February 8, 1984

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In the Matter of
ARIZONA PUBLIC SERVICE COMPANY, ET AL.
(Palo Verde Nuclear Generating Station, Units 2 and 3)
Docket Nos. STN 50-529 and STN 50-530

Gentlemen:

The purpose of this letter is to respond to West Valley's intention to withdraw its source term and modeling contentions from this proceeding as outlined in Warren Platt's November 16, 1983 letter. In our letter of November 23, 1983, we had notified you that at that time we were not in a position to support this withdrawal because West Valley's counsel, Kenneth Berlin, had notified us that, even though West Valley could no longer sponsor these contentions, he had certain significant information which might persuade us to insist upon their consideration in this proceeding. We thus decided to await the receipt of this information before reaching a decision. On January 9 and 23, 1984 we received from West Valley reports prepared by its consultants, Drs. Golay and Davis, respectively, regarding this subject which are attached hereto.

We have now had an opportunity to evaluate these reports. Dr. Golay's comments are directed to the July, 1983 report of the Environmental Systems Corporation (ECS) entitled "Development of a Drift Source Term, Palo Verde Nuclear Power Plant, Circular Mechanical Draft Cooling Tower" (the ECS report) which evaluates the amount of drift that can be expected to be emitted from the Palo Verde cooling towers. ECS found that for one of the two drift sampling techniques employed in its studies, "the tower composite of liquid drift represents a drift rate of 0.0002%." (ECS report at 4-11). This would appear to be a much smaller rate than the amount estimated by the manufacturer of the cooling towers, the Marley Company (0.0044%). In his comments, Dr. Golay has responded to the ECS report by listing a number of reasons why the current body of data upon which it is based may be inadequate. Insofar as Staff's assessments of drift source term is concerned, however, the validity of the ECS estimates is not material to us since we intend to use the more conservative Marley Company rates. There is accordingly no need for Dr. Golay's criticism of the ECS report to become the subject of a contention in this proceeding.

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The comments of Dr. Davis are likewise not cause for preserving West Valley's contentions in this proceeding. In the first place, contrary to our understanding that Dr. Davis' comments would contain new information regarding the modeling contentions, they appear to be basically the same positions that he had taken in his original affidavit which we have already considered. Second, because Dr. Davis' comments are almost entirely devoted to criticizing Applicant's FOG model, they are not actually relevant to our considerations since we never intended to base our ultimate conclusions on the FOG model but rather on an independent assessment prepared by us based upon a conservative atmospheric transport model.

For these reasons, Staff is now willing to join with the Applicant and the Intervenor in requesting that the source term and modeling contentions be withdrawn from this proceeding.

Sincerely,

Lee Scott Dewey
Counsel for NRC Staff

Enclosure: As Stated

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Concur, with changes as noted

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14406 Butternut Court
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January 5, 1984

Mr. Kenneth Berlin
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References: 1. Documents submitted by Joint Applicants in response to request for production of documents and interrogatories by West Valley Agricultural Protection Council, Inc., pp. W000123-W00146, W000317-W000327 W000334-W000335, W000364, W000369-W000374 W000405-W000409, W000444-W000468, W000487-W000528, W000892-W001244.

2. Exhibit B in petition by West Valley Agricultural Protection Council, Inc. to intervene in the matter of Arizona Public Service Company, et al, (USNRC Docket Nos. STN 50-528, STN 50-529, STN 50-530).

Dear Mr. Berlin:

As you requested the documents in Reference 1 have been reviewed for technical content applicable to modeling of saline drift deposition to offsite locations around the Palo Verde Nuclear Generating Station. In particular, they have been reviewed in relation to the modeling deficiencies noted in our petition (Reference 2).

It is my understanding that further modeling analyses are to be performed by the Nuclear Regulatory Commission and that these are to use conservative but reasonable assumptions so as to obtain upper limits to expected salt deposition to locations around the Palo Verde Site. In addition, I assume that NUS Corporation is proceeding with corresponding work (see Ref. 1, pp. W000444-W000451) to address some of the questions raised in our petition

(Ref. 2). These studies should greatly improve the estimates of salt deposition to be expected from the cooling towers and other sources. Once new study results are available, they should be carefully reviewed to verify that they meet West Valley's requirements.

