the ESC studies and shown in figure 24. The deposition fluxes at each distance were averaged and plotted in figures 25 and 26. As can be seen, agreement with the ESC data is quite encouraging.

BNW also ran tests on the deposition fluxes at the same time that they ran the air concentration studies described previously. Their method of obtaining the chromium concentration in the air differed from the ESC and ATDL studies. BNW directly measured the amount of chromium falling on the ground. The results for the average of all test dates are given in figure 25. The curve is found to lie slightly below the results of ESC and ATDL. The differences may have been partially due to the method in which the chromium deposition flux was obtained. Quite conceivably, a portion of the liquid droplets falling on the sensitive paper during the ESC and ATDL tests were not drift but pure water formed when vapor in the plume condensed. If this were the case, the amount of chromium calculated would have overestimated the true chromium deposition by the percentage of the liquid fallout which was actually condensed vapor. Another reason for the difference between the BNW results and the ESC and ATDL values may be due to the wind direction variability. As shown in figure 22, the wind direction changed frequently and caused the plume leaving the cooling tower to dissipate over a wide area. The wind direction during the ESC and ATDL studies was steadier and the plume better defined. Thus, the deposition flux could be expected to be less during the BNW tests.

An interesting result was obtained when the results of Runs B and E and Runs C and D were grouped separately as shown in figures 27 and 28. The peaks for figure 27 seemed to occur within 50 m of the cooling tower whereas the peak of figure 28 occurred at a significantly greater distance. The differences in temperature gradient offer the best explanation for differences in flux distributions. As shown in table 10, the runs occurring under conditions of steepest temperature gradient resulted in the greatest plume rise and consequently the distribution of drift over the greatest distance range.

EFFECT ON VEGETATION

Having completed a study of the amount of drift emitted from the cooling tower and having mapped the deposition flux and air concentration of the drift in the cooling tower surroundings, it is important in the final analysis to determine the effect of metallic elements in this drift on the vegetation.

