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ENVIRONMENTAL IMPACT OF SALT DRIFT FROM A NATURAL DRAFT COOLING TOWER

An experimental program has been conducted to quantify the salt emission, salt deposition, and terrestrial biological effects of the operation of a large natural draft cooling tower at Chalk Point, Maryland, using brackish water as makeup. A predictive methodology was developed to permit estimates of salt deposition impact over extended periods of tower operation. The results of the predictive modeling are transferable to other towers and sites if the new site parameters and tower design are properly considered.

INTRODUCTION

Historically, steam electric generating stations have used once-through cooling as the preferred form of heat removal. Such systems are relatively simple, inexpensive, and efficient. However, during the 1960's, as electric generation equipment grew larger, concern developed regarding the environmental impact of heat disposal into natural waters by once-through cooling. Also, many sites that are otherwise extremely desirable for the construction of electric generating stations do not have adequate water to allow once-through cooling in such large plants. The proposed solution to both problems was the use of cooling towers. Ultimately, planning for the Chalk Point Electric Generating Plant of the Potomac Electric Power Company (PEPCO) incorporated two large natural draft towers, each a part of a 600 MWe[1] system.

By the late 1960's, the planning of many large power plants (i.e., 500-1000 MWe) incorporated large evaporative cooling towers in the heat removal systems. These plans took many forms, including proposals for banks of mechanical draft towers, circular arrays of mechanical draft towers, fan assisted natural draft towers, and large hyperbolic natural draft towers, both singly and in clusters. While each of the above tower types has its own problems of design and placement, they all have the common objective of cooling the condenser to the lowest feasible temperature. Even at best the temperature rise across the condenser is much larger than it is in once-through cooling, and this results in higher back pressure on the turbine and reduced efficiency of electrical generation with an overall increase in operating costs.

As is often the case, the apparent solution to one problem gives rise to another. While emissions from cooling towers are largely water vapor and condensed vapor as aerosol droplets, there is also a small amount of aerosol consisting of droplets that are formed directly from the circulating water. Environmental concerns that developed in the late 1960's and early 1970's suggested that the mineral salts contained in the drift originating from the circulating waters might be harmful to native vegetation in the vicinity of a large cooling tower, particularly if the makeup water (i.e., the water used to replace evaporation) was taken from a brackish or saline source. Cooling tower manufacturers responded with improved drift eliminators while attempting not to degrade the tower's cooling function in the process. For example, the Marley Co.[1] improved its drift eliminator system to achieve a drift fraction (i.e., the ratio of the drift emission rate to the circulating water rate) of 0.001%, which is about one-tenth its previous value. In light of this new concern, the Chalk Point Generating Station was a prime candidate for study in 1970: it was proposed to use brackish makeup water in the improved Marley cooling tower, and the plant was to be located in a prime Maryland agricultural setting. At that time, special interest was expressed regarding the impact on tobacco, the burning rate of which is very sensitive to chloride concentration in the leaves. Also of concern were corn and soybeans, both important elements of Maryland's economy, and native vegetation.

ORGANIZATION OF THE CHALK POINT COOLING TOWER STUDY

The environmental issues were raised at the legislative and regulatory levels in Maryland. As a result, a June 1971 action by the Maryland Public Service Commission required, as a condition in the construction permit for the Chalk Point Plant, that a research and monitoring program be initiated to determine the impact of salt drift. This was the origin of the Chalk Point Cooling Tower Program. In its early stages, the Agronomy and Botany Departments of The University of Maryland (UM) designed and implemented a program of vegetation and soil monitoring at several sites near the plant. Research was also initiated to establish the tolerance of crops, plants, and soils to saltwater aerosol spray. These field programs, started in 1973, have continued into 1979 with excellent data recovery, both prior to plant operation and after the plant came on line.

In 1973, the scope of the program was expanded to include the development and validation of methods of estimating salt drift emission from the cooling towers. In addition to a model development effort, the program required the acquisition of cooling tower emission data, plume trajectory data, and drift deposition data for use in the validation process. Clearly, such data were also of value for the Chalk Point monitoring effort. In support of the expanded program, the contractor team was enlarged and by early 1975, the objectives of the expanded program had been formalized (Table 1). The experimental and analysis programs from 1972 to 1979 have been largely successful in achieving these objectives.

Table 1

OBJECTIVES OF THE CHALK POINT COOLING TOWER PROGRAM

1. Establish the environmental impact of salt drift by monitoring crops, soils, and native vegetation.
2. Develop methods for studying salt damage. Determine symptoms of salt drift injury. Determine threshold levels for injury.
3. Develop a practical, validated salt drift transport and deposition model.
4. Develop validated vapor plume models.
5. Develop an archival data base suitable for development and validation of models.
6. Determine the range of variability of cooling tower emission over one year's time.

THE EXPERIMENTAL PROGRAM

The experimental program consisted of two essentially separable elements: (a) the agricultural and native plant and soil tests conducted by UM, and (b) the modeling and model validation program conducted by other contractors. These program elements can be described, and indeed have been conducted, relatively independently. The two efforts converge at the conclusion of the program and provide a basis for judging whether predicted salt depositions will cause serious harm to plant species of interest.

