MODEL PARAMETER SENSITIVITY ANALYSIS

Volume 1 of 2

U.S. EPA Region 6 Center for Combustion Science and Engineering

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1. EXECUTIVE SUMMARY

The EPA-developed ISCST3 model is recommended in the Draft SLHHRA Protocol (2/28/97) for performing air dispersion and deposition modeling. ISCST3 modeled outputs for ambient air concentration and wet and dry deposition rates provide the inputs to evaluate COPC fate and transport. ISCST3 requires the modeler to select many input parameter values for which technical descriptions and ranges of values are provided with no information on the sensitivity of modeled results to selected values. Similarly, the EPA-developed meteorological preprocessor program PCRAMMET requires numerous parameter specifications within ranges of values identified from reference literature without identifying model sensitivity.

This sensitivity analysis provides comparisons of ISCST3 modeled results using the Protocol recommended values to modeled results using the upper and lower range values for identified elements. The eight priority and seven secondary elements are selected by EPA Region 6 considering the availability of information for selection, experience on prior risk analyses, and anticipated impact on modeled results. The Protocol recommended values represent typical site characteristics that may be used to model conservative screening results without collecting site-specific data. However, the modeler may elect to collect site-specific data to refine model results. The following table provides a qualitative summary of the sensitivity of modeled results to variations in the selected values for the fifteen elements evaluated in this study. The sensitivity is 'slight' for variations less than 10% in ISCST3 modeled results using the element range limits compared to the Protocol recommended values. Sensitivity is 'moderate' for variations less than 50% from Protocol results. Sensitivity is 'severe' for variations greater than 50% from Protocol results. Seven elements produce slight or no variations from the Protocol results. Two elements produce moderate variations. Six elements produce severe variations from Protocol results. The two moderate elements require consideration by EPA Region 6 for ensuring the Protocol recommendations represent the desired level of conservativeness for a screening level risk assessment. The six severe elements should have required values or methods specified in the Protocol or always require collection of site specific data.

PARAMETER	SENSITIVITY	RECOMMENDATION
Elevated vs. Flat Terrain	Severe	Must include terrain < 1-2 km; Hills > stack height only if > 5 km
Rural vs. Urban Air Dispersion Coefficients	Severe	Detailed land use analysis required
Surface Roughness (Application Site)	Severe	EPA-required method, or site-specific justification
Watershed Size and Proximity	Severe	Use actual watershed area near source; use representative points >10 km away
Anemometer Height	Moderate	Under estimates < 1 km
Particle Size Distribution and Density	Moderate	Require stack test data for particle size and density
Polar vs. Cartesian Grid Nodes	Slight	Applicant selects grid
Terrain Grid File	None	No impact on model results
Minimum Monin-Obukhov Length	Slight	Specify default values
Surface Roughness (Measurement Site)	Severe	EPA-required value for NWS site of 0.10 meters
Noon-time Albedo	Slight	Specify default values
Bowen Ratio	Slight	Specify default values
Anthropogenic Heat Flux	None	No impact on model results
Fraction of Net Radiation Absorbed	None	No impact on model results
Scavenging Coefficients	Severe	Isolated events 300%, but rare occurrence in EPA 6

2. INTRODUCTION

This analysis is presented in eight chapters of Volume 1 with three appendices in Volume 2. Chapter 1 is the Executive Summary of all elements evaluated with recommendations for providing guidance to applicants based on the model sensitivity to selected element values. Chapter 2 provides a document overview with a discussion of the background and purpose for this analysis. Chapter 3 provides an overview of the eight priority elements and seven secondary elements evaluated. Chapter 4 describes the base case modeling in ISCST3 applying Protocol recommended values for each study element. Chapters 5 and 6 present the technical objective, theoretical basis, modeling methodology, results and recommendations for the individual studies on priority and secondary elements, respectively. Chapter 7 summarizes results for all elements. Chapter 8 presents recommendations for all elements.

Volume 2 includes three appendices. Appendix A contains tables of absolute and normalized values of concentration, dry deposition and wet deposition for vapor, particle-bound and particle phase modeling results of each element. The absolute values are extracted from the ISCST3 model runs. The normalized values are computed in spreadsheets by dividing the absolute values for the test cases by the absolute values for the base case. The figures provided in Chapters 5 and 6 are plots of these normalized values to graphically indicate percentage deviation of test case results from base case results. Appendix B includes printouts of the input files for ISCST3 for all evaluations. Limited copies of Volume 2 contain Appendix C with a CD-ROM of all models and files in this analysis including the ISCST3 model (version 96113), PCRAMMET meteorological pre-processor (version 95300), ISCST3 input files, ISCST3 output files, ISCST3 plot files, ISCST3 terrain grid files, and ISCST3 meteorological files.