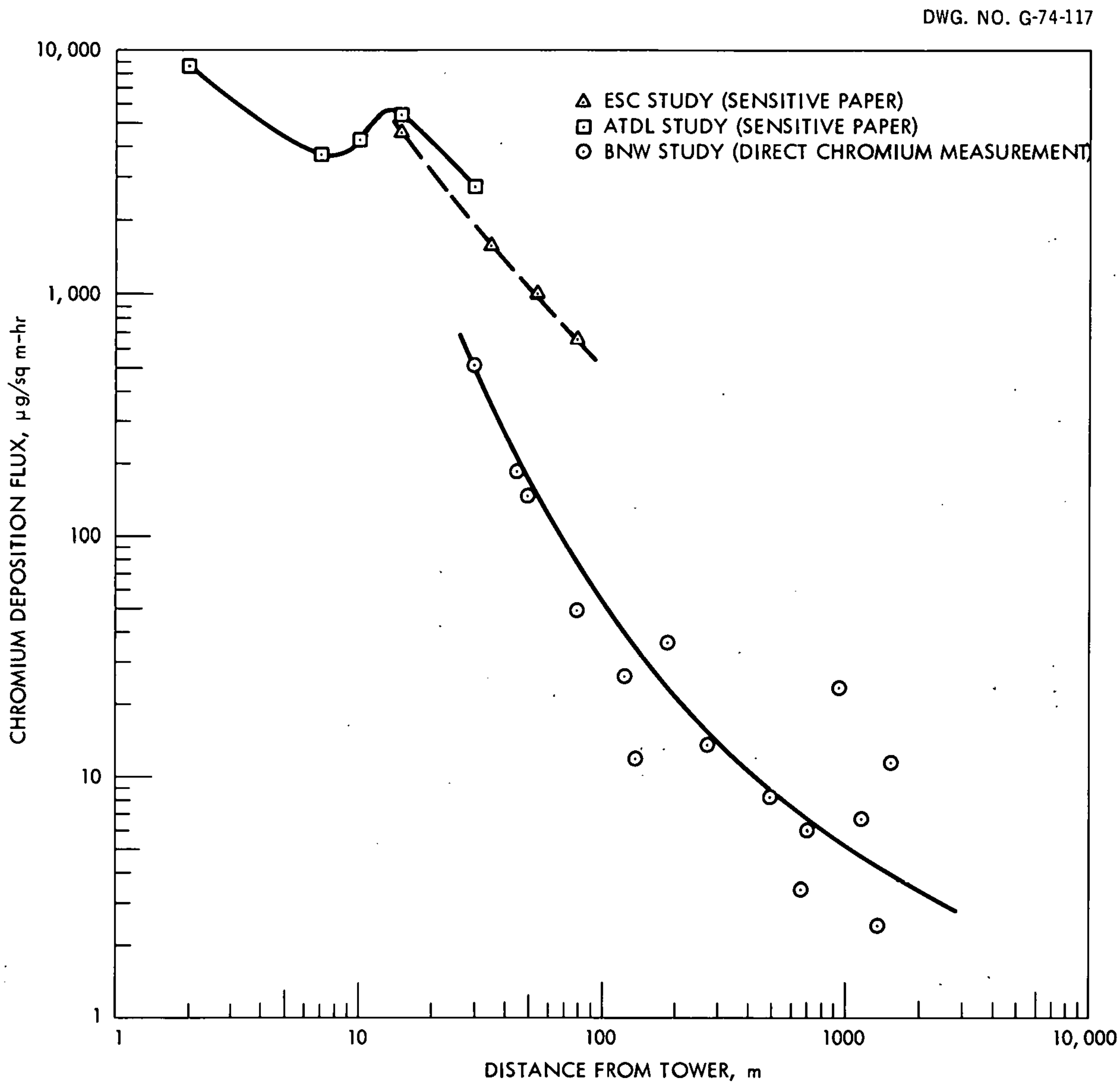


Figure 25

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

DWG. NO. G-74-118

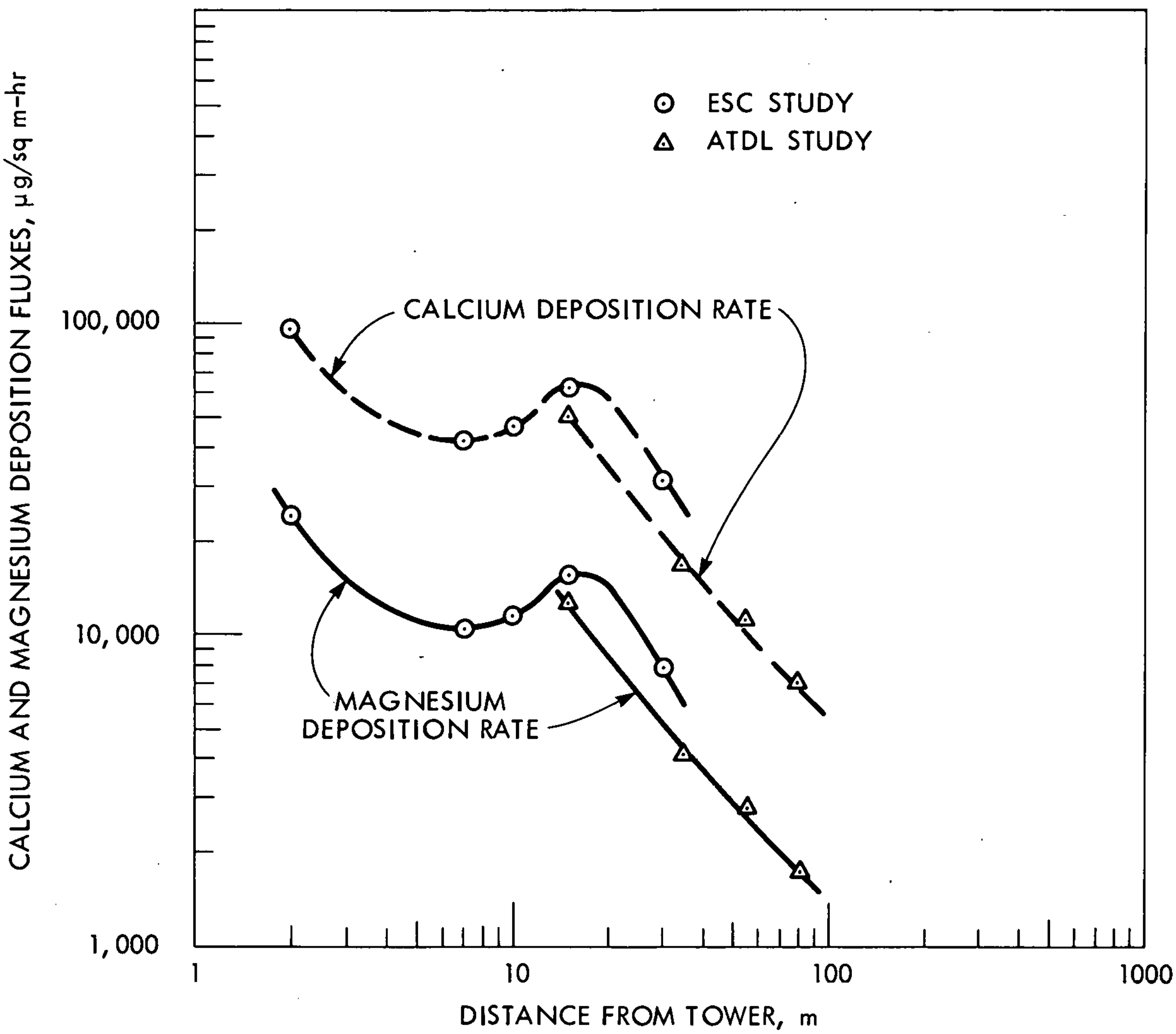


Figure 26

CALCIUM AND MAGNESIUM DEPOSITION FLUXES
AS A FUNCTION OF DISTANCE FROM K-31 TOWER

Table 8

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.

Table 9

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.