The Agricultural and Native Plant and Soil Tests[3,4]

Description of the Experimental Work—Tests were conducted under the general direction of the Water Resources Research Center of UM and were done in support of Objectives 1 and 2 in Table 1. The monitoring program used a modified factorial experimental design, an analysis of variance approach that has become standard in agricultural experiments. Test plots (Fig. 1) were established at several locations around the cooling tower (Fig. 2). Controllable factors included fertilization, tilling, seed stock, and margin plantings. Meteorological variables and salt drift deposition at the various sites were functions of ambient meteorological conditions and of plant location. The monitoring was conducted from 1973 through 1978, and observations were made of visible damage, yields, chloride content, burning rate (tobacco), and plant metabolism.

The research, which was directed toward establishing salt tolerances for important species, was conducted by UM and consisted of the controlled spraying of various crops at the UM experimental farm. Tests were conducted for a three-year period using aerosol sprays of approximately 100-μm-diameter droplets at a dose rate of 0 to 90 kg/Ha-mo[5] during an eight-week growing season. The principal crops tested were corn, soybeans, and tobacco. The experiments attempted to relate damage, yield reduction, and leaf chloride content to the integrated salt exposure over a growing season.

Results of the Soil and Plant Tests—With the system being operated as a cycling unit (30% average utilization), the monitoring program at the test sites, both on-site and off-site, revealed no identifiable, detrimental effects on the plant species under test. Statistically, the dustfall collectors at

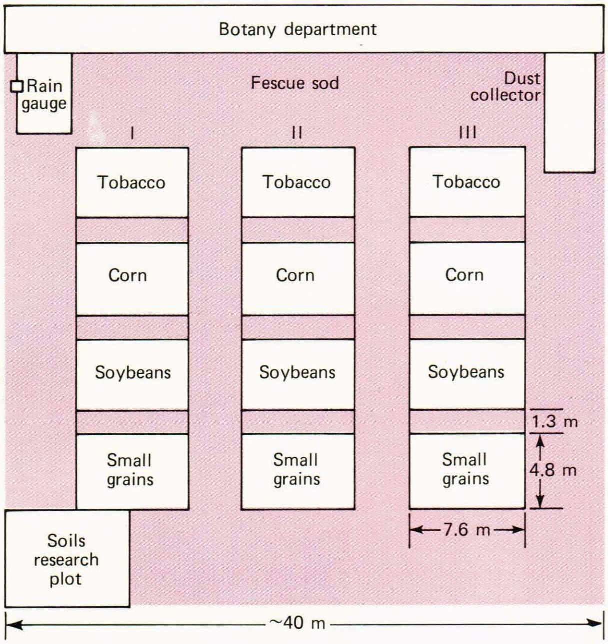

Fig. 1—Experimental agronomy plots located at selected sites near Chalk point. The statistical design and plot, design were done by the UM Department of Agronomy.

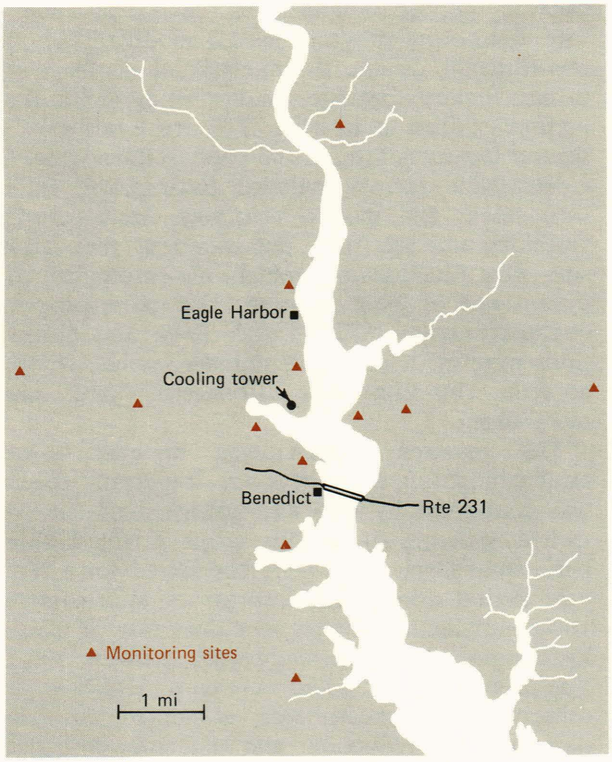

Fig. 2—Stations for monitoring pre- and post-operational salt deposition in the Chalk Point area were established in this north-south, east-west pattern.

the monitoring sites showed slightly higher levels at the locations closer to the towers. Tests of undisturbed soil at the monitoring sites revealed no significant changes in key parameters such as soil acidity (pH), extractable sodium and chloride, and electrical conductivity. This is a most encouraging result.

The results of the UM plant research program have been extremely useful in the impact studies. Regression equations have been obtained that relate the yield reduction of corn and soybeans[6] (Fig. 3) and the percent reduction in burning time for tobacco[7] (Fig. 4). These data were used in the impact assessment, together with the separate results from the modeling of deposition.

THE MODELING AND MODEL VALIDATION PROGRAM

The program of model development and model validation was conducted concurrently with, but largely independently of, the agricultural experiments and supported Objectives 3 through 6 of Table 1. Four major phases were completed over a period of five to six years.