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2.1 BACKGROUND

The Protocol document provides a history of screening level risk assessments for human health. Prior EPA and North Carolina documents included references to the literature containing ranges and limits of values for the fifteen study elements. The modeler selects literature values based on land use, season, precipitation climate, vegetation and geographic location. In the tiered approach of these prior documents, first tier screening provides very conservative results that infrequently satisfy risk criteria. Second and third tiers allow for less restrictive assumptions and site-specific data to refine the risk assessment for more practicable results. Each proposed value requires applicant evaluation and submittal to the agency for review and approval. This process prolongs the permit review process while consuming significant agency and applicant resources.

EPA Region 6 experiences in risk assessment at several sites indicate sensitivity of ISCST3 results to certain input model parameters. The eight priority elements in this analysis either provide significant impacts on prior risk assessments, or are suspected strongly to influence results. The secondary elements may have effects that should be quantified in support of Protocol recommended values.

2.2 PURPOSE

This sensitivity study assesses quantitatively the Protocol recommendations relative to variations of specific input parameters within literature ranges. For insensitive parameters, the expense of site-specific data collection may be avoided if refinement of the parameter does not yield significant refinement in modeled results. For sensitive parameters, recommendations may include a) no change in Protocol recommended value; b) revised Protocol recommended value; c) change in method of determination of value; or, d) need for additional study of parameter to assess appropriate value. Additional study may include literature review, site-specific data collection or basic research.

3. OVERVIEW OF ELEMENTS EVALUATED

Of priority to EPA Region 6 is ISCST3 sensitivity to the following elements: elevated terrain, rural versus urban air dispersion coefficients, surface roughness at the application site, watershed size and proximity, anemometer height, particle size distribution and density, polar versus Cartesian grid nodes, and terrain grids. A second level of elements also require an assessment of quantifiable sensitivity: minimum Monin-Obukhov length, noon-time albedo, surface roughness at the measurement site, Bowen ratio, anthropogenic heat flux, fraction of net radiation absorbed at the ground, and scavenging coefficients. A brief overview of the analyses conducted for these eight priority and seven secondary elements is provided below.

3.1 PRIORITY ELEMENTS EVALUATED

- **ELEVATED VERSUS FLAT TERRAIN**

  The ISCST3 model allows the user to account for terrain rise above stack base by inputting stack base and receptor elevations into model runs. EPA Region 6 recommends using actual terrain elevations in all modeling analyses. The purpose of the elevated versus flat terrain analysis is to determine whether small variations in terrain elevation relative to plant base may be ignored without underestimating modeled impacts. Specifically, the Protocol allows for ignoring terrain if the highest elevation within 5 kilometers is less than 1/4 the height of the shortest stack, or more conservatively using 10% of the height of the shortest stack.

- **RURAL VERSUS URBAN AIR DISPERSION COEFFICIENTS**

  Air dispersion coefficients define the COPC plume as a function of downwind distance from the source and atmospheric stability. The ISCST3 model contains two sets of predefined dispersion coefficients, one for rural sites and one for urban sites. The issue of the rural versus urban air dispersion coefficients analysis is the impact if a modeler incorrectly uses rural coefficients and corresponding rural meteorology or urban coefficients and urban meteorology.

- **SURFACE ROUGHNESS HEIGHT AT APPLICATION SITE**

  Surface roughness is a measure of the height above ground level which separates free air flow from stagnant air near the ground. The height is related to the height of the obstacles in the wind flow and is input to the meteorological preprocessor. The method recommended in the Protocol for determining surface roughness at a site is rigorous because dry deposition is very sensitive to the value specified when processing the meteorological files. The sensitivity analysis models a base case using a surface roughness value typical of many sites along the Texas and Louisiana coast with grassland and predominantly summer conditions (0.1 meter). These results are compared to results for a very large surface roughness (1.3 meters typical of heavily forested areas in summer) and results for a very small surface roughness (0.001 meters representing grassland during winter).