DWG. NO. G-74-119

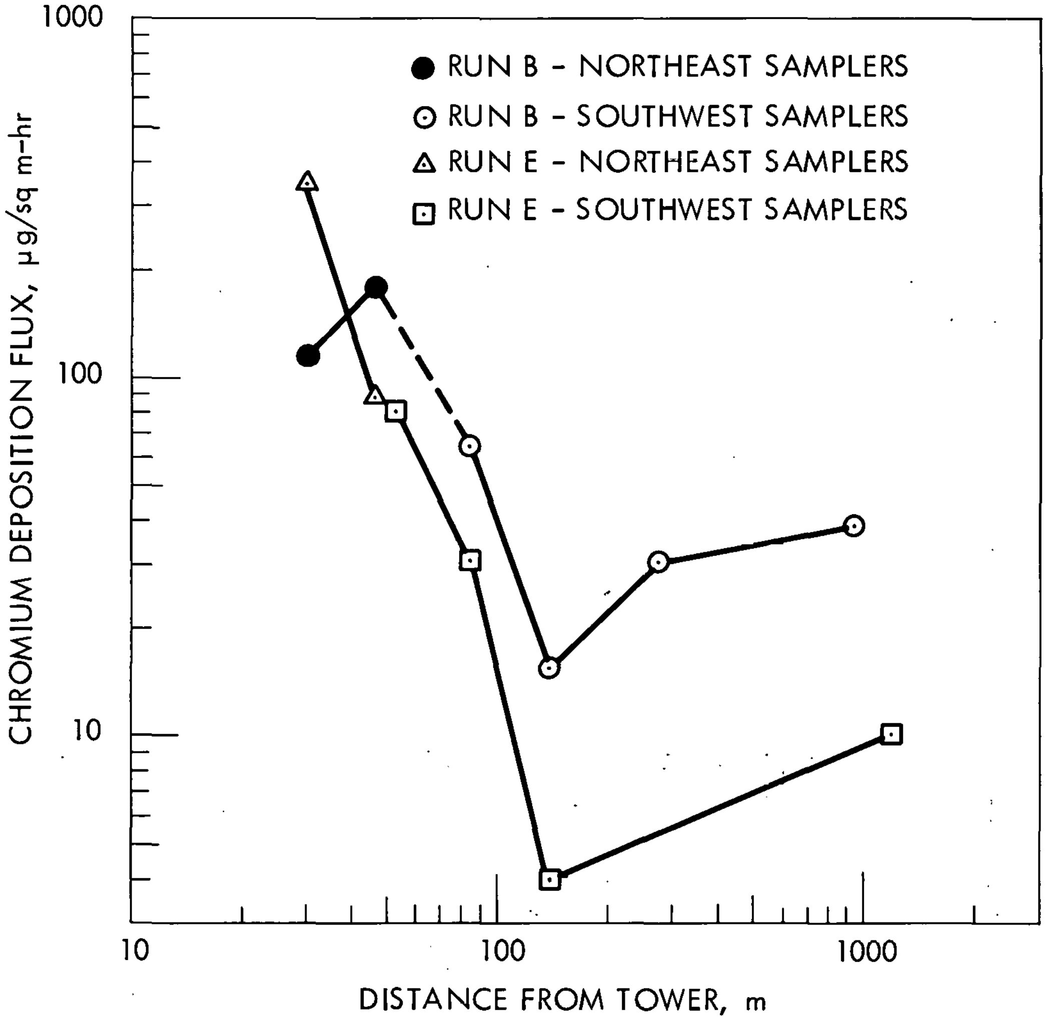


Figure 27

CHROMIUM DEPOSITION FLUX, RUNS B AND E, BNW TESTS

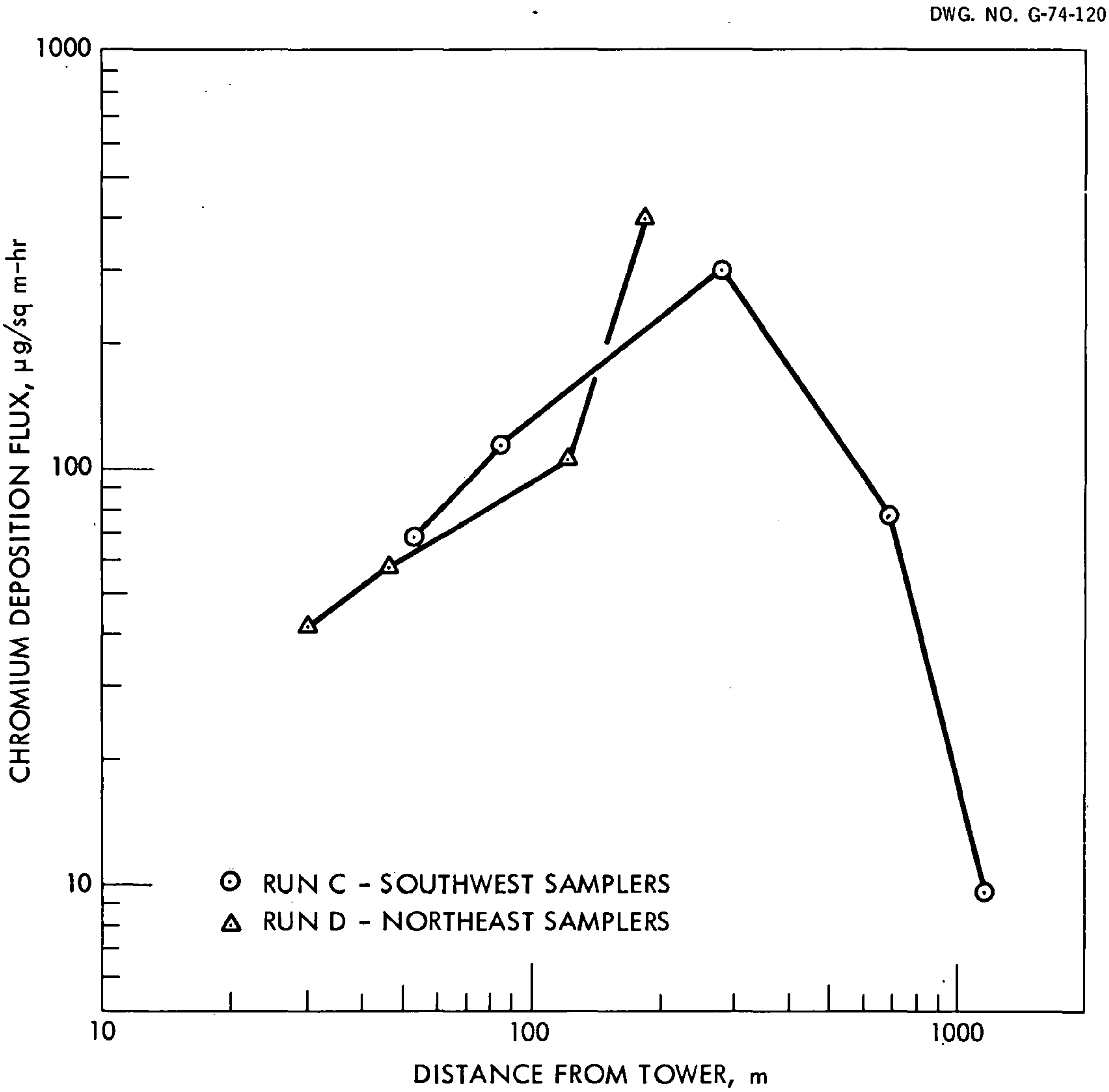


Figure 28

CHROMIUM DEPOSITION FLUX, RUNS C AND D, BNW TESTS

Table 10

WIND SPEED AND AMBIENT AIR TEMPERATURE GRADIENT, BNW TESTS

Run	Wind Speed, m/sec	$\left(T_{\text{at top of cooling tower}} - T_{\text{ground level}}\right)$, °C
B	1.4	- 0.39
C	0.9	- 2.06
D	0.9	- 1.06
E	1.0	- 0.22

Accumulation of Zinc and Chromium in Vegetation

ORNL ran tests on samples of grasses, forbs, trees, and soil to determine the amounts of zinc and chromium in the vegetation. The sampling locations were shown in figure 4. The proposed site of the Liquid Metal Fast Breeder Reactor (LMFBR) along the Clinch River was selected as a control area for vegetation and soil sampling since it was remote from cooling towers and underlaid by the same geological formation as the ORGDP facility.