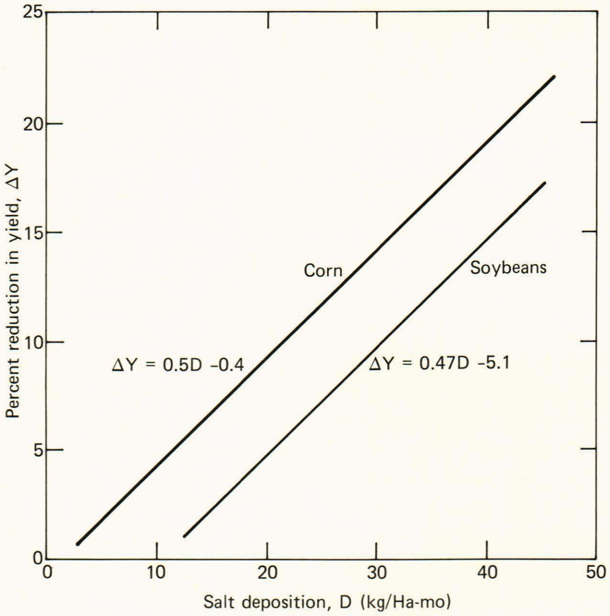

Fig. 3—Impact of salt drift on crop-yield reductions (corn and soybeans), as determined by UM agronomists using regression methods with controlled salt-spray test data.[6]

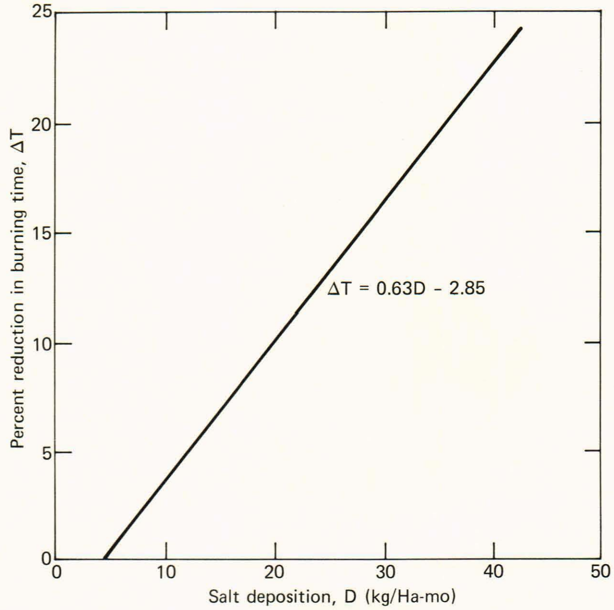

Fig. 4—Impact of salt drift on reduction in tobacco burning time, as determined by UM agronomists using controlled salt-spray test data.[7]

Instrumentation—This portion of the program required the acquisition of enough data to describe the tower emissions, the plume rise parameters, the deposition external to the tower, and the ambient meteorology. Environmental Systems Corp. (ESC) of Knoxville, Tenn., was selected as the principal instrumentation contractor. ESC designed, constructed, and operated a special instrumentation[6] package to measure plume thermodynamic and meteorological parameters within the tower. In addition to the plume exit variables of temperature, dew point, and vertical velocity, the instrumentation measured both salt emission (using an isokinetic sampler) and the drift droplet size-number distributions (using Particulate Instrumentation by Laser Light Scattering (PILLS) and sensitive paper). The equipment enabled the investigators to obtain drift size-number distributions of a quality not possible previously.

ESC also instrumented several ground sampling stations at ranges of three to six miles from the tower, primarily on north-south and east-west lines. Measurements of salt deposition and salt droplet spectra were made. Camera facilities and sites for plume photo acquisition were also prepared.

Additional specialized instrumentation provided by other contractors included a 100 m meteorological tower, instrumented at three levels (Bendix Environmental Services); radiosonde instrumentation for use in critical tests (APL); and an aircraft instrumented by Meteorology Research, Inc. (MRI) to provide a variety of plume level drift and meteorological data.

Experimental Operations—The first phase of the experimental operations program was performed by ESC in the spring of 1975 and consisted of a long and tedious characterization of the tower emissions. The characterization was used primarily to establish representative sampling points and to check out procedures. In addition, these data provided information on repeatability and constancy of the various parameters. The early measurements were useful in establishing the drift rate of the tower and in providing preliminary data concerning the size-number distribution of the drift. Figure 5 shows the general arrangement used by ESC in the sampling program. It is emphasized that the rather elaborate arrangement for sampling the internal meteorological and thermodynamic properties of the tower was vital to the model validation program.

The collection of data to relate emission to deposition began in December 1975. All the above instrumentation was used. The first intensive period of testing provided additional samples of source term data (cooling tower emissions) and confirmed a growing concern that the existing ground deposition and aircraft instrumentation was not adequate for acquiring drift data for model validation. The plume thermodynamics data measured by the aircraft were excellent. The first test series confirmed that the heavier salt concentrations were appearing much closer to the plant than had been expected.

In June 1976, a second intensive test program was conducted. For some of these tests, ESC established four ground deposition stations along a radial line within one mile of the tower, and MRI modified one sensitive-film impactor (data collector) to greatly increase the capture cross section for drift. Both of the modifications were effective in detecting the drift droplets, but at rather low levels of statistical validity.