- **WATERSHED SIZE AND PROXIMITY**

  Watersheds are evaluated in separate receptor grids in modeling for risk assessment. The purpose of this analysis is to determine the sensitivity of modeled results to the size of the watershed grid selected and the proximity of the watershed to the COPC emission sources. The study includes an investigation of whether a watershed grid covering only a small portion of the total watershed area is representative of the larger watershed area for a watershed located more than 10 kilometers from the source. If so, significant model run time and analyst post-processing time may be conserved.

- **ANEMOMETER HEIGHT**

  The anemometer height is the height above ground level of the wind speed instrument at National Weather Service stations. Typical heights vary from 20 feet (6.1 meters) to 10 meters. Wind speeds at stack top are calculated in ISCST3 using measured wind speeds at anemometer height extrapolated exponentially to stack top. These computed stack top wind speeds are critical in ISCST3 dispersion calculations. This analysis is to determine the effect on modeled results if a modeler inputs an incorrect anemometer height into either the meteorological preprocessor, ISCST3 input file, or both.

- **PARTICLE SIZE DISTRIBUTION AND DENSITY**

  The physical characteristics of particles emitted from stacks must be determined to produce representative estimates of wet and dry particle deposition. Several parameters related to particles are evaluated, including particle size resolution, particle mass distribution, number of particle size categories, and particle density. Applicants must provide representative particle data for their facilities from stack tests which are costly and time-consuming. This analysis determines the sensitivity of modeled results to the amount of particle data provided.

- **POLAR VERSUS CARTESIAN GRID NODES**

  The Protocol recommends using Cartesian grid nodes rather than polar grid nodes for risk assessment modeling. The benefit of Cartesian grid nodes is that the modeler can specify equal spacing between nodes. Also, Cartesian grid nodes correspond to rectilinear terrain grid files required for many sites. Previous risk assessment guidance recommends polar rather than Cartesian grid nodes to reduce model run times. This analysis compares model results, set up and run times using the Cartesian grid specified in the Protocol versus the polar grid recommended in previous documents.

- **TERRAIN GRID FILE**

  A terrain grid file is used to refine dry particulate depletion by providing better terrain elevation resolution between grid nodes for sites with elevated terrain. This analysis is to determine whether the increase in labor and run times required to use terrain grid files in ISCST3 modeling significantly affect modeled results. Test cases are performed with and without the use of a terrain grid file. Also, the resolution of the terrain grid file is tested for sensitivity by comparing 500 meter, 250 meter, and 100 meter spaced terrain grids.

3.2 SECONDARY ELEMENTS EVALUATED

- **MINIMUM MONIN-OBUKHOV LENGTH**

  The Monin-Obukhov length (L) is a measure of atmospheric stability calculated from other meteorological preprocessor input parameters, such as noon-time albedo and Bowen ratio. This analysis is to determine the effect on modeled results at urban sites of using various values of minimum L. Test cases using the lowest (2 meters) and highest (150 meters) potential values for minimum L are compared with modeled results using a more typical minimum L value (50 meters).

- **SURFACE ROUGHNESS AT MEASUREMENT SITE**

  This analysis is to determine the sensitivity of modeled results to the surface roughness at the wind measurement site. The base case is a surface roughness value of 0.1 meters typical of most National Weather Service (NWS) station locations that satisfy NWS siting criteria. Test cases compare model results to the base case using a very large surface roughness (1.3 meters, typical of heavily forested areas during summer) and a very small surface roughness (0.001 meters, grassland during winter).

- **NOON-TIME ALBEDO**

  Noon-time albedo is the fraction of reflected solar radiation when the sun is directly overhead driving net heat balance in computing hourly Monin-Obukhov length. This analysis determines model sensitivity to noon-time albedo specified in PCRAMMET.

Results using a typical value of 0.18 (grassland, summer) are compared to minimum value of 0.10 (water, summer) and maximum value of 0.60 (grassland, winter).

- **BOWEN RATIO**

  The Bowen ratio is a measure of surface moisture that affects hourly Monin-Obukhov length calculated by PCRAMMET. This analysis determines sensitivity to the Bowen ratio value specified in PCRAMMET. Results using a typical value in average moisture areas of 0.7 are compared to minimum (0.1) and maximum values (4.0).

- **ANTHROPOGENIC HEAT FLUX**

  Anthropogenic heat flux is the surface heating caused by human activity. It is applicable only for urban areas and is used to calculate hourly Monin-Obukhov lengths in PCRAMMET. The purpose of this analysis is to determine model sensitivity to the value specified in PCRAMMET. Modeled results using a typical anthropogenic heat flux of 20 watts/m^2 representative of year-round anthropogenic heat flux in a southern U.S. city (Los Angeles is 21 watts/m^2) are compared to modeled results using a maximum anthropogenic heat flux of 198 watts/m^2 representing a northern U.S. city during the winter.