A plot of the concentration of zinc in the vegetation is shown in figure 29. As can be seen, this concentration is significantly above background levels (as measured at the control area) only at distances of less than 40 m from the cooling towers. As shown in figure 30, the concentrations of chromium found at the sampling locations were appreciably higher than the background level in the control area. The amount in the vegetation was highest adjacent to the cooling tower and decreased exponentially with distance. While deviations in absolute concentration differed among the various types of vegetation, the general trends were the same. Even at distances of 2400 m, the concentration levels encountered were higher than the background levels. In the case of the soil samples, the results were different. As shown in figure 31, the concentration of extractable chromium was low and, at distances of about 400 m and beyond, quite close to the background level. Little difference was observed between the soil samples gathered at 0- to 1-cm and 0- to 5-cm depths. The rise in the concentration of chromium beginning at a distance of 300 m and going on out to 1200 m may to some degree be accounted for by noting that grass vegetation covered the ground to a distance of about 450 m from the tower. This grass may have absorbed most of the chromium fallout and thus shielded the underlying soil. Another explanation may lie in the study of the deposition flux in the vicinity of the cooling towers. It is worth noting that figure 27, illustrating the deposition flux of the chromium measured

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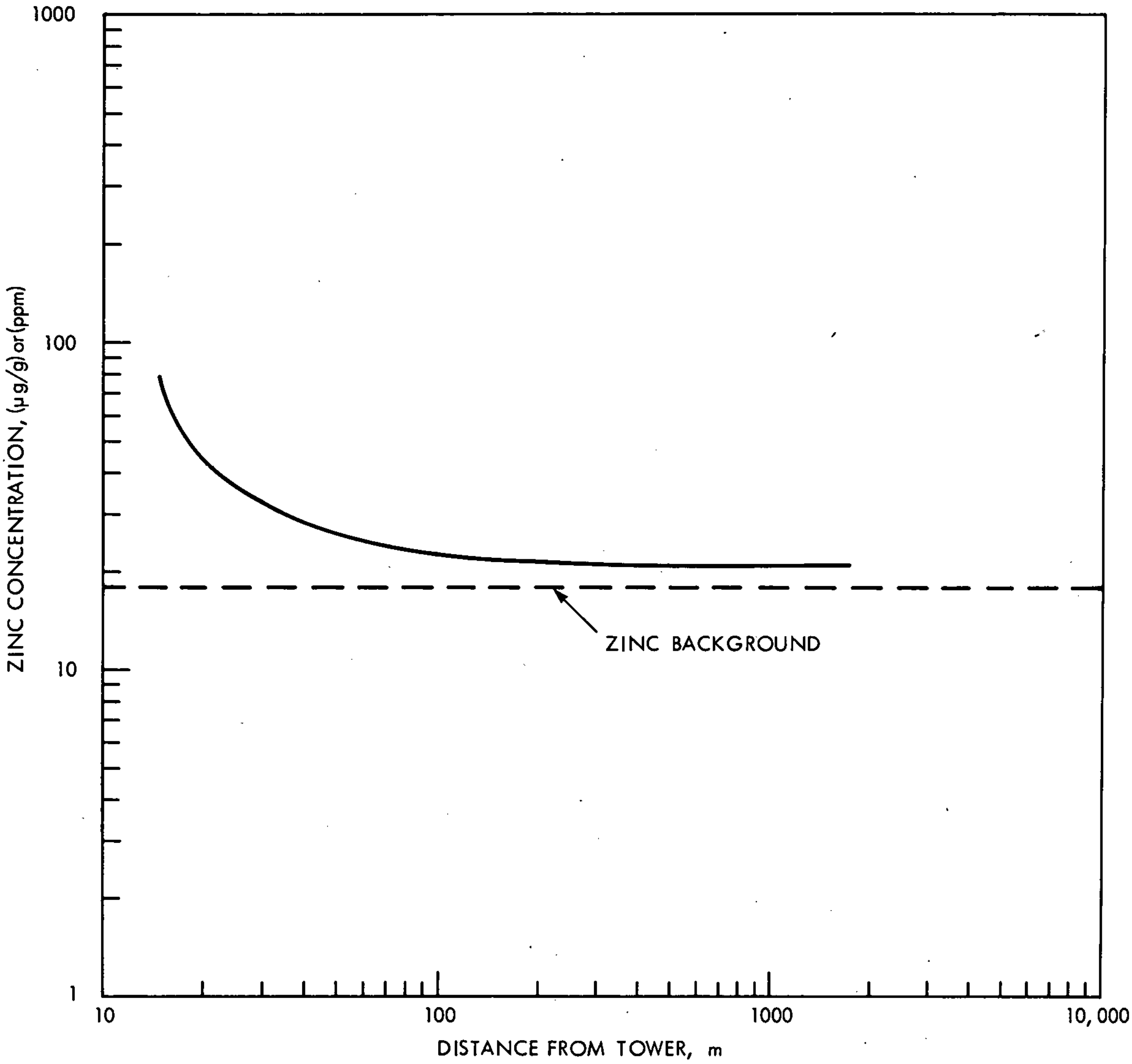