The data[8] from these three test series have been valuable for the following purposes:

1. It was established that the drift rate is about 0.001% (i.e., about 3 gal/min). Data of this type were valuable in acceptance of the tower.
2. Libraries of source term data were collected for the December and June tests. These libraries, together with a cooling tower thermodynamic model developed by APL, were used to obtain source terms for monthly, seasonal, and annual impact predictions.
3. A large library of plume photographs and concurrent meteorological data was obtained and used to tune the plume rise model used in the predictions.

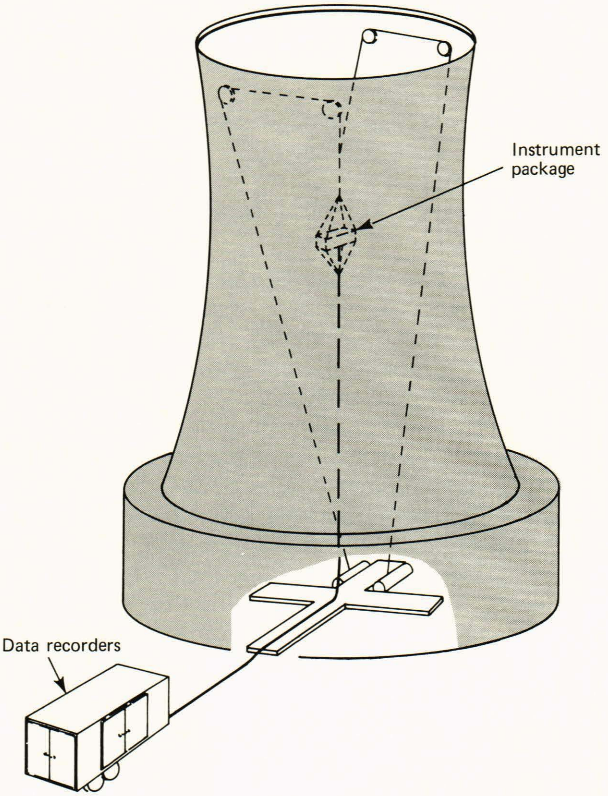

Fig. 5—Chalk Point cooling tower instrumentation for source term measurement, which was designed, constructed, and operated by ESC. Thermodynamic variables and aerosol drop sizes were measured.

The deposition data obtained were not considered adequate for model validation.

Improved Validation Test—During the last half of 1976 and early 1977, planning was under way to conduct a test having the specific objective of obtaining significantly better data for model validation. The planning included:

1. Full source term, photographic, and meteorological data as in the previous intensive tests;
2. Improved ground concentration detectors arranged to ensure detection under the plume at 0.5 and 1.0 km from the tower;
3. The use of a tracer in the cooling tower water to ensure a one-to-one correspondence be-

tween cooling water emission and detected deposition (it was important to discriminate between sea salt and salt from the boiler stack scrubber);

4. Greatly increased deposition detector sizes to ensure statistical adequacy of the drift droplet data; and
5. Stable meteorological conditions for the experiment.

In June 1977, the validation test was conducted using a close-in, dense array of deposition samplers, with the circulating water from the cooling tower charged to 1 ppm with rhodamine (WT) dye. This allowed unambiguous identification of cooling tower drift. Deposition data acquired included the total deposition (from funnel samplers) and drop size-number counts (from 12 in. papers). Because the dye is photosensitive, the test was conducted at night. It was fully successful. The cooling tower, charged with rhodamine (WT) dye, is shown in Fig. 6, the sampling array for the test is shown in Fig. 7, and the instrumentation at each station is shown in Fig. 8. The quality of data obtained was extremely rewarding.[9,10]

Modeling and Analysis—In 1973, a program of drift model development was initiated,[13] with Dr. Israel (UM), Dr. Overcamp (UM/Clemson), and Dr. Schrecker (ESC) as direct participants. Several existing proprietary models were considered. Because APL had developed and used salt drift models in connection with other work in power plant site evaluation, we were given increased responsibility in the modeling area late in 1975, and chose our own models for the validation program. The APL model bears many similarities to the models of Overcamp and Schrecker, but it also includes features for the evaluation of area impacts. The essential features of the APL salt drift model are shown in Fig. 9. The model requires source term data, including a size-number distribution, thermal characteristics of the plume, ambient meteorology, and (for validation) photographic plume data and deposition data (either total deposition or deposition size-number distribution).

The APL model[14] incorporates the physical processes that are expected to contribute significantly to the amount and distribution of drift deposition. The vapor plume submodel predicts the trajectory and extent of the vapor plume from the tower. It incorporates buoyancy and entrainment and is tuned to photographic validation data. A drift transport submodel predicts the transport of saline drift droplets and computes the deposition of salt on the area around the tower. An aerosol droplet representing a drift aerosol size class is analyzed in a time-incremented simulation. It is subjected to the forces caused by buoyant plume rise, viscosity, gravity and ambient horizontal wind while it is in the plume, and, thereafter, to viscous falling at terminal velocity, evaporation, dispersion, and the ambient wind flow. Model predictions can be obtained in forms suitable for model validation and area impact descriptions.