Unless some care is exercised in these studies, important questions may still remain. Those foreseen at this time are outlined below:

1. FOG Model Applicability. In our petition Exhibit B (Ref. 2) it was agreed that the FOG model, used by the Applicant to predict salt deposition, is a state-of-the-art model. This is confirmed by Professor Dunn's examination of the model (Ref. 1, pp. W001166-W001244). In that examination the model's predictions were compared to the data collected at Chalk Point, Maryland, on a natural draft cooling tower and to the predictions of the EPRI model. This work helps establish the fact that the FOG model is indeed state-of-the-art and, if properly used, can be expected to give reasonable results when applied to situations where the model's physics applies.

However, the climatology of the Palo Verde site is quite different than that of the Chalk Point site. The data at Chalk Point were collected under very humid, nighttime conditions. Hence, a model's prediction of droplet evaporation cannot be tested using that data. Yet prediction of droplet evaporation could be very significant in applying a model to the arid Palo Verde conditions. Professor Dunn's examination of the FOG model's evaporation routine leads one to question its applicability to Palo Verde conditions (Ref. 1, p. W001184). This feature of the model should be examined very carefully prior to further model use to insure that it supports the desired conservative predictions of salt deposition.

Some question also remains whether the FOG model will predict proper plume behavior under the hot, dry conditions common at Palo Verde. Under these conditions plume temperature can be cooler than the ambient. The plume buoyancy and rise predicted by the Brigg's equations as used in the model may not give satisfactory predictions leading to conservative salt deposition estimates. It is likely that predictions of plume rise are too high thus reducing off-site salt deposition. This feature of the model should also be examined for applicability to Palo Verde conditions.

Since there is no verifying data taken under conditions similar to those at Palo Verde, confidence in the FOG model's predictions (or those of any other model) can only be established by a satisfactory examination of the model's physics. Quite often models have built in assumptions that are adequate under the conditions of its envisioned use but fail when the model is applied to other sharply different conditions. This could easily be the case in applying a model to study salt deposition at the Palo Verde site. A definite effort should be made to avoid this and to insure that predictions are indeed conservative ones.

2. FOG Model Use. As pointed out in our petition Exhibit B (Ref. 2), the salt deposition predictions can be underestimated unless care is used in setting up the model for making computer runs. In particular, the size distribution of drift droplets must be represented by a sufficiently large number of size intervals and a sufficiently larger number of breakaway points for droplet release from the rising plume must be used. Unless these precautions are used, unsatisfactory model predictions may be obtained. Professor Dunn makes the same observation (Ref. 1, p. W001183, W001220, and W001239). His results clearly show this (Ref. 1, Figs. 13-18, pp. W001226-W001231). They also confirm our suspicions noted in our petition Exhibit B (Ref. 2) that the FOG model as used by the Applicant had under predicted salt deposition (by more than a factor of ten at some offsite locations).

3. Modeling Deficiencies. Two deficiencies remain in the FOG model that can possibly be of significance in making conservative estimates of salt deposition. Both were discussed in our petition Exhibit B (Ref. 2). The first is turbulent dispersion of small salt particles which allows them to reach the ground at nearby offsite locations even though they could not do so by simply falling to the ground (as the FOG model assumes). Hence, deposition of these particles are underestimated in the FOG model. Professor Dunn points out this limitation of the FOG model (Reference 1, P. W001185).

The second deficiency is the neglect of plume trapping by elevated temperature inversions. This phenomenon can cause the drift rise to be cut-off, allowing droplets to fall to the ground at closer distances and thereby increasing salt deposition.

These deficiencies should be carefully considered in further modeling of drift and salt deposition from the Palo Verde cooling towers since both can cause increased deposition from salt particle sizes of interest to offsite locations.

4. Drift Droplet Sizes. As noted in our petition Exhibit B (Ref. 2), the droplet size spectrum used by the applicant was devoid of sizes above 200 microns, an unusual circumstance. The Marley Company suggested a more reasonable distribution with about 90 percent of droplet mass below 200 microns. Subsequent measurements by Environmental Systems Corporation (ESC) at the Palo Verde site are given in Ref. 1, pp. W000892-W001165. An extensive number of measurements were made on selected cells of tower C of Unit 1. These were combined to estimate a representative droplet size distribution. The result is in marked disagreement with that given by Marley and by others at other sites, in that the distribution has only 21 percent of the droplet mass below 200 microns (Ref. 1, p. W000925). That is, there is a great number of large droplets. The repeated measurements on cell K indicate that considerable error may be present.

In light of these uncertainties future modeling should insure that the droplet size distribution to be used will lead to conservative predictions of offsite deposition.