Figure 29

CONCENTRATION OF ZINC IN VEGETATION
AS A FUNCTION OF DISTANCE FROM K-33 COOLING TOWER

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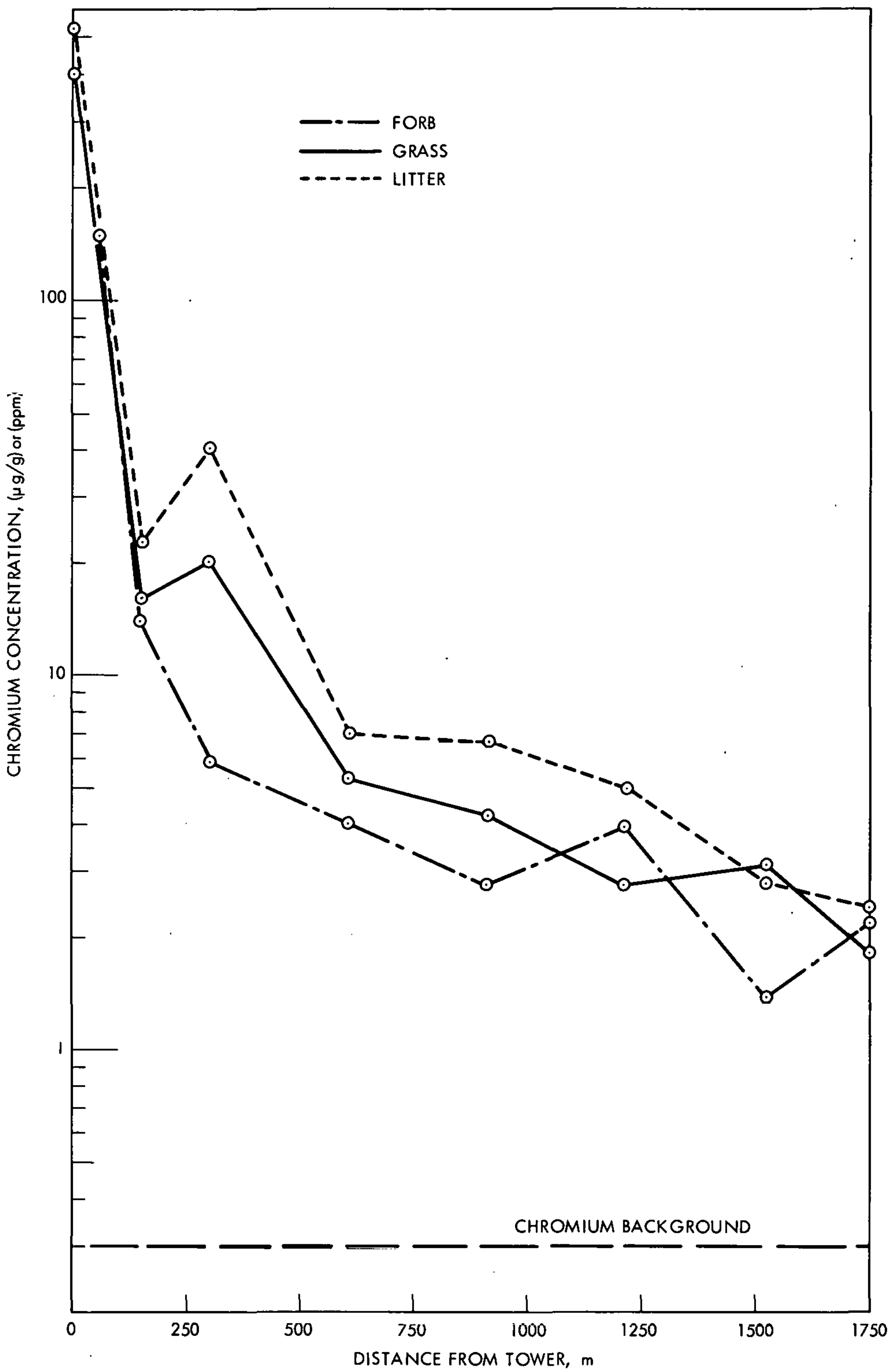

Figure 30

CONCENTRATION OF CHROMIUM IN VEGETATION AS A FUNCTION OF DISTANCE FROM K-33 COOLING TOWER

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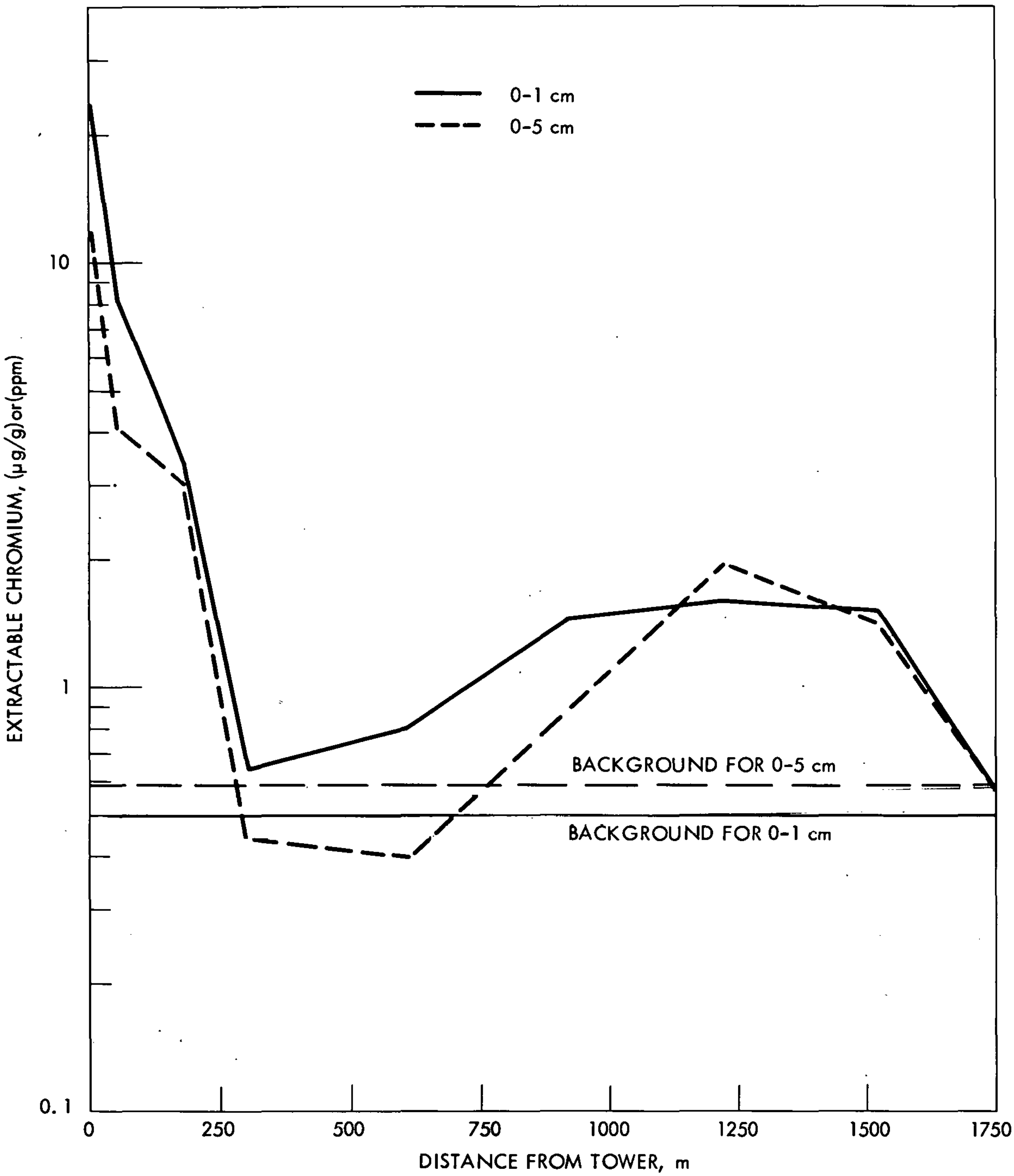

