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TENNESSEE VALLEY AUTHORITY

COOLING TOWER AND STEAM PLANT PLUME MERGENCE AT THE WATTS BAR SITE

50-390 WATTS BAR NUCLEAR PLANT
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DIVISION OF NATURAL RESOURCE SERVICES

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TENNESSEE VALLEY AUTHORITY

Division of Natural Resource Services

Air Quality Branch

COOLING TOWER AND STEAM PLANT PLUME MERGENCE AT THE WATTS BAR SITE

Prepared by

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SUMMARY

This report documents the results of an investigation of the potential terrestrial impacts resulting from the mergence of plumes from the Watts Bar Steam Plant and the cooling towers at the Watts Bar Nuclear Plant. The object of the investigation is to determine the necessity of continuing with the existing terrestrial surveillance and control commitments. The analysis relies heavily on onsite meteorology and modeling information. It is determined that acid drift effects on the terrestrial environment will be negligible and not clearly identifiable as resulting from simultaneous operation of the two sources. It is concluded that there will be no discernible enhancement of the protection of local ecosystems by the implementation of the vegetation surveillance or steam plant operational control programs.

COOLING TOWER AND STEAM PLANT PLUME MERGENCE AT THE WATTS BAR SITE

INTRODUCTION

This report documents the results of an investigation of the potential terrestrial impacts resulting from the mergence of plumes from the Watts Bar Steam Plant and the cooling towers at the Watts Bar Nuclear Plant. The object is to determine the necessity of continuing with the existing terrestrial surveillance and control commitments. The investigation of environmental impacts resulting from operation of the Watts Bar Nuclear Plant, performed during preparation of the Final Environmental Statement, revealed a potential for acid mist effects resulting from simultaneous operation of the nuclear plant cooling towers and the nearby Watts Bar Steam Plant. Because the analytical tools necessary for the assessment of this potential impact were not available at that time, commitments were made which called for terrestrial surveillance, and operational control of the steam plant under meteorological conditions associated with plume mergence.

ASPECTS OF PLUME MERGENCE

The potential effects of cooling tower plume and smoke plume interaction include enhanced sulfate production and the ensuing production of sulfuric acid aerosols, acid mist (drift), and acid fly ash. These interaction products may be generated from reactions involving sulfur dioxide (SO_2) and fly ash in the smoke plume with water vapor or water droplets contained in the cooling tower plume.

The mechanisms by which SO_2 is oxidized to sulfates are important because they determine the rate of formation and, to some extent, the final form of sulfate. The following are transformation mechanisms which are important when considering the mergence of the smoke plume and cooling tower plume.

- The gaseous SO_2 dissolves in the water droplet and is subsequently oxidized to sulfuric acid. Laboratory studies have shown that this liquid phase oxidation of SO_2 is quite rapid.[1,2]
- The oxidation of SO_2 can be catalyzed by dissolved ozone, hydrogen peroxide, and metal ions (e.g., Fe and Mn).[3,4]
- Sulfate aerosols, either emitted from the steam plant, or generated in the atmosphere, can be assimilated into the drift droplets by nucleation process and by contact with an existing droplet.[5]

The results of plume mergence could manifest itself in three ways: (1) the drift carried to the ground (subsequent to mergence with the smoke plume) could have a lower pH due to the dissolved acid sulfates,

(2) evaporation of drift droplets (subsequent to plume mergence), could release dissolved sulfate aerosols resulting in an enhancement of the plume sulfate levels, and (3) smoke plume sulfate levels could be enhanced due to the presence of water (vapor and droplets) associated with the cooling tower plume.

IMPACTS OF ACID MIST DEPOSITION

The deposition of acidic drift and/or acid fly ash presents the only potential for local terrestrial environmental impact. Such acidity, in sufficient concentrations and quantities, can cause increased leaching of soil cations which can contribute to lessened plant growth in the affected areas.[6] These responses have been demonstrated by application of sulfuric acid mist and acidic solution to various crop and forest species in controlled environment experiments. The specific nature of these deleterious effects are not only specie dependent, but may also be affected by other environmental stresses.

Injury to vegetation due to acidic deposition has been reported by trained observers in the vicinity of the Paradise Steam Plant.[7,8] The injury symptoms on the foliage of corn and other herbaceous vegetation in the area of the plant were of the type caused by the deposition of acidified fly ash. These observations have indicated that only relatively small areas, at distances of about one-half to two miles (800 to 3200 meters) from the plant, have shown visible damage attributable to acidic deposition. Such effects have been found to occur most frequently at the Paradise Steam Plant when idle units were restarted, resulting in the expulsion of an apparent buildup of residue from the stacks.

However, it is unclear whether operation of the cooling towers contributed to the observed vegetation damage.

COMMITMENTS

Specific features of the Watts Bar site which give an indication of potential acid mist and/or acid fly ash problems are primarily the proximity and orientation of the nuclear plant cooling towers and steam plant stacks. Figure 1 shows that the cooling towers and smoke stacks are oriented on a north-northeast--south-southwest line approximately 1 kilometer apart. Based on onsite data, the frequency of wind directions in these sectors is about 30 percent.* The separation distance is also particularly important since it is sufficiently small so that each source is within the other's area of influence.

The potential for terrestrial environmental impacts resulting from cooling tower and smoke plume mergence was recognized during preparation of the Watts Bar Nuclear Plant Final Environmental Statement. Statements pertaining to this potential are given in Appendix A.

The remainder of this report is an examination of the potential for plume interaction and terrestrial impacts and of the need for an environmental effects monitoring program. The bases for this determination are found in NRC Regulatory Guide 4.11, "Terrestrial Environmental Studies for Nuclear Power Station - Revision 1," August 1977. Pertinent portions of this regulatory guide are included as Appendix B.

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*Wind direction measured at the 93-meter level at the permanent meteorological facility.

METEOROLOGY AND PLUME BEHAVIOR

The analytical method used for determining the potential for cooling tower and smoke interaction is based on onsite meteorology and cooling tower and smoke plume modeling.

METEOROLOGY

The permanent meteorological facility, which began operation in June 1973, consists of a 93-meter tower, instrumented at the 10-, 46-, and 91-meter levels with temperature sensors; and at the 10-, 46-, and 93-meter levels with wind sensors. Dewpoint temperature has also been measured at the 10-meter level since September 1976. The data are logged on a NOVA digital data processing system. The facility is located about 800 meters south-southwest of the plant in a well exposed, relatively large flat area, and has a base elevation of 216.7 meters MSL. Meteorological data collected at the permanent facility has been accepted as representative of conditions at the plant site. Additional information concerning system specifications and the representativeness of the permanent tower data for release conditions at the plant are given in section 2.3 of the FSAR.

The effect of the general northeast-southwest orientation of the Tennessee River valley at the site on low-level air flow patterns is identified by the maximum frequency of occurrence of wind directions in the up- and downvalley sectors. The percentage frequencies of wind direction given in table 1 indicate that, for the period July 1973 through June 1978, the sectors with the highest frequency of occurrence

are the north-northeast and south-southwest sectors, with about 13 and 16 percent, respectively. These sectors correspond directly with the orientation of the cooling towers and smoke stacks.

The distribution of wind speed by stability class (table 2), for the same 5-year period, shows D, E, and F stabilities (46- to 93-meter ΔT), accounting for about 92 percent of the total hourly stability readings, with mean wind speeds of 4.1, 3.3, and 2.4 meters per second (mps), respectively.

The subsequent analysis of the intersection of the cooling tower vapor plume and drift with the steam plant smoke plume is based solely on the data from the period January 1-December 31, 1977. This period was determined primarily from the availability of valid onsite dewpoint data. Tables 3 and 4 present percentage frequencies of wind speed by wind direction and wind speed by stability class for this period.

The following is a comparison of conditions represented by the single year used in this assessment, to longer term conditions. Wind direction frequencies for those sectors which exhibit the maximum potential for plume mergence, i.e., north through northeast and south through southwest, are about 13 and 22 percent for the 1-year period (table 3), as compared to percentage frequencies of 13 and 16 for those respective sectors for the longer term (table 1). The higher frequencies of occurrence of winds in these sectors for the 1-year analysis period may lead to slight overestimates of impacts in these sectors as compared to the longer term.

The occurrence of D, E, and F stability classes account for about 95 and 93 percent of the total valid observations for the respective 1- and 5-year periods. The distribution of wind speeds in each of these stability classes is also similar. Based on these comparisons, it is judged that the 1-year period of onsite data is acceptable for representing longer term conditions.

SMOKE PLUME, VAPOR PLUME, AND DRIFT BEHAVIOR

The frequency and nature of cooling tower and steam plant plume intersection has been evaluated. This evaluation utilizes plume rise and dispersion models for stack releases from the steam plant and vapor plume and drift deposition models for defining cooling tower plume characteristics.

The meteorological conditions for plume rise calculations given in table 5 are based on the previously identified one year of data from the onsite meteorological facility. This set of meteorological conditions represents about 70 and 80 percent of the possible combinations of wind speed and stability class for upvalley and downvalley flow, respectively.* It is expected that at the elevations of smoke plume dispersion, there exists higher percentages of D and E stability class occurrences and larger percentages in the higher wind speed categories. Relevant design characteristics of the steam plant, which also served as input for the plume rise calculations, are presented in Appendix C.