5. Tower Drift Rate. Estimates of drift rate were made by ESC based on measurements on selected cells of tower C of Unit 1. Two methods were used: 1) directly measuring flux with isokinetic hot glass bead samplers, and 2) computing drift flux from droplets impacting sensitive paper samplers. Both techniques are subject to considerable error. The techniques gave drift rates of approximately 0.0012 and 0.0002 percent of circulating water. The guarantee design value is 0.0044 percent.

For modeling it is suggested that 0.0044 be used for a conservative estimate. Results can then be directly scaled to any rate after the modeling is completed.

6. Other Sources of Salt Deposition. Two sources other than the cooling towers have been identified as potentially significant sources of salt drift. These are: 1) saline water drift from the spray ponds, and 2) salt blowoff from the evaporation ponds. These were discussed in our petition Exhibit B (Ref. 2). The scope of the work plan by the Applicant for further study of drift deposition at the Palo Verde site includes consideration of these sources (Ref. 1, pp. W000446 and W000447). These sources were also cited by the Nuclear Regulatory Commission in their Environmental Statements for the Palo Verde project (as noted in Ref. 2).

Since these sources could be significant sources of salt deposition to offsite locations, they should be modeled appropriately and conservative estimates made of their contribution.

Should you need any further discussion of the above considerations, I would be happy to respond.

Sincerely,

Edward A. Davis

Edward A. Davis, Ph.D.
Consultant

Critique of the Report, "Development of a Drift Source Term, Palo Verde Nuclear Plant Circular Mechanical Draft Cooling Tower

by

Michael W. Golay
Consultant

Prepared for:
West Valley Agricultural Protection Alliance
Phoenix, Arizona

December 23, 1983

Introduction

In May 1983, drift measurements were performed on Tower C of the Palo Verde Nuclear Generating Station (PVNGS) by the Environmental Sciences Corporation (ESC). The net outcome of these measurements is an indicated drift release rate of 0.0002% of the recirculating water flow rate. The vendor-guaranteed value is 0.0048%. Thus, these tests would indicate that drift releases are approximately 24 times lower than the guarantee would allow. These estimations are based solely upon the sensitive paper measurements.

The following discussion explores possible sources of uncertainty in this measurement. It is based entirely upon the test report provided to Arizona Public Service Company by ESC.[1]

The PVNGS cooling tower is powered by fans arrayed in two concentric circles, with an additional fan placed upon the vertical axis of symmetry of the tower. All fans are positioned at the same elevation on the fan deck. It is above and downstream of the cooling tower fill, which is arranged over the height of the outer circumference of the tower. Measurements were performed upon the central fan (fan N), upon one fan in the inner ring (fan P), and upon two diametrically opposed fans (I and K) in the outer ring. In each case drift was measured using both an isokinetic sampler and an array of sensitive papers. For each fan, all measurements were performed in an array of stations in a plane which is approximately that of the upper rim (i.e. outlet) of the fan stack.

In each series of drift measurements the isokinetic sampler and sensitive paper (device) were stationed at twelve successive positions, traversing the fan stack diameter. Each measurement station was selected to be centered in a different $\frac{1}{24}$ - total area segment of the fan-stack outlet plane area. Two traverses were made for each fan stack, with the orientations of the two diameters traversed being mutually perpendicular. Thus, a total of 24 measurement stations were sampled with each device in each fan cell. At each station a new sensitive paper was exposed.

The tests were performed on four consecutive days (May 7-10, 1983). Wind speeds were low on the first day (2 to 10 mph), moderate (10 to 18 mph) on the second day, and high (16 - 42 mph) on the last two days. At all times the fan exit conditions were observed to be unsaturated with water vapor (i.e. the relative humidity was less than unity), a condition which would permit evaporation of drift droplets prior to their detection, and which would lead to consistent underestimation of drift losses via the sensitive paper technique.

The tests on the various fans were performed upon successive days, during which wind conditions varied greatly. It is reasonable to expect that the drift flux distributions leaving the various fans would depend sensitively upon the wind speed and exhaust flow relative humidity. In the ESC analysis of the data no accounting is made of the dependence of the drift releases upon either of these two factors. Rather they are ignored in the estimation of the tower's drift releases. This is an important omission which could invalidate the results presented. Whether it does so can be determined only through additional experimental work. However, these two factors alone - in the absence of further supporting work - are sufficient to justify refusal to accept these data for purposes of defining the drift releases from the cooling tower.