Figure 31

CONCENTRATION OF EXTRACTABLE CHROMIUM IN THE SOIL SAMPLES AS A FUNCTION OF DISTANCE FROM K-33 COOLING TOWER during Runs B and E of the BNW tests, is remarkably similar in shape to the ORNL results on the concentration in the soil. The relative occurrence of the type of deposition illustrated in figure 27 in contrast to that shown in figure 28 is presently unknown and thus the effect of the deposition flux distribution or the chromium concentration in the soil is uncertain.

Effect of Chromium on Tobacco Growth

One of the best ways of measuring the effect of chromium on vegetation is to see the effect that this element has on the growth rate of a plant which is sensitive to foreign elements. Tobacco was chosen and numerous plants were located at distances of 15 to 1400 m from the tower. Four plants were harvested each week for eight weeks and the accumulated chromium level is presented in figure 32. It is interesting to note that all plants accumulated chromium above background levels within one week and that the concentration at the 15-m distance was approximately 237 ppm after five weeks. The decrease in the curve after the fifth week may have been related to a 40% reduction in the chromate content of cooling tower makeup water.

The effect of the chromium on the leaf sizes of the tobacco plants, which are quite sensitive to chromium, is shown in figure 33. The plants at the 15-m location actually shrunk in size while those at 200 m increased only slightly in size. The plants at 600 and 1400 m were almost unaffected by the chromium and their growth rate was statistically the same as plants in the control area.

THRESHOLD LIMITS OF ELEMENTS IN COOLING TOWER DRIFT

In order for a decision to be made as to whether the amounts of chromium, calcium, magnesium, zinc, and phosphorus emitted by the cooling towers at ORGDP pose a hazard to health, there should be clear scientific and ultimately legal guidelines for use as a measure. Unfortunately, at the present, there are no legally acceptable limits with which to compare the results described in this report. There are, however, some guidelines which have been developed by technical and governmental organizations using previous industrial experience and the results of numerous medical and scientific tests. Threshold Limit Values (TLV) developed by the American Conference of Governmental Industrial Hygienists[10] refer to airborne concentrations of substances and represent conditions to which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. These limit values refer to time-weighted concentrations for a 7- or 8-hour workday and a 40-hour workweek. For the case of substances dissolved in water, numerous organizations, such as the California State Water Quality Control Board[11] and the Federal Water Pollution Control Administration, U. S. Department of the Interior,[12] have presented standards which are either used as limits in drinking water or recommended as quality criteria for farmstead uses. While these limits are not directly related to cooling tower drift, they can, at the present, serve at least as yardsticks in evaluating the effect of the cooling towers on the environment. Pertinent values from the above sources are summarized in tables 11 and 12.