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*Wind directions measured at the 93-meter level on the permanent meteorological tower. South, south-southwest, and southwest wind directions are considered for upvalley flow; and north, north-northeast, and northeast wind directions are considered for downvalley flow.

Plume rise estimates for stack releases at the steam plants were obtained by the Briggs semiempirical method, which is briefly discussed in Appendix D. The results of the plume rise calculations are presented in table 6. As seen in the table, maximum effective plume heights are approximately 500 meters and occur for the neutral stability condition and a wind speed of about 2 meters per second (mps). Predicted effective plume heights in the 250- to 500-meter range occur only for class D stability situations for wind speeds of about 3 to 5 mps. Maximum effective plume heights less than 250 meters are predicted for the combination of class D stability with wind speed in excess of about 6 mps and also for all combinations of class E and F stabilities and wind speeds. The distance from the source required to achieve the maximum effective plume height is at most about 1 kilometer. The minimum predicted distances required to achieve maximum plume rise are less than 500 meters. These distances correspond to plume heights of less than 200 meters.

Calculations for the moist plume from the cooling towers are based on a model developed by P. R. Slawson. A discussion of the governing equations and assumptions for this model are given in Appendix E, while relevant cooling tower design features are given in Appendix D. Plume length values for several height intervals are summarized in tables 7 through 11. Briefly, the model predictions indicate that vapor plumes with centerline heights less than about 150 meters above ground will be nonexistent. Annually, plume lengths in the 150- to 250-meter height interval are predicted to occur about 37 percent of the time. Plume lengths in this height interval are predicted to not exceed

200 meters. Plumes in the 250- to 350-meter elevation range will be less frequent (about 15 percent), with maximum lengths of about 600 meters. Plume lengths for heights greater than about 350 meters cover a range from less than 200 meters to about 7000 meters. Predicted plume lengths for all plume heights (table 11) compare very well to observations of cooling tower plumes at the Paradise Steam Plant.[9]

Drift deposition predictions are summarized in table 12. The values in the table represent the deposition of solid material contained in the drift droplets. The model estimates do not account for the scavenging of the smoke plume constituents in the affected sectors. Modifications to the drift deposition model to incorporate scavenging effects were not pursued since it was determined that the additional information gained would not justify the development of a defensible technical approach and subsequent model modifications. Therefore, for the purpose of assessing acidic drift deposition impacts, these values should be used only to give relative impacts for the affected areas. Maximum cooling tower drift deposition rates of solid material [4 kilograms/hectare-year (kg/ha-yr)] are predicted to occur at distances of 1400 to 1600 meters from the cooling towers, in the north-northeast and south-southwest sectors.

PLUME MERGENCE

Vapor plume and smoke plume intersection is investigated with the assumption that only those hourly wind directions which are logged as north through northeast and south through southwest allow significant potential for interaction of the plumes. The resulting potential impact

will be on regional sulfate levels and will not influence the terrestrial ecosystem in the immediate vicinity of the Watts Bar site. On the other hand, the potential impact of interaction between the smoke plume and the cooling tower drift will be limited to the north-northeast and south-southwest sectors, with the potential impact confined to the immediate vicinity of the site (2000 to 2400 meters from the cooling towers).

VAPOR PLUME AND SMOKE PLUME INTERSECTION

A detailed quantitative assessment of the consequences of plume interactions cannot be attempted at this time due to the limited knowledge of plume chemistry relationships and vegetation sensitivity to the interaction products. Therefore, much of the subsequent analysis to anticipate terrestrial impacts of plume interaction is necessarily qualitative.

The intersection of the visible vapor plume and smoke plume centerlines represents the condition for maximum potential enhancement of sulfate and acidic aerosol production. Under upvalley flow (southsouthwest wind directions) only visible vapor plumes with centerline heights in excess of 350 meters extend from the cooling towers to the steam plant or beyond. Smoke plumes rising to this height are anticipated only for neutral stability conditions (class D) with light winds (less than about 3.5 mph). The frequency of these meteorological conditions indicates that this centerline plume intersection for upvalley flow may occur only about five percent of the time. The intersection of the vapor plume

with a moisture content below saturation, but above ambient, is not considered in this estimate. Generally, under low ambient moisture conditions the increase in ambient moisture at the steam plant is expected to be slight because of the dispersed state of the vapor plume at the steam plant. Also, under high ambient moisture conditions, which are generally necessary in order for the plume to remain visible as far downwind as the steam plant, the additional moisture contribution will not be significant. Therefore, it is reasonable to conclude that this condition has only a minimal effect on subregional sulfate levels.

During other combinations of meteorological conditions for upvalley flow, the plume intersection will be noncenterline and at greater distances from the site. Two important characteristics of plume mergence under these conditions are: (1) the increased dilution of the plumes at these greater distances and travel times prior to intersection, and (2) plume intersection will be at the outer fringe of each plume where the concentrations of plume constituents are relatively small. The frequency of occurrence of these noncenterline plume intersections is about 17 percent. This information indicates that the potential for a significant increase in the ambient sulfate level, directly attributable to plume mergence, in the northeast quadrant from the site is minimal.

Under downvalley flow conditions (north through northeast wind directions) it is anticipated that varying degrees of mergence of the smoke plume centerline with the cooling tower effluents at or very near the cooling tower release point will occur for most combinations of stability class and wind speed. This represents the most fertile situation for the enhancement of SO_2 transformation to sulfate and the ensuing production of acidic aerosols. Based on the onsite meteorological

data used in the plume rise calculations, this situation can occur about 12 percent of the time. Predicted centerline SO_2 concentrations of the smoke plume at 1 km (cooling tower - steam plant approximate distance) range from about 10 mg/m^3 for class D stability with moderate winds to nearly 20,000 mg/m^3 for class F stability with light winds (table 6).

This merging of the smoke plume with relatively high concentrations with the vapor plume at or near its release point gives an indication of possible increases in sulfate and ensuing acidic aerosol production. The impact of this plume interaction will be to increase regional atmospheric sulfate levels in excess of the present contribution by the steam plant. The analysis of the ramifications of this regional-scale impact is beyond the scope of this assessment. However, it is believed that any increase in regional sulfate levels as a result of the interaction will be minimal.

COOLING TOWER DRIFT AND SMOKE PLUME INTERSECTION

The intersection of cooling tower drift droplets with the smoke plume represents the most potentially severe situation for terrestrial impacts to areas immediately adjacent to the Watts Bar site. Ground areas affected by the drift-plume intersection are in the north-northeast and south-southwest sectors at distances of from 1 to about 2.5 km from the cooling towers. Drift deposition predictions given in table 12 provide a basis for the following quasi-quantitative evaluation.

The acidification of cooling tower drift under south-southwest flow will occur as the drift droplets fall through the smoke plume

north-northeast of the steam plant. As seen in table 12, predicted annual drift deposition rates (exclusive of plume mergence) for the north-northeast sector approach 4 kg/ha, with values greater than 3 kg/ha occurring between 1200 and 1800 meters from the cooling towers. These maximum deposition rates approximately coincide with the location of the river north-northeast of the site (figure 1). Predicted annual drift deposition rates for land areas in the north-northeast sector are, at most, approximately 3.5 kg/ha.

The intersection of the cooling tower drift with the smoke plume under north-northeast flow conditions (drift deposition south-southwest of the site) will occur for essentially all combinations of wind speed and stability. Predicted drift deposition rates (exclusive of plume mergence) south-southwest of the site show a maximum value of slightly less than 4 kg/ha-yr at a distance of 1400 to 1600 meters from the cooling towers (table 12). Deposition rates greater than 3 kg/ha-yr are predicted for distances from 1400 meters through 1800 meters from the source. As was observed for drift deposition patterns in the north-northeast sector, the river coincides with much of the area affected by maximum deposition rates south-southwest of the site.

The assessment of the terrestrial impact resulting from this deposition of potentially acid drift in these sectors is forced to be qualitative due to the unavailability of applicable observational data. However, the following information does allow for a reasonable conclusion.

- Maximum annual deposition rates (exclusive of plume mergence) are on the order of 4 kg/ha-yr of solids or dissolved solids; whereas Regulatory Guide 4.11 (Appendix A) gives a value of 20 kg/ha-yr as an indicator of potential terrestrial impacts.

- Drift deposition rates will not be constant through the year, but will vary drastically with meteorological conditions. Maximum short-term deposition rates will occur during the nongrowing season when the probabilities of low temperature and high relative humidity meteorological conditions are maximized.
- Areas receiving the maximum drift deposition generally coincide with the river.
- The liquid drift deposition rate is computed to be less than 0.05 cm annually. This value is computed by using the maximum drift deposition rate of 4 kg/ha-yr for dry material, a cycles of concentration of the cooling water of 3, and a total dissolved solids content of the drift of 130 mg/l.
- The duration of exposure of each drift droplet to the smoke plume, as it falls through the smoke plume to the ground, will be relatively short. Increases in solids concentrations on the drift droplets are expected to be correspondingly small.

Based primarily on the above information, it is expected that impacts on terrestrial ecosystems (particularly vegetation) in the immediate vicinity of the site, resulting from simultaneous operation of the nuclear plant cooling towers and the steam plant, will be negligible and probably not clearly identifiable as resulting from simultaneous operation of the two sources.