Model validation involves a determination of the adequacy of the model to connect a set of time-

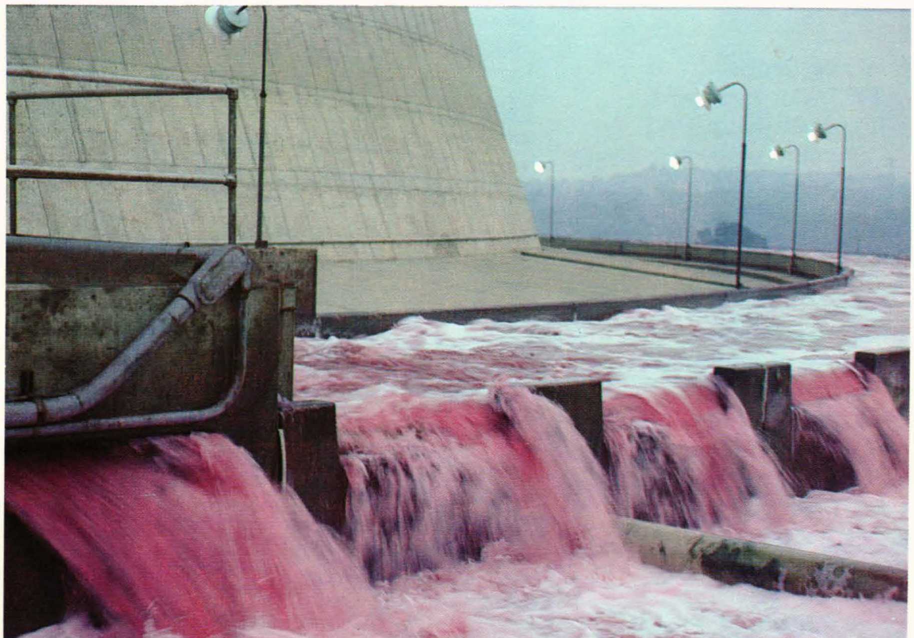

Fig. 6—The cooling tower was charged to about 1 ppm with rhodamine (WT) dye, for the June 16, 1977 model validation test. Emissions from the cooling tower were traced.

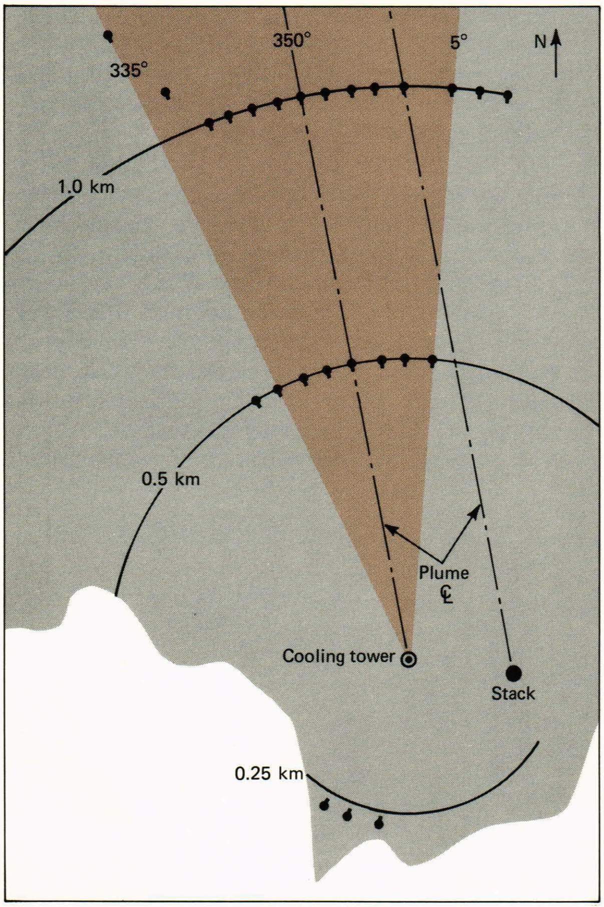

Fig. 7—Chalk Point cooling tower program test array for dye deposition. A dense array of receptors was used at distances up to 1 km to obtain the azimuthal deposition centerline.

coincident source term and deposition measurements. The data taken in the June 1977 dyed drift test were used for this purpose. The source term specification requires thermodynamic and basin measurements that are included in the data provided by ESC. The size-number distribution obtained by ESC in the special validation test is representative of this type of data obtained under various conditions in the Chalk Point Program.

It is important that the use of the dye tracer permits identification of salt originating from the tower and its separation from stack-salt emissions. These data (Fig. 10) obtained from the funnel collectors have been used with the appropriate source term data in our APL salt drift model; our prediction exceeds the measured value by about 50%. The data have been used with several models at Argonne National Laboratory (ANL),[15] and it is observed that the models of Hosler-Pena Pena, ESC/Schrecker, Overcamp, and several others agree reasonably well at these ranges. The more recent version of the Overcamp model tended to underpredict by about 50%. While these models differ from the APL formulation in details, most of them are of the same general structure.