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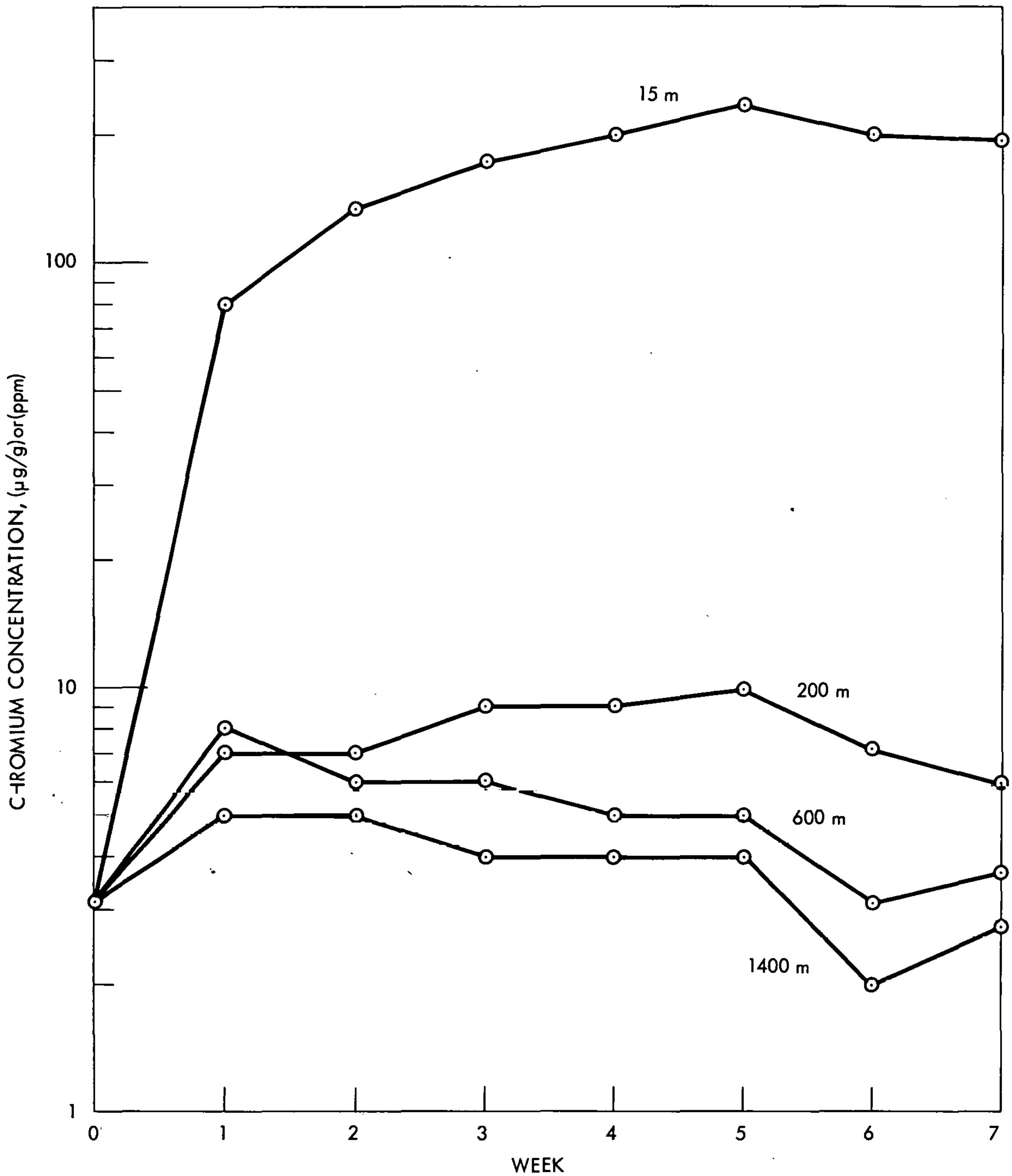

Figure 32

CONCENTRATION OF CHROMIUM IN TOBACCO PLANTS AS A FUNCTION OF TIME

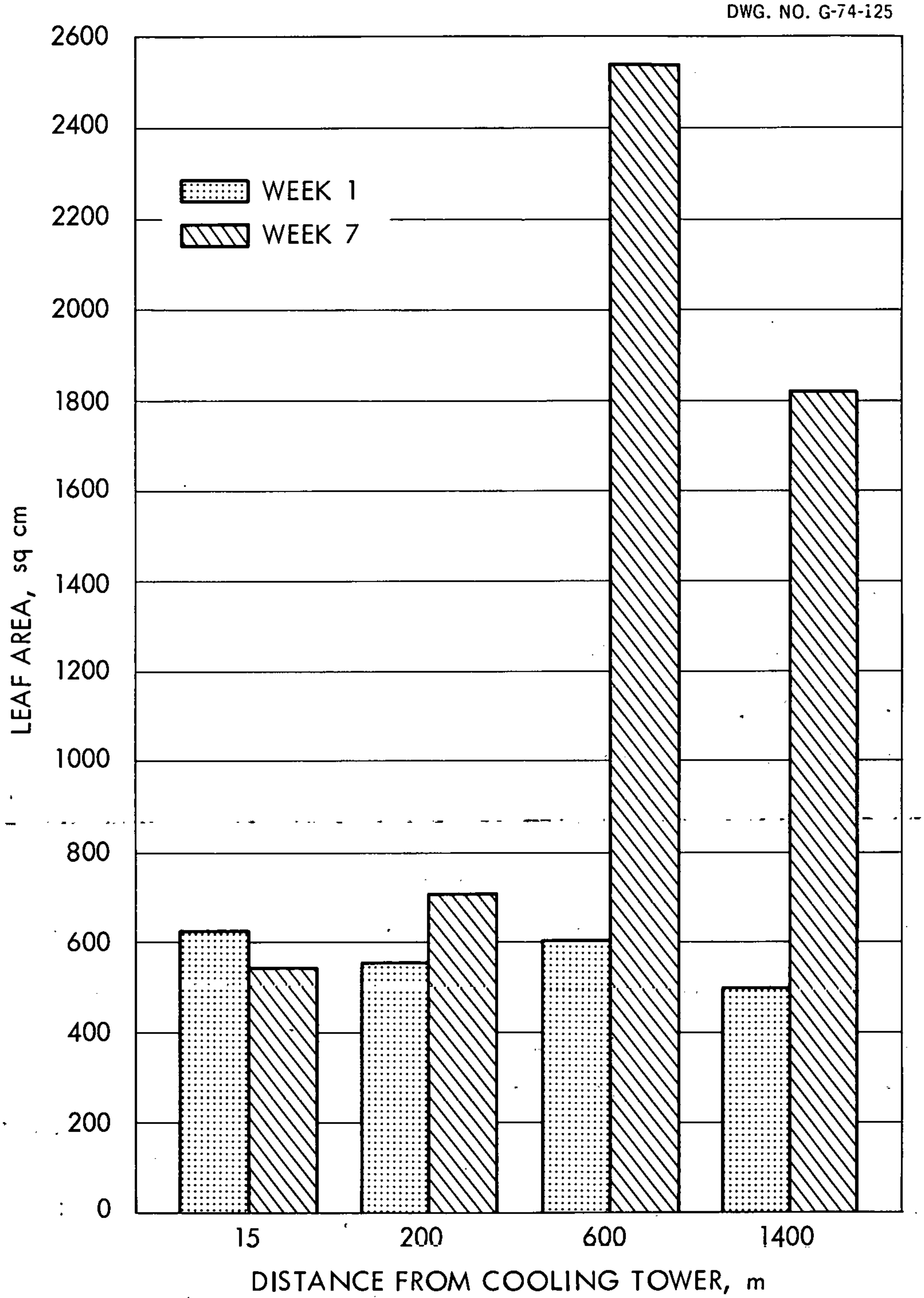

Figure 33
GROWTH RATE OF TOBACCO PLANTS

Table 11

THRESHOLD LIMIT VALUES IN AIR FOR SOME COMPOUNDS OF INTEREST[10]