COMPLIANCE WITH REGULATORY GUIDE 4.11 REQUIREMENTS

Pertinent discussions from Regulatory Guide 4.11, "Terrestrial Environmental Studies for Nuclear Power Stations-Revision 1," are given in Appendix B. Compliance with the guidelines given in the regulatory guide is determined from the previously given dry and wet deposition values. The deposition of solids contained in the drift, including results of plume interaction, is not expected to greatly exceed 4 kg/ha-yr. The corresponding deposition of liquid drift is expected to be less than 0.05 cm/yr. This information is adequate for showing that the deposition of cooling tower drift, including plume mergence effects, is sufficiently small to permit reasonable assurance that no adverse terrestrial impact will occur.

CONCLUSIONS AND RECOMMENDATIONS

The potential for terrestrial impacts resulting from the interaction of the smoke plume from the Watts Bar Steam Plant and the vapor plume and drift from the cooling towers at the Watts Bar Nuclear Plant was investigated. The investigation relied heavily on onsite meteorology and modeling information. This information supports the following conclusion:

- The intersection of the smoke plume with the cooling tower drift represents the most fertile situation for local terrestrial environmental impacts. However, based primarily on the predicted low drift deposition rates, it was determined that acid drift effects on the terrestrial environment will be negligible and not clearly identifiable as resulting from simultaneous operation of the two sources.

Based on this information, it is concluded that there will be no discernible enhancement of the protection of local ecological systems by the implementation of vegetation surveillance programs to detect vegetation damage from the deposition of acidic drift. The NRC requirement for remote sensing studies would not be applicable since no significant terrestrial impacts are predicted. Also, based on the information presented, the commitment for modifying the operation of the steam plant when the possibility for plume mergence exists, is not necessary in order to ensure the protection of local terrestrial ecosystems.

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TABLE 1

JOINT PERCENTAGE FREQUENCIES OF WIND SPEED BY DIRECTION

DISREGARDING STABILITY CLASS

WATTS BAR METEOROLOGICAL FACILITY

JUL 1, 73 - JUN 30, 78

WIND DIRECTION	WIND SPEED(MPS) CALM 0.6	0.7-1.5	1.6-2.4	2.5-3.3	3.4-5.5	5.6-8.2	8.3-10.9	≥10.9	TOTAL
N	0.13	0.99	1.25	1.26	2.65	1.30	0.10	0.0	7.68
NNE	0.13	1.54	2.77	2.68	4.11	1.26	0.13	0.0	12.62
NE	0.14	1.66	2.78	2.13	2.93	0.74	0.06	0.0	10.44
ENE	0.12	1.15	1.29	1.00	0.93	0.15	0.03	0.0	4.67
E	0.07	0.86	0.92	0.51	0.48	0.07	0.01	0.0	2.92
ESE	0.05	0.52	0.47	0.22	0.17	0.02	0.0	0.0	1.45
SE	0.09	0.58	0.52	0.13	0.17	0.08	0.02	0.0	1.59
SSE	0.07	0.77	0.71	0.28	0.36	0.16	0.03	0.01	2.39
S	0.09	1.03	1.19	1.00	1.44	0.73	0.29	0.09	5.96
SSW	0.09	1.30	2.86	2.95	5.38	2.74	0.80	0.15	16.27
SW	0.09	1.15	2.52	2.45	4.09	1.82	0.63	0.12	12.87
WSW	0.07	0.85	1.07	0.96	1.64	0.85	0.26	0.10	5.90
W	0.06	0.59	0.53	0.47	0.98	0.63	0.15	0.08	3.49
WNW	0.07	0.47	0.38	0.37	1.22	0.79	0.17	0.03	3.50
NW	0.07	0.49	0.41	0.44	1.55	0.87	0.17	0.01	4.01
NNW	0.09	0.62	0.50	0.55	1.46	1.10	0.15	0.0	4.47
SUBTOTAL	1.43	14.57	20.17	17.40	29.56	13.31	3.00	0.59	100.03

TOTAL HOURS OF VALID WIND OBSERVATIONS 39681
TOTAL HOURS OF OBSERVATIONS 43824
RECOVERABILITY PERCENTAGE 90.5
TOTAL HOURS CALM 9

ALL COLUMNS AND CALM TOTAL 100 PERCENT OF JOINT VALID OBSERVATIONS

METEOROLOGICAL FACILITY: 0.8 KM SSW OF WATTS BAR NUCLEAR PLANT
WIND SPEED AND DIRECTION MEASURED AT THE 93.3 METER LEVEL

DATE PRINTED: 10/20/78

MEAN WIND SPEED = 3.6 MPS

TABLE 2

JOINT PERCENTAGE FREQUENCIES OF WIND SPEED BY STABILITY CLASS

WATTS BAR METEOROLOGICAL FACILITY

JUL 1, 73 - JUN 30, 78

WIND SPEED (MPS)	STABILITY CLASS A	B	C	D	E	F	G
CALM - 0.6	0.0	0.0	0.0	0.25	0.46	0.42	0.33
0.7 - 1.5	0.05	0.11	0.15	4.91	4.49	3.11	1.82
1.6 - 2.4	0.12	0.26	0.30	8.97	5.81	3.17	1.58
2.5 - 3.3	0.06	0.22	0.26	8.30	5.35	2.31	0.81
3.4 - 5.5	0.11	0.37	0.54	17.38	8.57	2.00	0.55
5.6 - 8.2	0.07	0.15	0.24	9.60	3.03	0.23	0.07
8.3 - 10.9	0.02	0.01	0.04	2.34	0.48	0.03	0.01
> 10.9	0.01	0.0	0.0	0.54	0.03	0.0	0.0
TOTAL	0.44	1.12	1.53	52.29	28.22	11.27	5.17

TOTAL HOURS OF VALID STABILITY OBSERVATIONS	40359
TOTAL HOURS OF VALID WIND DIRECTION-WIND SPEED STABILITY OBSERVATIONS	37628
TOTAL HOURS OF OBSERVATIONS	43824
JOINT RECOVERABILITY PERCENTAGE	85.9

METEOROLOGICAL FACILITY: 0.8 KM SSW OF WATTS BAR NUCLEAR PLANT
STABILITY BASED ON LAPSE RATE MEASURED BETWEEN 45.63 AND 91.20 METERS
WIND SPEED AND DIRECTION MEASURED AT THE 93.3 METER LEVEL

DATE PRINTED: 10/20/78

	A	B	C	D	E	F	G
MEAN WIND SPEED (MPS)	3.9	3.8	3.8	4.1	3.3	2.4	2.0

TABLE 3

JOINT PERCENTAGE FREQUENCIES OF WIND SPEED BY DIRECTION

DISREGARDING STABILITY CLASS

WATTS BAR METEOROLOGICAL FACILITY

JAN 1, 77 - DEC 31, 77

WIND DIRECTION	WIND SPEED (MPS) CALM-0.6	0.7-1.5	1.6-2.4	2.5-3.3	3.4-5.5	5.6-8.2	8.3-10.9	> 10.9	TOTAL
N	0.13	1.23	1.41	1.26	2.99	1.44	0.06	0.0	8.52
NNE	0.11	1.49	3.08	3.54	4.00	0.89	0.02	0.0	13.13
NE	0.10	1.50	2.45	1.74	1.93	0.27	0.0	0.0	7.99
ENE	0.13	1.04	1.09	0.92	0.56	0.15	0.01	0.0	3.90
E	0.02	0.62	0.77	0.36	0.24	0.05	0.02	0.0	2.08
ESE	0.02	0.37	0.40	0.17	0.08	0.0	0.0	0.0	1.04
SE	0.07	0.51	0.79	0.16	0.31	0.17	0.10	0.01	2.12
SSE	0.04	0.73	1.03	0.47	0.52	0.34	0.07	0.02	3.22
S	0.07	1.08	1.60	1.25	1.89	0.83	0.39	0.10	7.21
SSW	0.06	1.33	3.38	4.29	7.92	3.54	1.00	0.21	21.73
SW	0.05	0.98	1.99	1.79	2.68	1.10	0.36	0.10	9.05
WSW	0.06	0.82	0.62	0.53	0.97	0.66	0.17	0.16	3.99
W	0.05	0.51	0.41	0.33	1.08	0.82	0.25	0.08	3.53
WNW	0.04	0.41	0.40	0.39	1.41	0.96	0.36	0.05	4.02
NW	0.05	0.46	0.42	0.48	1.62	1.02	0.22	0.0	4.27
NNW	0.02	0.59	0.47	0.54	1.28	1.16	0.12	0.0	4.18
SUBTOTAL	1.02	13.67	20.31	18.22	29.48	13.40	3.15	0.73	99.98

TOTAL HOURS OF VALID WIND OBSERVATIONS 8272
TOTAL HOURS OF OBSERVATIONS 8760
RECOVEABILITY PERCENTAGE 94.4
TOTAL HOURS CALM 0

ALL COLUMNS AND CALM TOTAL 100 PERCENT OF JOINT VALID OBSERVATIONS

METEOROLOGICAL FACILITY: 0.8 KM SSW OF WATTS BAR NUCLEAR PLANT
WIND SPEED AND DIRECTION MEASURED AT THE 93.33 METER LEVEL