Isokinetic Sampler Data

The isokinetic sampling measurements are to provide an indication of the mineral mass flow rate leaving the tower. The sampler in each case was oriented vertically and operated with the intention that the inlet gas velocity would be equal to the local vertical component of gas velocity. In doing this it is intended that the local gas velocity will be affected only minimally by the presence of the detector. Under the test conditions it is likely that these conditions were not realized. In general, isokinetic sampling has been shown to be difficult to perform accurately.(2) The conditions of these tests would make such sampling even more difficult by virtue of the detector not being aligned with the gas flow, by the strong nonuniformity of the velocity field, and by the presence of large turbulent eddies in the flow. Each of these factors is sufficient reason for abandoning the practice of performing drift measurements at the fan stack outlet, and they contribute great uncertainty regarding the validity of the measurements.

However, if it is assumed that the isokinetic sampler measurements are perfectly accurate, the resulting liquid drift rate is 152 gm/s, or 0.0012% of the recirculating water flow rate. This value is approximately six times greater than that indicated by the sensitive paper measurements. However, the wide variation in isokinetic sampler data between the different fan stacks ($\dot{m}_{max}$ = 2.28 gm/s; $\dot{m}_{min}$ = 0.428 gm/s), and between repeated measurements (e.g. for fan cell K, $\dot{m}$ = 1.82 and 2.28 gm/s, respectively, in two successive measurements) indicates that the precision of this drift measurement is low. It should be noted that under no-wind conditions a decrease in the drift level would be expected as one goes from the outer ring of fan cells to the central fan. Thus some of the variation of data between cells (see Ref. 1, Table 4.1) could be explained by this effect. However, the data for all cells except I were obtained under windy conditions, which makes it impossible to comment meaningfully upon the causes of this variation.

Sensitive Paper Data

The sensitive paper measurements were performed by exposing a static coated paper disk in an orientation perpendicular to the flow. A drift droplet striking the disk will leave a stain, the diameter of which can be related to that of the droplet via an undisclosed calibration relationship.

The two major difficulties associated with this technique are those of calibration and of statistics. The calibration problem has two components. The first is that of accounting correctly for the disturbance in the drift droplet flow and drift data caused by the obstruction created by the disk. The second calibration problem is that of creating droplets of a controlled size and of simulating prototypic flow conditions so that the correspondence between a known upstream drift flux and the resulting sensitive paper information is known accurately. It is stated by ESC that these problems have been solved satisfactorily, but secretly. In the absence of more information it is impossible to reach a conclusion regarding whether these calibration problems have been addressed well, but their inherent difficulty justifies a more conclusive demonstration that this has been done.

The problem of providing adequate statistics in the sensitive paper data is most serious regarding the large droplet portion of the droplet size spectrum. A given drift flow can contain droplets with diameter sizes ranging from a few tens of microns (one micron = 10^{-6} m = 1 μm) to several thousand microns. The mass of a single droplet, m_d, depends upon the droplet diameter, d, according to the relationship:

$$m_d = \rho \frac{4}{3} \pi (\frac{d}{2})^3$$

where ρ = the droplet density. Thus, a single droplet with a diameter of 1000 μm has the same mass as one million droplets, each having a diameter of 10 μm. The droplet size range in the ESC data is 10 to 1000 μm.

A drift droplet population distribution will typically have many members in the diameter range of 10's of microns and relatively few members in the diameter range greater than 300 μm. However, most of the drift mass flow will be accounted for by these larger droplets.

A statistical problem exists when this technique is used for measurement of the drift mass flux. The time interval during which the paper may be exposed is limited to a value small enough that the stains of different individual droplets will not obscure each other. In practice this limit is reached when the stains from the small droplets cover a large fraction of the paper surface. Typically this will happen long before many large droplets can be captured. As a result the statistical quality of the small droplet flux measurement is usually much better than that of the large droplet flux. However, the latter is the quantity of primary interest for purposes of assessing the environmental effects of drift.

These points are illustrated in Tables 1 and 2. In each case I have attempted to transform the ESC size-dependent drift mass flux data back into its original form - that of the size-dependent number of droplets actually counted in the measurement. This was done using the ESC size-dependent mass flux data and the relationship:

$$n(d_i) = A_p f(d_i) \dot{n}(d_i) \Delta t = f(d_i) \frac{\ddot{m}(d_i)}{m_d(d_i)} \Delta t$$

where

$n(d_i)$ = number of droplets detected within the diameter interval $d_i - \frac{\Delta d}{2} < d < d_i + \frac{\Delta d}{2}$;

A_p = sensitive paper area;

$f(d)$ = size-dependent droplet counting calibration factor (assumed equal to unity in this discussion);

$\dot{n}(d_i)$ = number flux of droplets within the d_i size interval striking the paper (droplets/m^2 s);

Δt = paper exposure time duration;

$\ddot{m}(d_i)$ = mass flux of droplets in the d_i size interval.