- **FRACTION OF NET RADIATION ABSORBED AT GROUND**

  The fraction of net radiation absorbed at the ground is used for calculating hourly values of Monin-Obukhov length. The purpose of the fraction of net radiation sensitivity analysis is to determine the sensitivity of modeled results to the fraction of net radiation specified in PCRAMMET. Modeled results using the Protocol recommended value of 0.27 for urban areas are compared to modeled results using a value of 0.22 for suburban areas.

- **SCAVENGING COEFFICIENTS**

Wet deposition flux is calculated by multiplying a scavenging ratio by the vertically integrated concentration. The scavenging ratio is the product of a scavenging coefficient and a precipitation rate. The ISCST3 model distinguishes between liquid and frozen scavenging coefficients. As a conservative estimate, the frozen scavenging coefficients are assumed to be equal to the liquid scavenging coefficients. However, research has indicated that frozen precipitation scavenging coefficients are about one-third that of liquid precipitation. The purpose of the scavenging coefficient sensitivity analysis is to compare modeled wet deposition and concentration assuming frozen scavenging coefficients are equal to liquid scavenging coefficients with modeled wet deposition and concentration assuming frozen scavenging coefficients are one-third of liquid scavenging coefficients

4. BASE CASE

The sensitivity studies for each of the elements are compared to a base case representing modeled concentration and deposition from a typical Boilers and Industrial Furnaces (BIF) combustion unit stack using Protocol recommended methods or values. One or more test cases are then modeled for concentration and deposition from the same combustion unit stack by varying methods or values.

4.1 STACK PARAMETERS

The base case for a typical BIF stack is modeled with a unit emission rate of 1 gram per second (g/s) and the following stack parameters:

PARAMETER	ENGLISH UNITS	METRIC UNITS
Stack Height	60 feet	18.29 meters
Stack Diameter	8 feet	2.44 meters
Stack Gas Temperature	300° Fahrenheit	422.1° Kelvin
Stack Gas Velocity	5.31 feet/second	1.62 meters/sec

The stack is assumed to be above the zone of influence of wake effects by nearby structures. Therefore, no building downwash parameters are included in this sensitivity report.

4.2 MODEL OPTIONS

Model options are specified in the control pathway of the ISCST3 model input file to direct ISCST3 to perform the desired computations. Regulatory default options are invoked in all of the model runs. They consist of:

- Using stack-tip downwash.
- Using buoyancy-induced dispersion.
- Not using final plume rise.
- Using the calms processing routines.
- Using upper-bound concentration estimates for sources influenced by building downwash from super-squat buildings.
- Using default vertical potential temperature gradients.

The "Period" option is used in ISCST3 for all model runs providing 5-year average concentrations and 5-year cumulative dry and wet deposition rates. By specifying "Period" rather than "Annual" in the ISCST3 input deck, deposition rates (especially dry deposition) retain significant digits at greater distances and, therefore, normalized output is more presentable. If the reader would prefer to analyze the dry and wet deposition results in terms of annual average deposition rates, simply divide the cumulative 5-year deposition rates by 5.

The "Rural" dispersion option is utilized in the base case and test cases for all elements for which rural dispersion coefficients are applicable. Rural is chosen over urban because the majority of industrial sites are classified as rural based on the Auer method specified in the Guideline on Air Quality Models (40 CFR Part 51, Appendix W). Concentration, dry deposition, dry depletion, wet deposition, and wet depletion algorithms are selected in accordance with the Protocol.

The flat terrain option is utilized in the base case model runs for all study elements except terrain grid. The base case for the terrain grid is described in Section 5.8.