DATE PRINTED: 10/04/78

MEAN WIND SPEED = 3.6 MPS

TABLE 4

JOINT PERCENTAGE FREQUENCIES OF WIND SPEED BY STABILITY CLASS

WATTS BAR METEOROLOGICAL FACILITY

JAN 1, 77 - DEC 31, 77

	STABILITY CLASS						
	A	B	C	D	E	F	G
WIND SPEED (MPS)							
CALM-0.6	0.0	0.0	0.0	0.19	0.36	0.17	0.22
0.7 - 1.5	0.0	0.0	0.0	4.14	4.83	3.16	1.69
1.6 - 2.4	0.01	0.02	0.0	9.16	6.44	3.15	1.73
2.5 - 3.3	0.0	0.0	0.01	8.32	6.58	2.56	0.69
3.4 - 5.5	0.01	0.01	0.0	17.05	9.54	1.85	0.43
5.6 - 8.2	0.0	0.01	0.01	9.33	3.66	0.31	0.05
8.3 - 10.9	0.0	0.0	0.0	2.54	0.63	0.0	0.0
> 10.9	0.0	0.0	0.0	0.67	0.06	0.0	0.0
TOTAL	0.02	0.04	0.02	51.40	32.10	11.20	4.81

TOTAL HOURS OF VALID STABILITY OBSERVATIONS	8550
TOTAL HOURS OF VALID WIND DIRECTION-WIND SPEED STABILITY OBSERVATIONS	8090
TOTAL HOURS OF OBSERVATIONS	8760
JOINT RECOVERABILITY PERCENTAGE	92.4

METEOROLOGICAL FACILITY: 0.8 KM SSW OF WATTS BAR NUCLEAR PLANT
STABILITY BASED ON LAPSE RATE MEASURED BETWEEN 45.63 AND 91.20 METERS
WIND SPEED AND DIRECTION MEASURED AT THE 93.3 METER LEVEL

DATE PRINTED: 10/04/78

	A	B	C	D	E	F	G
MEAN WIND SPEED (MPS)	2.8	3.6	4.7	4.2	3.4	2.4	2.0

TABLE 5

Frequency of Meteorological Conditions Used As Input to Plume Rise Calculations[a]

Stability	Wind Speed (mps)[b]	Percentage Frequency[c]	
		Downvalley	Upvalley
D	2.2	2.42	2.36
D	3.1	2.53	3.10
D	4.5	5.16	6.21
D	7.6	2.09	2.74
E	2.2	2.26	2.31
E	3.1	2.25	3.09
E	4.5	2.86	4.73
F	1.2	1.02	0.76
F	2.2	1.55	0.86
F	3.1	1.31	0.96

a. Watts Bar Nuclear Plant permanent meteorological facility. Period of record January 1, 1977 - December 31, 1977.

b. Wind speed categories associated with these assigned values are as follows: 1.2, 0.6 - 1.5; 2.2, 1.5 - 2.4; 3.1, 2.4 - 3.3; 4.5, 3.3 - 5.5; 7.6; 5.5 - 8.2 mps.

c. Frequencies for north, north-northeast, and northeast wind directions are totalled for downvalley flow and south, south-southwest, and southwest wind direction frequencies are totalled for upvalley flow for the specific wind speed and stability condition.

TABLE 6

Effective Heights and SO_2 Concentrations for Watts Bar Steam Plant Plumes

Stability	Wind Speed (mps)	Downwind Distance (m)	EH[a] (m)	Plume Centerline SO_2 Conc. mg/m^3	Downwind Distance (m)	EH (m)	Plume Centerline SO_2 Conc. mg/m^3	Downwind Distance to FEH[b] (m)	Final Effective Plume Height (m)	Plume Centerline SO_2 Conc. mg/m^3
D	2.2	500	350	102	1,000	510	32	1,100	540	31
D	3.1	500	260	73	1,000	380	22	1,100	400	22
D	4.5	500	200	50	1,000	280	15	1,100	300	14
D	7.6	500	150	30	1,000	190	9	1,100	210	9
E	2.2	500	180	192	1,000	180	62	300	180	628
E	3.1	500	170	137	1,000	170	44	400	170	410
E	4.5	500	160	94	1,000	160	30	500	160	94
F	1.2	500	190	793	1,000	190	259	100	190	7,654
F	2.2	500	160	433	1,000	160	141	200	160	2,192
F	3.1	500	150	307	1,000	150	100	300	150	828

a. Effective plume height.
b. Final effective plume height.

TABLE 7

WATTS BAR VAPOR PLUME MODEL 1/1/77 - 12/31/77

DATE PRINTED 12/01/78

PLUME LENGTH FREQUENCY (%) FOR PLUME HEIGHTS LESS THAN 150 METERS

PLUME LENGTH (M)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0- 200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200- 400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
400- 600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
600- 800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
800- 1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000- 1200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1200- 1400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1400- 1600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1600- 1800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1800- 2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000- 2200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2200- 2400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2400- 2600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2600- 2800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2800- 3000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000- 3200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3200- 3400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3400- 3600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3600- 3800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3800- 4000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4000- 4200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4200- 4400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4400- 4600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4600- 4800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4800- 5000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5000- 5200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5200- 5400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5400- 5600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5600- 5800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5800- 6000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6000- 6200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6200- 6400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6400- 6600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6600- 6800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6800- 7000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7000- 7200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7200- 7400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7400- 7600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7600- 7800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7800- 8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8000- 8200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8200- 8400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8400- 8600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8600- 8800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8800- 9000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9000- 9200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9200- 9400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9400- 9600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9600- 9800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9800-10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 8

WATTS BAR VAPOR PLUME MODEL 1/1/77 - 12/31/77 DATE PRINTED 12/01/78

PLUME LENGTH FREQUENCY (%) FOR PLUME HEIGHTS BETWEEN 150 AND 250 METERS

PLUME LENGTH (M)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0- 200	3.68	8.90	3.41	1.10	0.99	1.00	0.92	1.33	2.66	3.84	2.81	1.99	1.15	0.56	1.04	1.96	37.3
200- 400	0.0	0.03	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
400- 600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
600- 800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
800- 1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000- 1200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1200- 1400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1400- 1600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1600- 1800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1800- 2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000- 2200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2200- 2400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2400- 2600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2600- 2800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2800- 3000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000- 3200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3200- 3400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3400- 3600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3600- 3800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3800- 4000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4000- 4200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4200- 4400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4400- 4600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4600- 4800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4800- 5000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5000- 5200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5200- 5400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5400- 5600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5600- 5800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5800- 6000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6000- 6200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6200- 6400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6400- 6600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6600- 6800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6800- 7000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7000- 7200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7200- 7400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7400- 7600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7600- 7800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7800- 8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8000- 8200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8200- 8400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8400- 8600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8600- 8800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8800- 9000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9000- 9200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9200- 9400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9400- 9600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9600- 9800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9800-10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	3.7	8.9	3.4	1.1	1.0	1.0	0.9	1.3	2.7	3.8	2.8	2.0	1.2	0.6	1.0	2.0	37.4

TABLE 9

WATTS BAR VAPOR PLUME MODEL 1/1/77 - 12/31/77 DATE PRINTED 12/01/78

PLUME LENGTH FREQUENCY (%) FOR PLUME HEIGHTS BETWEEN 250 AND 350 METERS

PLUME LENGTH (M)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0- 200	0.42	1.43	0.82	0.51	0.43	0.43	0.36	0.24	0.89	1.58	0.75	0.18	0.17	0.14	0.17	0.25	8.8
200- 400	0.25	1.63	0.46	0.39	0.53	0.44	0.39	0.31	0.64	0.43	0.25	0.06	0.0	0.0	0.08	0.04	5.9
400- 600	0.06	0.25	0.01	0.01	0.01	0.0	0.01	0.06	0.06	0.01	0.03	0.0	0.03	0.0	0.08	0.01	0.6
600- 800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
800- 1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000- 1200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1200- 1400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1400- 1600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1600- 1800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1800- 2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000- 2200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2200- 2400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2400- 2600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2600- 2800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2800- 3000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000- 3200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3200- 3400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3400- 3600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3600- 3800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3800- 4000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4000- 4200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4200- 4400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4400- 4600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4600- 4800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4800- 5000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5000- 5200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5200- 5400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5400- 5600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5600- 5800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5800- 6000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6000- 6200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6200- 6400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6400- 6600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6600- 6800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6800- 7000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7000- 7200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7200- 7400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7400- 7600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7600- 7800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7800- 8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8000- 8200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8200- 8400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8400- 8600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8600- 8800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8800- 9000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9000- 9200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9200- 9400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9400- 9600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9600- 9800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9800-10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	0.7	3.3	1.3	0.9	1.0	0.9	0.8	0.6	1.6	2.0	1.0	0.2	0.2	0.1	0.3	0.3	15.3