The data reported by ESC include $\ddot{m}(d_i)$ over a range of size intervals and A_p. By knowing the value of $m_d(d_i)$, that $\Delta t \leq 10$ min, and that only an integral number of droplets may be detected, it is possible to estimate the value of $n(d_i)$ for a particular test. In cases where $\Delta t \ll 10$ min, this method results in overestimates of the number of droplets detected.

Using this method the ESC data for fan cell I and the data for cell K obtained from the second diametric traverse in both the initial and repeat runs have been expressed as $n(d_i)$ distributions. The calculated results are summarized in Tables 1 and 2, respectively. Both of these fan cells are in the outer ring.

Table 1 shows the estimated number of droplets detected in each size category at each measurement station in fan cell I. These data were obtained on the first day of tests, under light wind conditions. The data display a strong variation in size-dependent droplet abundance upon measurement station location within the fan cell, and they are distributed with only weak symmetry. Typically one would expect relatively more drift droplets of a given size to be detected in the outside portion of the fan cell since they would enter the cell from that direction, and few droplets would be expected to be found in the cell center near the fan hub. The latter point reflects the gas flow vertical velocity distributions reported in Appendix E of Ref. 1, where the hub region velocities are typically small, and sometimes negative. (Regarding these Ref. 1 velocity data, it is mystifying that the "Propeller Response vs. Wind Angle" velocity measurement calibration factors of Appendix D do not correspond to the correction factors employed in Appendix E, as it appears that they should do so.)

The most important aspect of Table 1 is that it shows that much of the reported drift mass flux data summarized in Ref. 1, Table 4.4a (and by implication also the data of Tables 4.4b - e, 4.5 and Fig. 4.1) is based upon detection of very few droplets. Consequently, the statistical uncertainty associated with these sparse population measurements is large, as is the uncertainty of the stated drift mass flux data deduced from these measurements.

These points are also illustrated in Table 2, where corresponding estimated data concerning the size-dependent numbers of droplets detected in the second traverse measurements - initial and repeat cases - in fan cell K are summarized. In this table it is possible to compare the two data sets for internal consistency. It is seen at many of the different measurement stations that the relative size dependence of the numbers of droplets detected is typically different between data runs, and that the statistics of the sparse-population data bins are not consistent between measurement runs. For example, the repeat measurements at stations

13 through 22 typically indicate the flow of larger drift droplets than those of the initial measurement. However, at stations 23 and 24 the opposite trend is evident.

From this table we can conclude that the data for cell K are mutually inconsistent, and that a null measurement for drift droplets of a particular large size is often unlikely to indicate that such droplets are not present in the flow.

Between these two sets of measurements the wind speed increased from 20 to 28 mph. This change could account for some of the inconsistency in these two data sets. However, if so, it raises serious concerns regarding the applicability of the overall data set to the validation of the guaranteed drift rate in that this drift rate applies only to design point, low wind conditions. Because of the large variations in windspeed and direction which occurred during these tests, it is doubtful that the data obtained can be combined to support any conclusive statements regarding the drift elimination performance of this cooling tower.

Droplet Detection Probabilities

Because so many sparse population measurements appear in the data set reported in Ref. 1, it is important to consider the probabilities of droplet detection in detail. Each sensitive paper is exposed in a $\frac{1}{24}$-total area sector of the fan stack outlet plane. In interpreting the results of a single measurement it is implicitly assumed that the droplet size-dependent flux indicated by the sensitive paper is typical of the entire $\frac{1}{24}$-sector, and that the data obtained correspond to the sector-average of the quantity observed. From Tables 1 and 2 it is evident that the size-dependent flux spectrum is not uniform within the fan exit plane, and should not be expected to be uniform within each $\frac{1}{24}$-sector. However, even if the flux distribution were uniform, the measurement data still would not generally represent the sector-average. This is because the instantaneous spatial distribution of droplets can be expected to vary during an exposure interval, due to the strong influence of turbulent diffusion and of stochastic process arising in the generation of drift droplets. Effectively, such variations introduce a random probabilistic influence in the determination of the number of droplets within a particular size interval which will be intercepted by the sensitive paper during a measurement.