Compounds	TLV, mg/cu m
Chromium, sol. chromic, chromous salts as chromium	0.5
Chromic acid and Chromates (as Cr_4O_3)	0.1
Calcium oxide	5
Magnesium oxide fume	10
Zinc chloride fume	1
Zinc oxide fume	5
Phosphorus (yellow)	0.1
Phosphoric acid	1
Phorphorus pentachloride	1
Phosphorus pentasulfide	1
Phosphorus trichloride	3 (0.5 ppm)

Table 12

WATER CONCENTRATION LIMITS FOR ELEMENTS EMITTED FROM THE ORGDP COOLING TOWERS

Element	Limit
Chromium	The USPHS Drinking Water Standards of 1962 set a mandatory limit of 0.05 mg/ℓ for hexavalent chromium, but none for the trivalent form.[10]
Magnesium	Livestock can tolerate 2050 mg/ℓ of magnesium sulfate in their drinking water.[12]
Zinc	The USPHS Drinking Water Standards of 1962 set a limit of 5 mg/ℓ of zinc in acceptable water supplies when no alternate sources are available.[11]
Phosphorus	Excessive growths of algae developed in lakes when the average concentration of inorganic phosphorus was over 0.01 mg/ℓ.[11]

These threshold limits may be compared with the experimental values obtained at and in the vicinity of the cooling towers.

Air Concentration on K-31 Tower

At the mouth of Cell 6, ESC obtained the following drift flux (from table 3):

4.22 g/sq m-sec using PILLS and sensitive paper; 1st diametral traverse. Dividing this by the average fan velocity of 7.99 m/sec, one obtains the concentration of 0.5282 g/cu m for the drift. Using water concentrations of 175.84, 43.85, and 15.83 ppm for calcium, magnesium, and chromium, respectively, the following air concentrations are obtained:

Calcium	0.0929 mg/cu m
Magnesium	0.0232 mg/cu m
Chromium	0.00836 mg/cu m

When compared to the Threshold Limit Values above, it is seen that all three air concentrations are below these limits. At distances further away from the tower, the air concentration is less and, therefore, provides an even greater safety margin.

Air Concentration on K-33 Tower

The highest measured drift emission for a K-33 fan was 7.0 g/sec, obtained by ATDL for Cell 9G, Fan 18, as shown in table 6. Dividing this by the volumetric flux of 204.2 cu m-sec, a concentration of 0.03428 g/cu m is obtained. Since this is more than an order of magnitude less than the K-31 tower value, it is also safe.

Water Concentration on K-31 Tower

The water concentrations given above in terms of ppm can be rewritten in the following units:

Calcium	175.84 mg/ℓ
Magnesium	43.85 mg/ℓ
Chromium	15.83 mg/ℓ

One unknown factor at this time is how the cumulative effect of these elements, as recorded in the previous section, compares with standards.

None was found pertaining to concentrations in soil or in plants during the search made in the literature. The results from the previous section tend to indicate that at distances of 600 m, the drift seems to have little effect on the growth of tobacco plants which are quite sensitive to the presence of chromium and other elements. In addition, if the regions around the cooling towers are used for grazing, both the elements inside the plants and those on the surface would be ingested by the animal. Thus, limits on the deposition flux need to be formulated. On the basis of the test described above and on the observation that more than 20 years of operation seem to have done no discernible damage to the surroundings, the ORGDP cooling towers, under present operating conditions, are not creating an adverse impact upon the environment.

CONCLUSIONS

Information has been presented here on the drift emission characteristics of the K-31 and K-33 cooling towers under a limited range of operating conditions. As a result of these tests, one can conclude the following:

1. A drift fraction of between 0.08 and 0.12% was obtained for the K-31 tower. For the K-33 tower, the drift fraction was much lower due to the better condition of some of the drift eliminators, the lower operating level, or both.

2. The total drift flux from the K-33 tower is only about one-half to one-third that from the K-31 tower.

3. The concentration of the elements in the drift is below the TLV's at the top of the cooling tower.

4. The conditions of some of the drift eliminators have deteriorated. This is especially true of Cell 6 of the K-31 tower. These deteriorations contribute significantly to the drift concentration in the air.

5. Deposition fluxes in the vicinity of the cooling tower - from 2 to 1500 m - were obtained. No standards are available with which to compare these results.

6. The distribution of the deposition flux in the vicinity of the cooling tower is dependent on the temperature gradient between the ambient air at ground level and the air at the same elevation as the top of the cooling tower.

7. The droplet size distribution is slightly different between the K-31 and K-33 towers. While in both cases the maximum drift flux occurs approximately in the 120- to 180-µm range, the K-33 tower emits droplets only as large as 1500 µm. The droplets from the K-31 tower vary in size to as high as approximately 5000 µm. Droplets in excess of 1000 µm constitute only about 7.5% of the total drift flux in the K-31 tower.

8. Close to the tower, the largest size droplets tend to fall out at a much higher rate than the smaller droplets.

9. Tentative experimental verification has been obtained for models of drift transport.

10. Based on the limited tests performed so far, operation of the towers under present power loads has not and is not causing any undesirable effect on the native vegetation surrounding ORGDP.

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