TABLE 10

WATTS BAR VAPOR PLUME MODEL 1/1/77 - 12/31/77 DATE PRINTED 12/01/78

PLUME LENGTH FREQUENCY (%) FOR PLUME HEIGHTS GREATER THAN 350 METERS

PLUME LENGTH (M)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0- 200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200- 400	0.18	0.47	0.24	0.13	0.10	0.13	0.22	0.14	0.22	0.38	0.49	0.24	0.15	0.06	0.06	0.07	3.3
400- 600	0.28	1.95	0.88	0.60	0.70	1.20	1.46	0.97	1.52	1.28	0.76	0.15	0.04	0.0	0.07	0.07	11.9
600- 800	0.0	0.10	0.01	0.01	0.0	0.0	0.0	0.0	0.0	0.06	0.10	0.0	0.0	0.0	0.0	0.01	0.3
800- 1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000- 1200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1200- 1400	0.03	0.04	0.01	0.0	0.03	0.0	0.01	0.0	0.0	0.03	0.0	0.01	0.01	0.0	0.04	0.0	0.2
1400- 1600	0.14	0.24	0.11	0.10	0.08	0.06	0.06	0.10	0.17	0.29	0.22	0.13	0.10	0.03	0.15	0.14	2.1
1600- 1800	0.22	0.57	0.28	0.07	0.01	0.03	0.06	0.01	0.26	0.47	0.14	0.07	0.06	0.0	0.07	0.07	2.4
1800- 2000	0.11	0.35	0.14	0.01	0.0	0.01	0.0	0.01	0.04	0.14	0.04	0.01	0.0	0.0	0.03	0.0	0.9
2000- 2200	0.49	1.24	0.71	0.21	0.07	0.04	0.11	0.26	0.51	1.42	0.54	0.38	0.10	0.07	0.17	0.35	6.7
2200- 2400	0.28	1.00	0.26	0.08	0.04	0.07	0.0	0.07	0.25	0.63	0.19	0.10	0.03	0.01	0.01	0.03	3.1
2400- 2600	0.32	1.10	0.40	0.28	0.06	0.17	0.07	0.11	0.43	1.24	0.71	0.13	0.04	0.08	0.13	0.14	5.4
2600- 2800	0.04	0.24	0.01	0.01	0.0	0.0	0.0	0.01	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.03	0.4
2800- 3000	0.15	0.99	0.44	0.14	0.07	0.18	0.14	0.18	0.39	1.10	0.47	0.18	0.07	0.01	0.06	0.04	4.7
3000- 3200	0.04	0.06	0.03	0.03	0.01	0.01	0.01	0.01	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.3
3200- 3400	0.13	0.24	0.14	0.07	0.07	0.08	0.07	0.10	0.21	0.33	0.07	0.06	0.03	0.04	0.0	0.01	1.6
3400- 3600	0.01	0.04	0.04	0.0	0.01	0.01	0.0	0.03	0.0	0.11	0.06	0.03	0.0	0.0	0.0	0.0	0.3
3600- 3800	0.01	0.06	0.04	0.03	0.01	0.01	0.01	0.03	0.03	0.07	0.0	0.0	0.0	0.0	0.0	0.0	0.3
3800- 4000	0.03	0.08	0.03	0.03	0.0	0.0	0.0	0.0	0.01	0.03	0.03	0.04	0.0	0.01	0.0	0.0	0.3
4000- 4200	0.11	0.28	0.29	0.06	0.06	0.04	0.01	0.0	0.0	0.06	0.04	0.01	0.0	0.0	0.0	0.01	1.0
4200- 4400	0.06	0.01	0.07	0.01	0.0	0.01	0.01	0.0	0.0	0.04	0.03	0.04	0.01	0.01	0.0	0.0	0.3
4400- 4600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4600- 4800	0.07	0.01	0.08	0.03	0.06	0.04	0.01	0.0	0.03	0.14	0.10	0.0	0.06	0.0	0.0	0.04	0.7
4800- 5000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5000- 5200	0.06	0.14	0.07	0.06	0.01	0.0	0.04	0.01	0.03	0.03	0.14	0.01	0.04	0.0	0.03	0.03	0.7
5200- 5400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5400- 5600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5600- 5800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5800- 6000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6000- 6200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6200- 6400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6400- 6600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6600- 6800	0.0	0.07	0.03	0.06	0.03	0.0	0.0	0.08	0.04	0.08	0.06	0.03	0.01	0.01	0.03	0.04	0.6
6800- 7000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7000- 7200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7200- 7400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7400- 7600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7600- 7800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7800- 8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8000- 8200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8200- 8400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8400- 8600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8600- 8800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8800- 9000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9000- 9200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9200- 9400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9400- 9600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9600- 9800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9800-10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	2.8	9.3	4.3	2.0	1.4	2.1	2.4	2.1	4.1	8.0	4.2	1.6	0.8	0.3	0.8	1.1	47.3

TABLE 11

WATTS BAR VAPOR PLUME MODEL 1/1/77 - 12/31/77

DATE PRINTED 12/01/78

PLUME LENGTH FREQUENCY (%)

PLUME LENGTH (M)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL
0- 200	4.10	10.33	4.23	1.61	1.42	1.43	1.28	1.57	3.55	5.42	3.56	2.17	1.32	0.70	1.21	2.21	46.1
200- 400	0.43	2.13	0.72	0.51	0.63	0.57	0.61	0.44	0.86	0.81	0.74	0.29	0.15	0.06	0.14	0.11	9.2
400- 600	0.33	2.20	0.89	0.61	0.71	1.20	1.47	1.03	1.57	1.29	0.79	0.15	0.07	0.0	0.15	0.08	12.6
600- 800	0.0	0.10	0.01	0.01	0.0	0.0	0.0	0.0	0.0	0.06	0.10	0.0	0.0	0.0	0.0	0.01	0.3
800- 1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000- 1200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1200- 1400	0.03	0.04	0.01	0.0	0.03	0.0	0.01	0.0	0.0	0.03	0.0	0.01	0.01	0.0	0.04	0.0	0.2
1400- 1600	0.14	0.24	0.11	0.10	0.08	0.06	0.06	0.10	0.17	0.29	0.22	0.13	0.10	0.03	0.15	0.14	2.1
1600- 1800	0.22	0.57	0.28	0.07	0.01	0.03	0.06	0.01	0.26	0.47	0.14	0.07	0.06	0.0	0.07	0.07	2.4
1800- 2000	0.11	0.35	0.14	0.01	0.0	0.01	0.0	0.01	0.04	0.14	0.04	0.01	0.0	0.0	0.03	0.0	0.9
2000- 2200	0.49	1.24	0.71	0.21	0.07	0.04	0.11	0.26	0.51	1.42	0.54	0.38	0.10	0.07	0.17	0.35	6.7
2200- 2400	0.28	1.00	0.26	0.08	0.04	0.07	0.0	0.07	0.25	0.63	0.19	0.10	0.03	0.01	0.01	0.03	3.1
2400- 2600	0.32	1.10	0.40	0.28	0.06	0.17	0.07	0.11	0.43	1.24	0.71	0.13	0.04	0.08	0.13	0.14	5.4
2600- 2800	0.04	0.24	0.01	0.01	0.0	0.0	0.0	0.01	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.03	0.4
2800- 3000	0.15	0.99	0.44	0.14	0.07	0.18	0.19	0.18	0.39	1.10	0.47	0.18	0.07	0.01	0.06	0.04	4.7
3000- 3200	0.04	0.06	0.03	0.03	0.01	0.01	0.01	0.01	0.0	0.04	0.0	0.0	0.0	0.0	0.0	0.0	0.3
3200- 3400	0.13	0.24	0.14	0.07	0.07	0.08	0.07	0.10	0.21	0.33	0.07	0.06	0.03	0.04	0.0	0.01	1.6
3400- 3600	0.01	0.04	0.04	0.0	0.01	0.01	0.0	0.03	0.0	0.11	0.06	0.03	0.0	0.0	0.0	0.0	0.3
3600- 3800	0.01	0.06	0.04	0.03	0.01	0.01	0.01	0.03	0.03	0.07	0.0	0.0	0.0	0.0	0.0	0.0	0.3
3800- 4000	0.03	0.08	0.03	0.03	0.0	0.0	0.0	0.0	0.01	0.03	0.03	0.04	0.0	0.01	0.0	0.0	0.3
4000- 4200	0.11	0.28	0.29	0.06	0.06	0.04	0.01	0.0	0.0	0.06	0.04	0.01	0.0	0.0	0.0	0.01	1.0
4200- 4400	0.06	0.01	0.07	0.01	0.0	0.01	0.01	0.0	0.0	0.04	0.03	0.04	0.01	0.01	0.0	0.0	0.3
4400- 4600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4600- 4800	0.07	0.01	0.08	0.03	0.06	0.04	0.01	0.0	0.03	0.14	0.10	0.0	0.06	0.0	0.0	0.04	0.7
4800- 5000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5000- 5200	0.06	0.14	0.07	0.06	0.01	0.0	0.04	0.01	0.03	0.03	0.14	0.01	0.04	0.0	0.03	0.03	0.7
5200- 5400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5400- 5600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5600- 5800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5800- 6000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6000- 6200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6200- 6400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6400- 6600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6600- 6800	0.0	0.07	0.03	0.06	0.03	0.0	0.0	0.08	0.04	0.08	0.06	0.03	0.01	0.01	0.03	0.04	0.6
6800- 7000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7000- 7200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7200- 7400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7400- 7600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7600- 7800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7800- 8000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8000- 8200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8200- 8400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8400- 8600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8600- 8800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8800- 9000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9000- 9200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9200- 9400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9400- 9600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9600- 9800	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9800-10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 10000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	7.2	21.5	9.1	4.0	3.4	4.0	4.0	4.1	8.4	13.9	8.0	3.8	2.1	1.0	2.2	3.4	100.0