We may view this process as one where a population of droplets, $n(d_i)$, of a particular size passes through the $\frac{1}{24}$-sector during an exposure interval and a number of them, $k(d_i)$, are intercepted by the sensitive paper. For a single randomly-distributed droplet passing through the sector the probability of capture, p, is given approximately as $p \approx A_p/A_{sector} = 0.00043$, where A_{sector} is the area of a $\frac{1}{24}$-sector. Conversely, the probability of not being captured is $q = 1-p$. Random events which have only two possible outcomes are governed by the binomial probability distribution,

$$P(n,k,p) = \frac{n!}{k!(n-k)!} p^k q^{n-k}$$

where

$P(n,k,p)$	=	the probability that out of n total events exactly k events will have a positive outcome (i.e. droplet interception), and the remainder will have a negative outcome (i.e. droplet escape);
p	=	the probability of a positive outcome in a single event;
q	=	the probability of a negative outcome in a single event;
q	=	$1-p$;
n!	=	the product $n \times (n-1) \times (n-2) \times \cdots \times 2 \times 1$.

From the binomial probability distribution it is seen that it is possible to have exactly k interception events for all integral values of n such that $k \leq n < \infty$, i.e. an infinite set of possible values of n exists. Thus, a problem in performing a sensitive paper drift data analysis is that of determining which value of n corresponds best to the known number of intercepted droplets, k. This is because the objective of the measurement is to obtain an indication of the total number of droplets of a particular size passing through the $\frac{1}{24}$-sector during the measurement interval.

What is done in interpreting the droplet capture data is to choose the value of n for which the value of $P(n,k,p)$ is greatest for the known values of k and p.

Stated differently, the maximum likelihood value of n, $n^* = \frac{k}{p}$, based upon knowledge of k and p, is selected for inferring the magnitude of the sector drift flux. However, it is important to recognize that other values of n are physically possible, but less likely than n^*. When k is large and p small, the probability that n is greatly different from n^* is small, and the use of n^* as the physically correct value of n is indicated by knowledge of k can be employed confidently.

However, when k is small this is not the case, and the likelihood of correctly inferring the value of n from knowledge of k and p is small. Stated differently, when k is small it is not possible to say that $n \approx n^* = \frac{k}{p}$ with a high degree of confidence. This is because a broad range of alternative values of n are only slightly less likely than is that of n^*.

These points are illustrated in Table 3 for cases where the value of k is small and $p = 0.00043$, such as obtains with many of the data in Tables 1 and 2. It is seen that for $k = 0$ (i.e. no droplets detected), a likely range of values of n is that of $0 \leq n < 5000$, with $n^* = 0$ being the most likely value. Thus, a null droplet flux measurement should not inspire confidence that the actual droplet flux value is actually zero.

For the case of a single detected droplet ($k = 1$) it is seen that the likely range of n is approximately $500 \leq n < 7000$, with $n^* = 2326$ being the most likely value. Note that for $n = 2326$ it is equally probable that either $k = 0$ or $k = 1$. Stated differently, the detection of a single droplet could indicate a range of values where the maximum likely flux would be roughly 14 times as great as the minimum likely flux.

For the case of two droplet detections the range of likely values of n is approximately $2000 \leq n < 10,000$, which is relatively narrower than that of a single droplet detection.

The main point of the examples of Table 3 is that the actual drift fluxes implied by the data of Tables 1 and 2 (and by the other sensitive paper measurements) may plausibly be much greater than or less than the expected (i. e. maximum likelihood) values quoted in Ref. 1. This range of possible flux values is so great that it would be unjustified to use these data for inference of more than the order of magnitude of the actual drift flux.

However, even this level of precision is not justified by the data of Ref. 1 because of the existence of substantial water vapor saturation deficits which would cause the droplets detected not to be typical of drift droplets leaving the fill. In such evaporating atmospheres the droplets detected and the drift levels indicated would be smaller than those obtained from the same measurements when the exhaust atmosphere had a relative humidity greater than or equal to unity. This effect is a likely contributor to the disagreeing values of drift fluxes indicated by the sensitive paper and the isokinetic sampler, with the latter technique indicating a value approximately six times greater than the former.