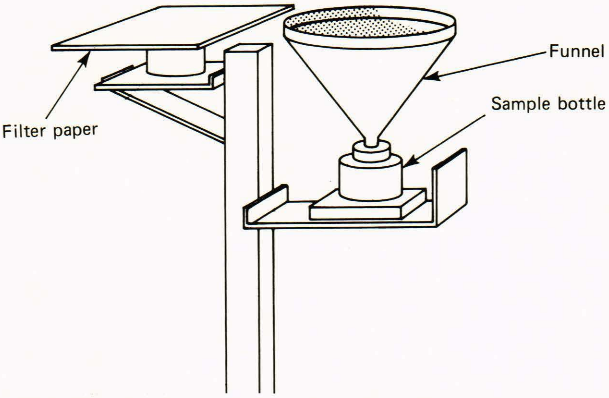

Fig. 8—The models being validated predict both total deposition and deposited size-number distribution. The two sampling devices shown were used to obtain both types of data. Special consideration was given to obtaining adequate statistics from the size-number data.

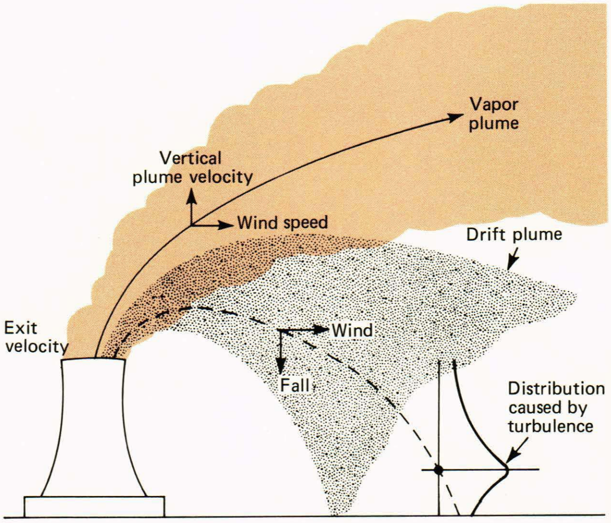

Fig. 9—APL's salt drift model is a formulation of a general class of models used to describe cooling tower drift. Individual particle sizes are subjected to the vertical velocity, gravity, horizontal wind, and viscous forces inside and outside the plume.

Because of uncertainties in the data and modeling assumptions and the size-number distribution characteristics of the source term data, the total deposition data described above are not adequate to completely validate the model. Therefore, it is important to determine whether the predicted and observed particle sizes contributing to the deposition at the ground collectors are in agreement and, if not, to introduce a tuning correction. Reviewing the data:

1. Figure 11, the source term mass-fraction data obtained by ESC, shows many small particles less than 100 μm, 70% of the mass being in these droplets. In addition, the source term size-number count is a rather slowly changing function of size for sizes greater than 200 μm.
2. Figure 12 shows the deposition size-number

distributions at 0.5 and 1.0 km. The distributions are seen to be bimodal. On the other hand, when these data are converted to mass fraction (Fig. 13), it is clear that the salt deposition is contributed entirely by the upper mode centering around 300 μm and that the mode center shifts with range. The large particles fall quite near the tower.

3. Our particle size deposition prediction does not agree well without correction. A simple wind-shear velocity correction based on radiosonde data achieves an excellent fit at 1.0 km but not concurrently at 0.5 km. This is shown in Fig. 14. It is assumed that local wind disturbances caused by the tower produce this effect, but the available wind field data do not permit further clarification of this point. This type of wind-shear correction was used in the impact evaluation. The results

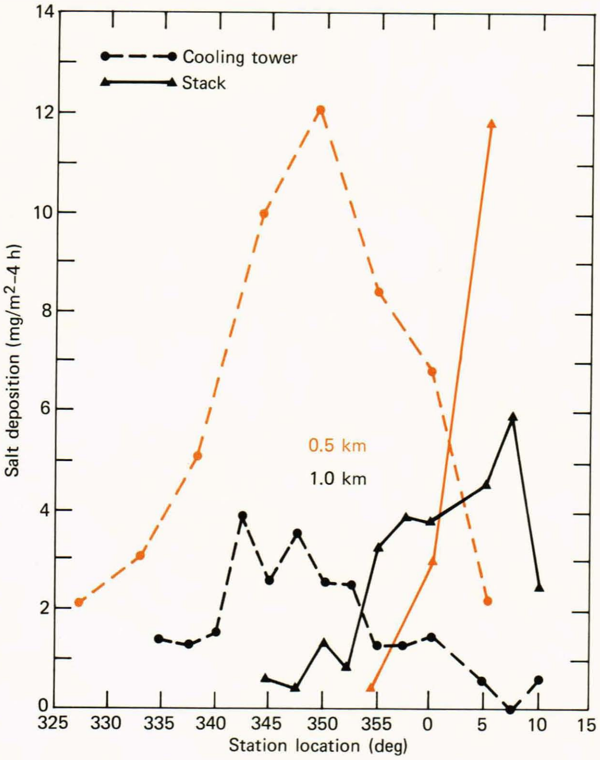

Fig. 10—Salt deposition rates from the cooling tower and stack were determined in the dye experiment for use in model validation.