TABLE 12

DATE PRINTED 10/12/78

PAGE 1 OF 2

COOLING TOWER DRIFT DEPOSITION (KG/HA) - WATTS BAR 1/1/77 - 12/31/77

DIST (M)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0- 200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200- 400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
400- 600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
600- 800	0.12	0.17	0.09	0.02	0.10	0.0	0.05	0.0	0.03	0.12	0.0	0.10	0.05	0.0	0.17	0.02
800- 1000	0.40	0.79	0.43	0.19	0.24	0.05	0.11	0.03	0.25	0.52	0.15	0.44	0.19	0.0	0.43	0.22
1000- 1200	1.14	2.29	1.75	0.74	0.38	0.19	0.21	0.58	1.48	1.75	1.02	1.26	0.45	0.18	0.73	0.96
1200- 1400	1.50	3.32	2.36	1.20	0.56	0.40	0.35	1.01	2.47	2.85	2.11	1.63	0.53	0.48	0.87	1.18
1400- 1600	1.94	3.92	2.76	1.51	0.78	0.58	0.50	1.03	2.79	3.81	2.97	1.63	0.71	0.59	0.90	1.30
1600- 1800	1.54	3.29	1.89	1.19	0.60	0.51	0.45	0.61	1.96	3.28	2.53	0.94	0.54	0.45	0.53	0.85
1800- 2000	1.04	2.65	1.22	0.62	0.33	0.26	0.29	0.28	0.95	2.13	1.43	0.33	0.35	0.18	0.24	0.44
2000- 2200	0.74	2.09	0.86	0.32	0.20	0.15	0.15	0.14	0.50	1.62	0.89	0.18	0.20	0.05	0.11	0.28
2200- 2400	0.62	2.13	0.68	0.28	0.10	0.07	0.13	0.11	0.43	1.50	0.89	0.17	0.11	0.02	0.13	0.22
2400- 2600	0.62	2.19	0.66	0.23	0.10	0.11	0.08	0.08	0.36	1.62	0.79	0.18	0.05	0.01	0.09	0.19
2600- 2800	0.55	2.01	0.61	0.21	0.10	0.10	0.09	0.06	0.34	1.48	0.76	0.16	0.05	0.02	0.07	0.15
2800- 3000	0.43	1.61	0.47	0.20	0.10	0.10	0.08	0.06	0.33	1.30	0.63	0.15	0.04	0.02	0.04	0.10
3000- 3200	0.38	1.48	0.44	0.16	0.08	0.07	0.07	0.05	0.26	1.03	0.46	0.12	0.04	0.01	0.02	0.08
3200- 3400	0.31	1.09	0.32	0.12	0.06	0.06	0.05	0.05	0.21	0.73	0.33	0.09	0.02	0.01	0.02	0.05
3400- 3600	0.27	0.99	0.30	0.10	0.05	0.05	0.03	0.06	0.18	0.60	0.20	0.07	0.02	0.01	0.01	0.04
3600- 3800	0.18	0.74	0.25	0.08	0.03	0.04	0.02	0.04	0.14	0.52	0.16	0.03	0.01	0.00	0.01	0.03
3800- 4000	0.17	0.68	0.23	0.08	0.03	0.04	0.02	0.04	0.13	0.49	0.12	0.03	0.01	0.0	0.01	0.03
4000- 4200	0.15	0.60	0.21	0.07	0.03	0.03	0.01	0.03	0.11	0.36	0.08	0.03	0.01	0.0	0.00	0.03
4200- 4400	0.12	0.45	0.18	0.06	0.03	0.03	0.01	0.03	0.06	0.24	0.03	0.01	0.01	0.0	0.00	0.02
4400- 4600	0.11	0.39	0.18	0.06	0.03	0.03	0.01	0.03	0.05	0.22	0.03	0.01	0.01	0.0	0.00	0.02
4600- 4800	0.10	0.36	0.17	0.06	0.03	0.03	0.01	0.04	0.04	0.20	0.03	0.01	0.01	0.0	0.00	0.01
4800- 5000	0.08	0.32	0.15	0.05	0.02	0.03	0.01	0.03	0.03	0.15	0.02	0.01	0.00	0.0	0.00	0.01

TABLE 12 (continued)

COOLING TOWER DRIFT DEPOSITION (KG/HA) - WATTS BAR 1/1/77 - 12/31/77

DATE PRINTED 10/12/78

DIST (M)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
5000- 5200	0.05	0.23	0.09	0.04	0.02	0.02	0.01	0.03	0.02	0.10	0.01	0.01	0.00	0.0	0.0	0.01
5200- 5400	0.05	0.19	0.10	0.03	0.01	0.01	0.01	0.02	0.01	0.09	0.01	0.01	0.00	0.0	0.0	0.01
5400- 5600	0.04	0.16	0.10	0.03	0.01	0.01	0.01	0.02	0.01	0.07	0.01	0.01	0.00	0.0	0.0	0.00
5600- 5800	0.04	0.14	0.09	0.03	0.01	0.01	0.01	0.01	0.01	0.06	0.01	0.01	0.00	0.0	0.0	0.00
5800- 6000	0.03	0.12	0.09	0.02	0.01	0.01	0.01	0.01	0.00	0.06	0.01	0.00	0.00	0.0	0.0	0.00
6000- 6200	0.02	0.09	0.07	0.02	0.01	0.00	0.01	0.01	0.00	0.03	0.01	0.00	0.00	0.0	0.0	0.00
6200- 6400	0.02	0.07	0.07	0.01	0.01	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.00	0.0	0.0	0.00
6400- 6600	0.02	0.07	0.06	0.01	0.01	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.0	0.0	0.00
6600- 6800	0.01	0.06	0.04	0.01	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.0	0.0	0.00
6800- 7000	0.01	0.03	0.03	0.01	0.00	0.00	0.01	0.00	0.0	0.01	0.00	0.00	0.00	0.0	0.0	0.00
7000- 7200	0.00	0.02	0.02	0.01	0.00	0.00	0.01	0.00	0.0	0.01	0.00	0.00	0.00	0.0	0.0	0.00
7200- 7400	0.00	0.02	0.02	0.01	0.00	0.00	0.01	0.00	0.0	0.01	0.00	0.00	0.00	0.0	0.0	0.00
7400- 7600	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
7600- 7800	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
7800- 8000	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
8000- 8200	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
8200- 8400	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
8400- 8600	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
8600- 8800	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
8800- 9000	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.00
9000- 9200	0.00	0.01	0.01	0.00	0.00	0.0	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0
9200- 9400	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0
9400- 9600	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0
9600- 9800	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0
9800-10000	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0
> 10000	0.00	0.01	0.02	0.00	0.00	0.0	0.00	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.0	0.0

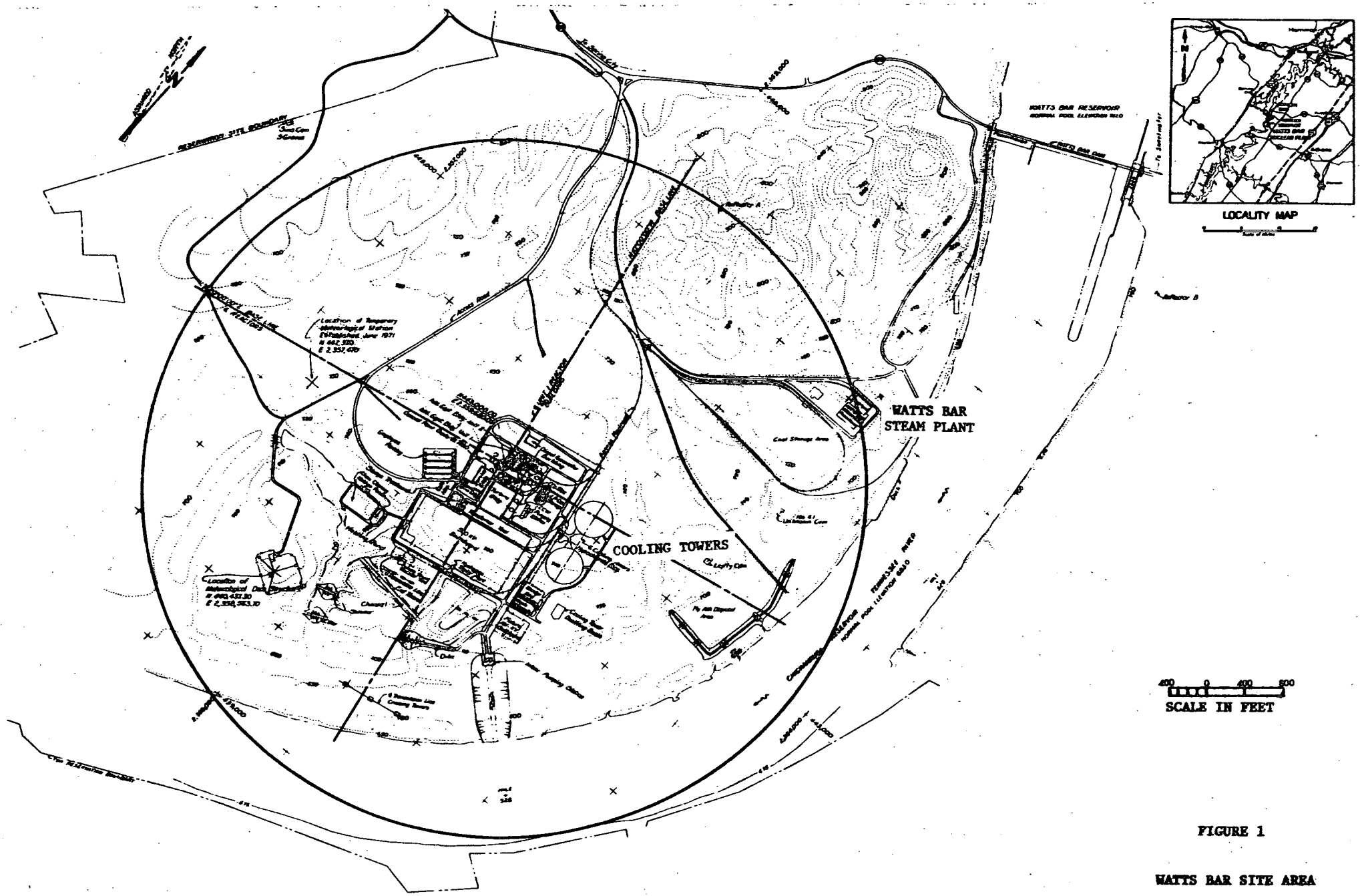

FIGURE 1

WATTS BAR SITE AREA

APPENDIXES

A - TVA Commitments and NRC Requirements

B - Pertinent Portions of Regulatory Guide 4.11

C - Design and Operational Data - Watts Bar Steam Plant and Watts Bar Nuclear Plant Cooling Towers