Summary and Conclusions

This report presents a partial discussion of the sources of possible uncertainties in the drift measurements made during May 7-10, 1983 by ESC at cooling tower C at the PVNGS. Major deficiencies are identified in the data obtained using both the isokinetic sampling and sensitive paper techniques. Many of the problems noted could be remedied through collection of a much larger data set and by use of more time-consuming experimental techniques. However, the current body of data is inadequate for conclusive definition of the drift emissions from the cooling tower. The major areas of deficiencies in this series of tests are the following:

Operational Conditions:

- The cooling tower's operational conditions varied significantly during the test series, particularly with respect to ambient wind conditions which varied from low to high values and which changed direction.
- The tower exhaust flow was chronically unsaturated, creating conditions which permit droplet evaporation.

Isokinetic Sampler Data:

- It is unlikely that isokinetic conditions obtained throughout these tests, because such conditions are difficult to create.
- Because the strong turbulence created by the fan (immediately upwind of the detector) would cause local flow conditions to be unstable.
- Because the sampler was usually not aligned with the local mean velocity vector.
- The initial and repeat data for fan call k do not agree well, which would indicate that the repeatability of the measurements is poor.

Sensitive Paper Data

- The statistical uncertainty of the sensitive paper data, and the drift flow rate deduced from them, is large, is not acknowledged in the data analysis, and is not accounted for in the estimation of the drift rate.
- The sensitive paper and isokinetic sampler data for individual fans and for the entire cooling tower do not agree well. These disagreements are not reconciled, rather they reenforce the concern that the sensitive paper data may

substantially underestimate the actual drift rate.

- The subsaturation of the exhaust flow would cause the droplets detected to be smaller than when emitted from the fill, leading to a consistent underestimate of the drift flow rate.
- The calibration method used is not disclosed. Concerns regarding adequacy are motivated by the inherent difficulty of reproducing prototypic flow conditions reliably in a calibration exercise.
- The sensitive paper data are not mutually consistent (in the initial and repeat measurements on fan cell k and between outer fan ring cells I and K).

For these reasons I conclude that it is unjustified to use the data of the May 1983 test series for characterization of the PVNGS site drift emissions. Many of the inadequacies of this test series are generic, and reflect more a need to improve general drift measurement practices than they do special problems with the PVNGS tests. Many of these deficiencies could be mitigated through additional work. However, failing that, the adequacy of the drift elimination performance of the PVNGS cooling towers will remain unestablished.

References

1. "Development of a Drift Source Term, Palo Verde Nuclear Plant Circular Mechanical Draft Cooling Tower", Environmental Systems Corporation report prepared for Arizona Public Service Co. (1983).
2. M. W. Golay, W. J. Glantschnig, and F. R. Best, "Comparison of Alternative Methods for Measurement of Cooling Tower Drift", Electric Power Research Institute Report, in press (1983).

R₀ ℄ Radial Posit

Droplet Size Bin Number	Maximum Droplet Diameter for Indicated Bin (μm)	First Traverse 1	2	3	4	5	6	7	8	9
		.957	.865	.762	.642	.493	.204	.204	.493	.642
8	110	482	577	939	353	262	33	0	140	37
9	130	359	503	621	472	420	32	0	53	25
10	150	370	342	422	309	273	0	0	41	15
11	180	340	407	334	522	264	10	10	10	16
12	210	428	235	334	307	135	0		0	7
13	240	265	227	191	161	42	10		10	3
14	270	118	263	247	174	47			10	1
15	300	64	301	320	177	46			10	4
16	350	160	477	625	268	55			10	
17	400	169	318	511	140	42				
18	450	194	132	323	93	30				
19	500	194	53	142	58	25				
20	600	287	22	74	20	22				
21	700	110	3	9	1	4				
22	800	38	0	3	0					
23	900	6	1	1	0					
24	1000	5			1					
25	1200	1								
26	1400	1								
27	1600	1								
28	1800	2								

tion, R	10	11	12	13	14	15	16	17	18	19	20
			Ro →	←				Second	℄	Traverse	
	.762	.865	.957	.957	.865	.762	.642	.493	.204	.204	.493
	47	63	140	40	55	220	225	682	37	11	55
	37	32	30	32	22	142	201	483	22	7	50
	20	13	0	8	7	47	111	320	20	2	30
	11	7	0	14	4	17	172	287	31	4	23
	6	4	10	1	2	8	161	286	8	5	11
	3	0	0	2	0	1	81	194	11	6	12
	0	1	0		1	3	86	164	5	1	4
	0		10		0	6	66	135	5	1	2
	0				2		63	176	3	1	3
	1						44	98	6		2
							20	39	0		
							13	61	0		
							10	33	1		
							1	9			
								2			
								1			