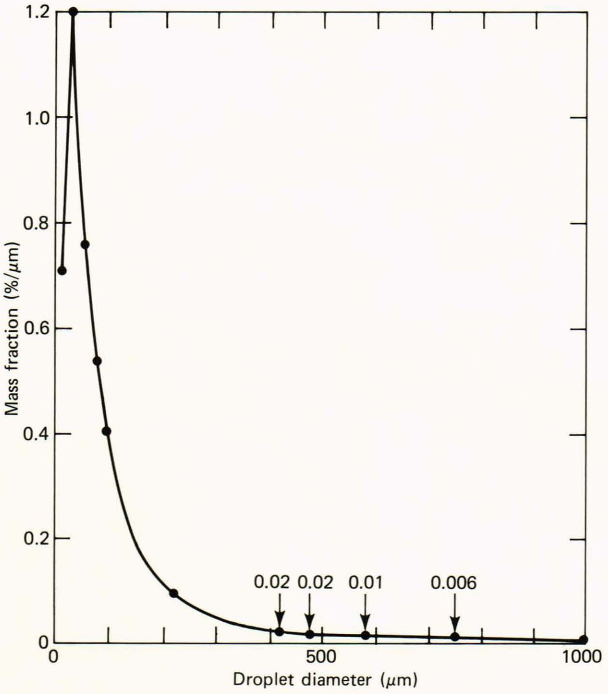

Fig. 11—Drift source term mass-fraction data from the dye test of June 16, 1977.

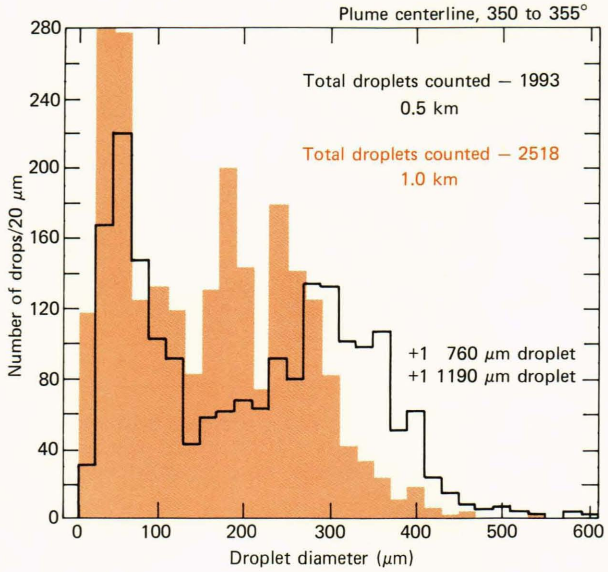

Fig. 12—Dyed drift deposition test data of June 16, 1977 (deposition size-number distribution, fluorescent drops). The double-peaked curve is typical of all the data obtained. The small particles make a negligible contribution to the salt deposition.

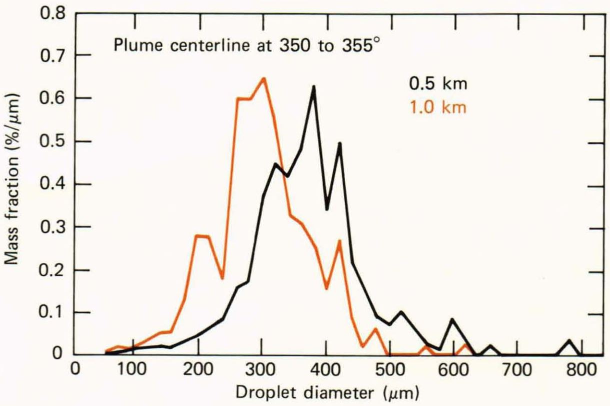

Fig. 13—The dyed drift test of June 16, 1977 (deposition mass-fraction distribution) confirms that only the aerosol sizes from 300 to 500 μm make significant contributions to the deposition.

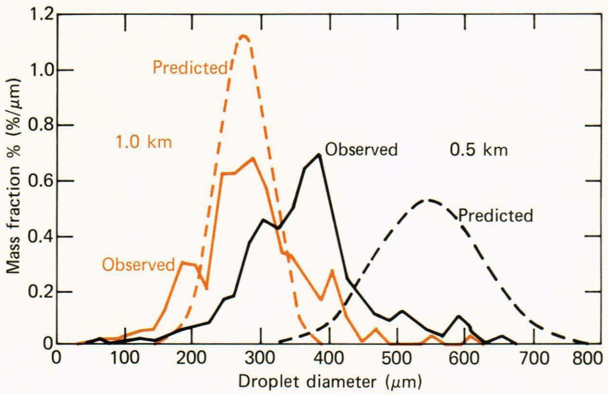

Fig. 14—Dyed drift deposition test of June 16, 1977 (validation with wind shear corrections). A simple wind shear correction consistent with close-in shading and downwash was used to achieve agreement with the model at 1.0 km.

are consistent with the existence of a wind shadow or downwash in the lee of the tower.

The final analysis task consisted of preparing monthly, seasonal, and annual salt deposition isopleths and relating these predictions to the tolerance levels established by UM. This task used the libraries of source term data, two years of meteorological data, the library of plume rise data, and separate models of plume thermodynamics. The inputs applied to the APL drift model produced predictive isopleths as shown in Fig. 15. Similar calculations for two cooling towers and two cooling towers plus two stacks indicate that the effects of salt drift at Chalk Point will be insignificant. The expected effects are shown in Table 2.[14]

Table 2
EFFECTS OF SALT DRIFT ON CROPS*

Source	*Max. Salt (kg/Ha-mo)*	*% Corn Yield Reduction*
One tower	2.0	1
One tower and one stack	3.2	1
Two towers plus two stacks	5.4	2

*Full load, continuous, off-site. Soybean yield and tobacco burn time were not affected.