D - Plume Rise Calculational Method

E - Cooling Tower Drift and Vapor Plume Models

APPENDIX A

TVA COMMITMENTS AND NRC REQUIREMENTS

1. TVA Final Environmental Statement - Watts Bar Nuclear Plant, Page 2.6-19

Based on observations at the Paradise power plant, the only effects of this type of mergence have been identified with acid fly ash fallout, particularly during plant unit startup and shutdown when the electrostatic precipitators are not operating at design efficiency. Under such conditions, some significant acid mist and acid fly ash fallout could occur. Such effects would be confined to within one-half to one mile of the plant and, in most cases, would be in the form of slight staining on metal objects and slight markings on vegetation. Steps will be taken which could include a change in fuel, plant operation limitations, or temporary shutdown of the coal-fired units whenever the nuclear and coal-fired units are operating simultaneously and the potential for plume mergence is likely to occur. However, since the anticipated future operation of the Watts Bar Steam Plant is expected to be limited to system peak conditions, and because of the low sulfur content of the fuel, the effects of the plume mergence should be minimal.

2. TVA Environmental Information Supplement No. 1 Response to NRC Questions for Operating License Stage Environmental Review, Question 2.a, Page 2-7:

Provide an outline of any plans to be taken to monitor release of acid mist and acid fly ash from plume mergence and possible resulting environmental impact (FEIS-CP, p. 2.6-19).

Response:

A routine surveillance program for terrestrial effects of the Watts Bar Steam Plant operation will be slightly expanded when the Watts Bar Nuclear Plant cooling towers begin to function (about 1979, if the projected schedule is maintained). During the growing season, at least three site visits will be made by qualified personnel in the Air Quality Branch to inspect vegetation for any evidence of damage from acid mist and/or acid fly ash. Spring will be the optimum time for inspection because the initial growth of the season is generally more vulnerable. However, it is not expected that there will be any significant effects, especially offsite.

The NRC's Draft Environmental Statement for the Watts Bar Nuclear Plant states this commitment as follows:

3a. NRC FES Watts Bar Nuclear Plant, Page 6-4:

6.2.5 Preoperational Terrestrial Monitoring

The staff requires a one-year preoperational aerial remote survey using color infrared and/or multispectral or multiband photography.

3b. NRC DES Watts Bar Nuclear Plant, Page 6-7:

6.3.6.1 Cooling Tower Drift and Plume Interaction

The applicant has committed to monitor the potential terrestrial effects of plume interaction and cooling tower drift from the Watts Bar Steam Plant operation and Watts Bar Nuclear Plant cooling towers. The proposed program is as follows:

> During the growing season, at least three site visits will be made by qualified TVA personnel to inspect vegetation for any evidence of damage from acid mist and/or acid fly ash. Spring has been suggested as the optimum time for inspection.

The staff requires that a limited term aerial remote sensing program be undertaken as part of the applicant's proposed monitoring program. This program may use color infrared and/or multispectral or multiband photography. This combined program of aerial remote sensing and ground inspection on an annual basis for a limited term would be highly sensitive in the rapid detection of any terrestrial effects due to cooling tower drift or plume interactions.

TVA's response to this expansion of the previous surveillance commitment was that remote sensing techniques for delineating effects of air pollution on vegetation are still in the experimental stage. Commitment to an experimental remote sensing surveillance program at this time would be premature and may not prove effective. Also, the on-the-ground surveillance will not be dependent on results from the remote sensing

program. Based on this, it was recommended that strong initiative be taken to remove the commitment for aerial remote sensing from the NRC final environmental statement.

APPENDIX B

PERTINENT PORTIONS OF REGULATORY GUIDE 4.11*

Pages 4.11-5 and 4.11-7:

"If the drift from either freshwater or saltwater towers is likely to contain toxic substances, their concentrations are measured unless it is clear that the amounts and concentrations are sufficiently low to preclude both short-term and cumulative adverse effects. Adverse biological effects can usually be ruled out with reasonable certainty for most elements and compounds found in nature when the expected additions combined with preexisting levels would not raise the concentration of the toxic substance outside the range of variation normally found in the biota or soils of the region."

"Chemical analyses of soils, plants, and animals in the drift field of freshwater cooling towers are not usually needed when all of the following apply: (1) the dominant salts are harmless mixtures of biological nutrients as shown in table 4, (2) the expected peak deposition beyond the site boundary is less than 20 kg/ha-yr (no more than 50 percent in any 30-day period during the growing season) of mixed salts, and (3) the drift does not contain toxic elements or compounds in amounts that could be hazardous to plants or animals either by direct or indirect exposure over the expected lifetime of the facility."

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*NRC Regulatory Guide 4.11, "Terrestrial Environmental Studies for Nuclear Power Stations-Revision 1," August 1977.

"Usually, reference specimens of soils, plants, and animals for possible future analysis are retained in cases where it is determined that drift presents a chemical hazard to the environment. The specimens may consist of subsamples of materials that were collected prior to tower operation and analyzed for baseline data. Such stored samples should be adequately protected for analytical purposes."

APPENDIX C

DESIGN AND OPERATIONAL DATA - WATTS BAR STEAM PLANT AND WATTS BAR NUCLEAR PLANT COOLING TOWERS

Watts Bar Steam Plant - Design

Units	1-4
Rated capacity per unit at normal full load	59 mw
Type of boiler design	Top fired
Stacks	
Number	2
Height	54 meters
Top inside diameter	4.9 meters
Exit velocity	10.9 meters/second
Gas temperature at exit	172°C
Spacing	34.7 meters
Fly ash collectors	
Type	Electrostatic precipitators
Design efficiency rating	95 percent
Total air boiler outlet	130 percent
SO_2 emission rate at normal full load, per unit*	230 g/sec

*Based on 1978 plant operational data, the heat content of the coal is about 11,500 Btu/lb and the sulfur content of the coal is about 2 percent.

Watts Bar Nuclear Plant - Cooling Tower Design

Number of towers	2
Separation of towers	215 meters
Tower height	155 meters
Tower top inside diameter	84 meters
Effluent exit velocity	3.7 meters/second
Effluent temperature at exit	36°C
Circulating water flow rate	31,540 liters/sec
Total dissolved solids content of makeup water	127 mg/liter
Concentration factor*	3
Drift droplet eliminator efficiency	99.99 percent

*Under normal operating conditions, the blowdown rate will be maintained to provide a condenser cooling system solids concentration about twice the solids concentration in the reservoir. Periods during which blowdown is discontinued are not expected to exceed 12 hours, and are expected to be an infrequent occurrence. During those periods, the concentration factor will increase to a maximum of about 4.

APPENDIX D

PLUME RISE CALCULATIONAL METHOD

Plume rise for stack releases from the steam plant are calculated by the Briggs method for buoyant plumes.[1,2] This method is summarized as follows.

For neutral or unstable conditions,

$$XS = 14\ F^{5/8} \text{ for } F < 55$$

$$XS = 34\ F^{2/5} \text{ for } F \geq 55$$

$$X_F = 3.5\ XS$$

$$V_F = {}^{\pi}/4\ WD^2 = 0.785\ WD^2$$

$$F = {}^{g}/_{\pi}\ V_F \left(\frac{Ts-T}{Ts} \right) = 3.12\ V_F \left(\frac{Ts-T}{Ts} \right)$$

Where:

W = exit velocity (m/sec)

X = distance from source (m)

U = wind speed (m/sec)

D = internal stack diameter (m)

S = stability parameter

$$S = \frac{g}{T} \frac{\partial \Theta}{\partial z}$$

g = acceleration of gravity (m/sec^2)

T = ambient temperature (deg K)

Ts = stack gas exit temperature (deg K)

$\frac{\partial \Theta}{\partial z}$ = vertical potential temperature gradient (deg K/m)

XS = distance at which atmospheric turbulence begins to dominate entrainment (m)

F = buoyancy flux parameter (m^4/sec^3)

X_F = distance of the final rise (m)

V_F = stack gas volume flow (m^3/sec)

$$H_{PR} = \frac{1.6F^{1/3} X_F^{2/3}}{u} \quad \text{for } X \geq X_F \qquad (1)$$

$$H_{PR} = \frac{1.6F^{1/3} X^{2/3}}{u} \quad \text{for } X \leq X_F \qquad (2)$$

For stable conditions,

$$X_F = \frac{3.14u}{S^{1/2}}$$

$$H_{PR} = 2.4 \left(\frac{F}{uS}\right)^{1/3} \quad \text{for } X \geq X_F \qquad (3)$$

$$H_{PR} = \frac{5.0F^{1/4}}{S^{3/8}} \quad \text{for } X \geq X_F \qquad (4)$$

Use the smaller of (3) and (4) as the final plume rise.

$$H_{PR} = \frac{1.6F^{1/3} X^{2/3}}{u} \quad \text{for } X < X_F \qquad (5)$$

When using equation (5), compare the result with (3) and (4) and use the more conservative value.