℄ Radial Position, R → Ro

T Traverse

5	6	7	8	9	10	11	12	13	14	15
.493	.204	.204	.493	.642	.762	.865	.957	1	.865	.762
262	33	0	140	37	47	63	140	40	55	220
420	32	0	53	25	37	32	30	32	22	142
273	0	0	41	15	20	13	0	8	7	47
264	10	10	10	16	11	7	0	14	4	19
135	0		0	7	6	4	10	1	2	8
42	10		10	3	3	0	0	2	0	1
47			10	1	0	1	0		1	3
46			10	4	0		10		0	6
55			10		0				2	
42					1					
30										
25										
22										
4										

Measurement Station	16	17	18	19	20	21	22	23	24
	Second		℄	Traverse					R₀
(R_i/R_o)	.642	.493	.204	.204	.493	.642	.762	.865	.957
	225	682	37	11	55	47	30	13	23
	201	483	22	7	50	28	23	20	11
	111	320	20	2	30	25	10	7	7
	172	287	31	4	23	22	14	4	5
	161	286	8	5	11	18	9	5	1
	81	194	11	6	12	11	3	1	
	86	164	5	1	4	10	4	5	
	66	135	5	1	2	5	2	1	
	63	176	3	1	3	4	5	0	
	44	98	6		2		1	1	
	20	39	0				0		
	13	61	0				0		
	10	33	1				0		
	1	9					0		
		2					1		
		1					0		
							1		

Table 1

Size-dependent Number of Droplets Detected at Various Measurement Stations in Fan Cell I

8402140116-02

R_0 ← ℄ Radial Pos

Droplet Size Bin Number	Maximum Droplet Diameter for Indicated Bin (μm)	13	14	15	16	17	18	19	20	21
		0.957	0.865	0.762	0.642	0.493	0.204	0.204	0.493	0.6
8	110	1060	594	390	139	222	0	70	818	861
		1246	924	1551	538	337	13	70	477	17
9	130	498	424	221	76	70	11	14	400	534
		832	427	382	109	174	12	22	314	8
10	150	17	220	68	38	47	0	7	322	152
		765	310	243	41	64	8	7	171	3
11	180	17	73	27	27	27	10		270	363
		380	384	104	56	79	4	14	243	5
12	210	52	18	14	27	4	0		164	196
		294	77	57	26	19	2	8	138	5
13	240	11	14	7	8	7	0		73	147
		138	66	33	11	10	2	9	70	1
14	270	3	6	6	3	2	10		58	136
		66	25	22	4	6	6	8	57	1
15	300	1	1	0	3	5			23	123
		19	11	6	4	4	0	4	42	1
16	350	1		1	3				31	180
		5	4	6	2	4	2	3	36	1
17	400				0				24	120
		2	1	1	1			3	12	[illegible]
18	450				1				18	60
		0						1	9	[illegible]
19	500								3	27
		1							6	
20	600								3	9
									8	
21	700									
									1	
22	800									
23	900									
24	1000									

tion, R → | R_o

	22	23	24
42	0.762	0.865	0.957
	282	274	265
82	470	928	269
	115	62	56
36	27	480	69
	45	31	16
12	15	110	20
	25	0	12
24	6	35	4
	12	1	12
24	6	35	
	5	1	1
17	20	5	
	0	1	
18	7	4	
	3	1	
64	5	1	
	0	0	
29	3		
	0	0	
88	7		
	1	1	
39	0		
6	1		
4	1		

Format:
Initial Measurement
Repeat Measurement

Table 2

Size-dependent Numbers of Droplets Detected at Various Measurement Stations, Second Traverse, Initial and Repeat Measurements in Fan Cell K

Table 3

Probabilities of intercepting exactly k droplets in the passage of n droplets through a 1/24-sector when p = 0.00043

n	P(n, k, p = 0.00043)		
	k = 0	k = 1	k = 2
0	1.0	-	-
1	0.99957	0.00043	-
5	0.99785	0.00215	1.85×10^{-6}
10	0.99571	0.00428	5.16×10^{-6}
100	0.958	0.0412	8.78×10^{-4}
1,000	0.650	0.280	0.060
2,326	0.368	0.368	0.184
5,000	0.116	0.250	0.288
10,000	0.0136	0.0583	0.125
20,000	0.000184	0.00158	0.0068
100,000	2.1×10^{-19}	9.01×10^{-18}	1.94×10^{-16}