SUMMARY AND CONCLUSIONS

This program, which has lasted about seven years, has fulfilled the basic program objectives. There have been several significant accomplishments:

1. Experimental data have been obtained concerning the effects of salt aerosol drift on plants and soils, and a methodology for conducting tests of this type has been established.

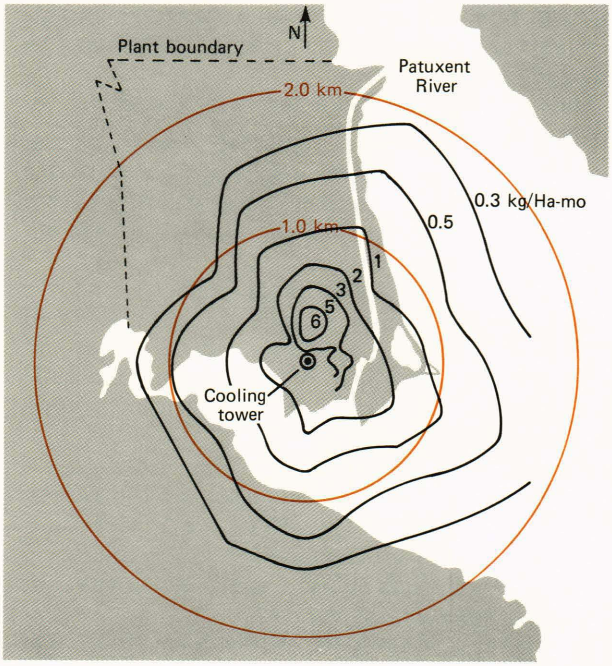

Fig. 15—Chalk Point cooling tower salt drift, annual salt-loading isopleths (kg/Ha-mo plant load, 590 MWe continuous). At all locations outside the plant boundary the salt deposition impact is negligible.

2. The art of cooling tower emission measurements has been advanced. In particular, ESC's PILLS system has provided a significant improvement in the measurement of size-number distributions in cooling tower drift emission.
3. Methods have been developed that permit the measurement of drift deposition data of a quality adequate for model validation. The special dyed drift test designed by APL was unique in separating the deposition from various sources, and it provided deposition data of a quality not previously obtained. Data obtained in this test permitted model validation for use in impact predictions.
4. A large library of data is available. Most of the data can be obtained from NTIS in the form of project reports, and data are also available on computer-compatible tape from APL.
5. A drift deposition model has been developed and configured for impact studies using the Chalk Point data as well as other data bases.
6. As a result of the above work, it is generally accepted that salt drift effects will be insignificant at Chalk Point.

In a broader sense, it is important to note that the results are useful to other sites. Although it is necessary to run the model to incorporate variations in local meteorology, first estimates of impact can be made by simple scaling of salinities, drift rates of the tower, circulating water rate, etc. The use of the model to produce estimates for towers not yet built will require a representative drift size/mass distribution, which can probably best be obtained by the manufacturer.

Some specific observations are also possible:

1. Further efforts to eliminate particle sizes greater than 600 μm would not be profitable because these particles are deposited very close to the tower and produce no off-site impact.
2. Efforts to reduce drift of particles that are less than 100 μm in size, at the expense of tower operating efficiency, appear to be unwarranted. Particles of this size are deposited very far downwind and over such large areas that the deposition density is insignificant.
3. Drift limits for towers in higher salinity areas should be set in consideration of the vegetation and cultural features of the area. For example, it is not appropriate to set tolerances for ocean-sited plants using sensitivity for corn, soybeans, and tobacco.
4. Finally, it should be clearly understood that the Chalk Point Cooling Tower Program did not attempt to establish a trade-off between cooling towers and once-through cooling. That trade-off is a site-specific issue involving many additional considerations.

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[5] 1 kg/Ha ≈ 0.9 lb/acre.

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ACKNOWLEDGMENTS—This program, which extended from 1973 to 1979, was sponsored by the Maryland Power Plant Siting Program, EPRI, DOE, EPA, and PEPCO. JHU/APL designed and conducted the dyed-drift validation test, prepared the final form of the predictive model, and formulated the overall impact predictions. The author is particularly indebted to Dr. Edward Davis, Dr. William Stanbro, and Mr. James H. Meyer for their extensive contributions to this portion of the work. All of the crops, plants, and soils research was done by the staff of the Agronomy and Plant Biology Departments of the University of Maryland. Environmental Systems Corporation (ESC) of Knoxville, Tennessee, provided and operated all of the source term measurement equipment, plume photography, and other range equipment and services. ESC provided a laser instrument for measuring aerosol particle size which was a major improvement in the state of the art and contributed significantly to the total program. Bendix Environmental Sciences provided meteorological tower instrumentation, and Meteorology Research, Inc. provided an instrumented aircraft that was used to collect data in and near the cooling tower plume.