References:

Briggs, Gary A., 1969, Plume Rise, USAES Critical Review Series TID-25075, National Technical Information Service, Springfield, Virginia 22151

Dispersion Estimate Suggestion No. 2 (Revised), USEPA, Model Application Branch, D. Bruce Turner, Acting Chief, May 1, 1973.

APPENDIX E

COOLING TOWER DRIFT AND VAPOR PLUME MODELS

Drift Deposition Model

The cooling tower drift deposition model presently used by TVA synthesizes state of the art models of droplet dynamics, plume rise, and plume dispersion.[1] In general, the model assumes that the drift droplets are uniformly distributed across the plume cross-section and that drift droplets will fall from the plume and deposit on the ground or evaporate and disperse their solid constituents in the prevailing flow.

Plume behavior is modeled by the conservation of mass, moisture, energy, horizontal and vertical momentum and kinematic relations between plume centerline position and time. Droplet evaporation is modeled by a standard equation taken from studies of cloud physics and by kinematic relations between droplet position and time. These equations describing plume and droplet behavior are expressed as differential equations and are solved numerically by a standard Runge-Kutta method.

The equations for cooling tower plume dynamics employ the Boussinesq approximation which assumes that differences between plume and ambient air density are ignored except for the case of plume buoyancy. Wake effects in the immediate lee of the cooling tower are modeled by subtracting an empirically derived vertical velocity from the vertical velocity of the plume. This treatment of cooling tower wake effect is based on plume characteristics observed at the Paradise Steam Plant.[2, 3] The model treats emissions from individual cooling towers as separate single sources until the plume diameters equal the separation distance between the towers. At this point, plume mergence is assumed to occur

and plume area and fluxes are multiplied by the number of towers. This treatment of multiple sources is a reasonable approach that is widely used in other models.[4]

The entrainment velocity of ambient air into the plume is generally assumed to equal three-tenths of the vertical velocity. This assumption has been supported by field studies.[2, 3]

The behavior of drift droplets is governed by their decay through evaporation, horizontal transport due to ambient wind, gravitational settling, diffusion due to turbulence, and vertical transport by the plume. Initially, a size spectrum of emitted drift droplets is specified and the behavior of each different droplet size is examined for each given set of meteorological conditions. The plume is assumed to be saturated as long as liquid moisture is present. The plume is never allowed to be supersaturated, and therefore, drift droplets do not grow due to condensation. Also, droplet growth due to coalescence and droplet breakup are judged to be minor effects and are not considered. Droplets larger than 50 μm are assumed to have ballistic trajectories, whereas smaller droplets are assumed to disperse in a Gaussian manner.

Other effects that are not accounted for in the model include the variability of the droplet spectrum over the cross-section of the cooling tower at release, wind direction and wind speed fluctuations across the plume cross-section, and counter-rotating vortices. The net result of these factors would probably be an increase in the deposition area of the drift droplets. This would result in lower predicted maximum deposition rates, with the drift being more evenly deposited over the area of influence of the towers.

Ambient temperature and relative humidity may be specified in the model at two levels above the top of the cooling tower. The model computes the ambient conditions by interpolating between the appropriate levels depending on the plume elevation. Wind speed is adjusted by vertical power law extrapolation from the measurement height on the meteorological tower to the top of the cooling tower, and held constant with elevation above that level. Joint probability distributions of wind speed and direction, dry-bulb temperature, and relative humidity are required as input by the model.

Vapor Plume Model

The cooling tower plume model presently used by TVA is a state-of-the-art model of vapor plume rise and vapor plume dispersion.[5] In general, the model assumes that the plume variables are distributed uniformly across the plume cross-section. In the plume rise region, equations for the conservation of mass, moisture, energy, and horizontal and vertical momentum determine plume characteristics. These equations are expressed as differential equations and are solved numerically by a standard Runge-Kutta method.

The equations for cooling tower plume dynamics employ the Boussinesq approximation which assumes that differences between plume and ambient air density are ignored except for the case of plume buoyancy.

Wake effects in the immediate lee of the cooling tower are modeled by reducing the plume vertical velocity by an empirically derived fraction, which depends on the wind speed. This treatment of cooling tower wake effect is based on plume effects observed at the Paradise Steam Plant.[2, 3] The model treats emissions from individual cooling towers as single sources until the plume diameters equal the separation distance between the towers. At this point plume mergence is assumed to occur and fluxes are multiplied by the number of towers. This treatment of multiple sources is a reasonable approach that is widely used in other models.[4]

The entrainment velocity of ambient air into the plume is assumed to equal three-tenths of the vertical velocity. This assumption has been supported by field studies.[2,3]

The plume is assumed to enter the dispersion phase when it reaches its final rise in stable conditions or when its vertical velocity equals 10 percent of the mean wind speed. At this transition point the distribution of plume variables is changed from a round top-hat to an elliptical top-hat* while conserving all plume fluxes. The spread of the plume in this phase is determined from standard diffusion curves. The end of the visible plume is assumed to be the point where the plume humidity falls below saturation. The effect on ground-level humidity is modeled in this atmospheric phase by calculating the plume humidity at ground level in the standard Gaussian manner as with other conservative gases.

The input of meteorological data is handled in an identical manner as with the drift deposition model.

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*Top-hat distributions of plume variables indicate that plume variables are constant across the plume cross-section, whereas round and elliptical merely define the shape of the plume.

Meteorological Input to Drift Deposition and Vapor Plume Models

The following is a listing of meteorological data periods, measurement levels, and categories into which the data were compiled for input to the drift deposition and vapor plume models for the plume mergence assessment.

Period of record	January 1, 1977-December 31, 1977
Wind direction	93 m
Wind speed	93 m
Dry-bulb temperature	91 m
Dewpoint temperature	10 m*

Joint probability frequency distributions of the meteorological data were developed under the following categorization.

Relative Humidity (%)

Interval	Assigned Value
RH $\leq$ 74	55
74 < RH $\leq$ 85	80
85 < RH $\leq$ 90	88
90 < RH $\leq$ 95	93
95 < RH	97

*The relative humidity at the 91-meter level was determined from a linear regression equation which predicts the 91-meter relative humidity from the 10-meter value. This relationship was developed from data collected at the Browns Ferry Nuclear Plant permanent meteorological tower.

Temperature (°C)

Internal	Assigned Value
$T \leq 4$	0
$4 < T \leq 13$	10
$13 < T \leq 19$	17
$19 < T \leq 23$	22
$23 < T$	27

Wind Speed (m/s)

Internal	Assigned Value
$\bar{u} \leq 1.7$	1.5
$1.7 < \bar{u} \leq 2.6$	2.5
$2.6 < \bar{u} \leq 3.7$	3.6
$3.7 < \bar{u} \leq 5.3$	5.0
$5.3 < \bar{u}$	7.4

The assigned wind speed values were determined from power law extrapolation, assuming neutral stability conditions (power law coefficient of 0.25, from 93 meters to the height of the cooling towers.[6] The determination of ambient relative humidity at the plume height consisted of linear interpolation from the assigned value at the cooling tower top to a value of 70 percent at 1,000 meters and interpolation to a value of 50 percent for the layer from 1,000 to 2,000 meters. An ambient temperature lapse rate of 0.65°C per 100 meters was assumed. Wind speeds were not varied above the cooling tower top.

APPENDIX E

References

1. Slawson, P. R. and A. Kumar. Cooling Tower Drift Deposition - Program Guide to ENDRIFT II (Numerical Solution). Prepared for the Tennessee Valley Authority, Air Quality Branch, April 1976.

2. Slawson, P. R., J. H. Coleman, and J. P. Blackwell. "Natural Draft Cooling Tower Plume Behavior at Paradise Steam Plant (Part I)," Tennessee Valley Authority, Air Quality Branch, August 1975.

3. Slawson, P. R., J. H. Coleman, and J. W. Frey. "Natural Draft Cooling Tower Behavior at Paradise Steam Plant (Part 2)," Tennessee Valley Authority, Air Quality Branch, February 1978.

4. Weil, Jeffery C. "Comparison Between Measured and Model-Estimated Ground-Level SO_2 Concentrations Downwind from the Dickerson Power Plant," Tennessee Valley Authority, Air Quality Branch, August 1975.

5. Slawson, P. R. Vapor Plume Theory and Example Computer Programs. Prepared for the Tennessee Valley Authority, Air Quality Branch, January 1976.

6. The American Society of Mechanical Engineers, "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents," Second Edition, 1973.