4.3 METEOROLOGICAL DATA

Meteorological data from the National Weather Service (NWS) station at Houston Intercontinental Airport (IAH) is selected in all base case and test case model runs. Several combustion waste sites requiring SLHHRA's are located in the Houston area. This station also has an anemometer height of 20 feet that is different from the standard 10 meter height of most NWS stations, which makes it a realistic scenario for the anemometer height sensitivity study. PCRAMMET meteorological preprocessor (U.S. EPA 1995a) is used to process raw meteorological data. Parameters specified in processing the meteorological data set for the base case are typical of many "rural" sites within EPA Region 6:

PARAMETER	VALUE	COMMENTS AND REFERENCES
Minimum Monin-Obukhov Length	2 m	Agricultural (Protocol, 3.6)
Anemometer Height	6.1 m	Height of Houston IAH Airport
Surface Roughness (Measurement Site)	0.10 m	Grassland, summer (Protocol, 3.6)
Surface Roughness (Application Site)	0.10 m	Grassland, summer (Protocol, 3.6)
Noon-time Albedo	0.18	Grassland, summer (Protocol, 3.6)
Bowen Ratio	0.7	Grassland, avg. moisture (Protocol, 3.6)
Anthropogenic Heat Flux	0.0 W/m^2	Rural areas (Protocol, 3.6)
Fraction of Net Radiation Absorbed	0.15	Rural areas (Protocol, 3.6)

Five years of meteorological data are merged into one meteorological file for this study to compare the sensitivity of changes in single parameters for 5-year values. Recognizing that the Protocol recommended method requires five separate yearly runs, the sensitivity study results and conclusions are identical using either method.

4.4 RECEPTOR GRID

The base case model runs use a Cartesian receptor grid with 100 meter spacing extending out to 1 kilometer from the source and 250 meter spacing from 1 to 2.5 kilometers. The purpose of the Cartesian grid base case model runs is to determine the directions of maximum impact for concentration, dry deposition, and wet deposition for all subsequent runs.

A set of discrete, linear grid nodes in the direction of maximum impact are then developed for each output type (concentration, dry deposition, and wet deposition). These receptors extend out to 50 kilometers from the source in the direction of maximum impact and are spaced according to guidance given in the Protocol (100 meter spacing out to 1 km, 250 meter spacing from 1 to 2.5 km, 500-meter spacing from 2.5 to 5 km, and 1 km spacing from 5 to 10 km). The base case model runs are then rerun using only the linear set of grid nodes.

4.5 PARTITIONING OF EMISSIONS

COPC emissions to the environment occur in either vapor or particle phase. Some vapor emissions (COPCs with vapor fraction (Fv) value of 1.0) are assumed to remain in vapor phase during dispersion computations in ISCST3. Other COPCs emitted in vapor phase adsorb onto the surface of particulates (Fv between 0.0 and 1.0) referred to as particle-bound phase. The remaining COPCs are emitted in the particle phase (Fv values of 0.0). The ISCST3 model (version 96113) is not designed to estimate vapor phase, particle phase and particle-bound phase concentration and deposition in a single model run. Separate model runs are required for each phase. The particle phase and particle-bound phase runs differ only in the values of mass allocated to the particle size categories. Therefore, a base case model run is performed for each of the phases separately.

4.6 PARTICLE PHASE BASE CASE

The specific inputs to the particle phase base case model run are based on the default particle size distribution provided in Table 3-1 of the Draft SLHHRA Protocol. The table identifies nine categories of particle size with corresponding mean particle diameter, mass fraction, and particle density. A default particle density of 1.0 g/cm^3 is used in the base case model runs.

For purposes of calculating wet deposition during precipitation both a liquid and frozen (ice) scavenging coefficient is input for each particle size category. The liquid scavenging coefficients are based on work of Jindal and Heinhold (I 991) presented in the ISC3 User's Guide (U.S. EPA 1995b). The frozen (ice) scavenging coefficients are assumed to be one-third of the liquid scavenging coefficients as recommended in the Protocol. Concentration, dry deposition, dry depletion, wet deposition, and wet depletion algorithms are all invoked in the particle phase model runs. The particle phase model inputs are summarized below:

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
Mass Fraction	.224	.076	.082	.105	.103	.073	.104	.105	.128
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

4.7 PARTICLE-BOUND PHASE BASE CASE

The specific inputs to the particle-bound phase base case model run are also based on the default particle size distribution provided in Table 3-1 of the Draft SLHHRA Protocol. They consist of nine categories of particle sizes, and within each category is a specified mean particle diameter, surface-area (SA) weighted fraction, and particle density. As with the particle phase base case, the frozen scavenging coefficients are assumed to be one-third of the liquid scavenging coefficients. Concentration, dry deposition, dry depletion, wet deposition, and wet depletion algorithms were all invoked in the particle-bound phase model runs. The particle-bound phase model inputs are summarized below:

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
SA Fraction	.488	.1656	.1290	.0915	.0499	.0231	.0224	.0146	.0149
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

4.8 VAPOR PHASE BASE CASE

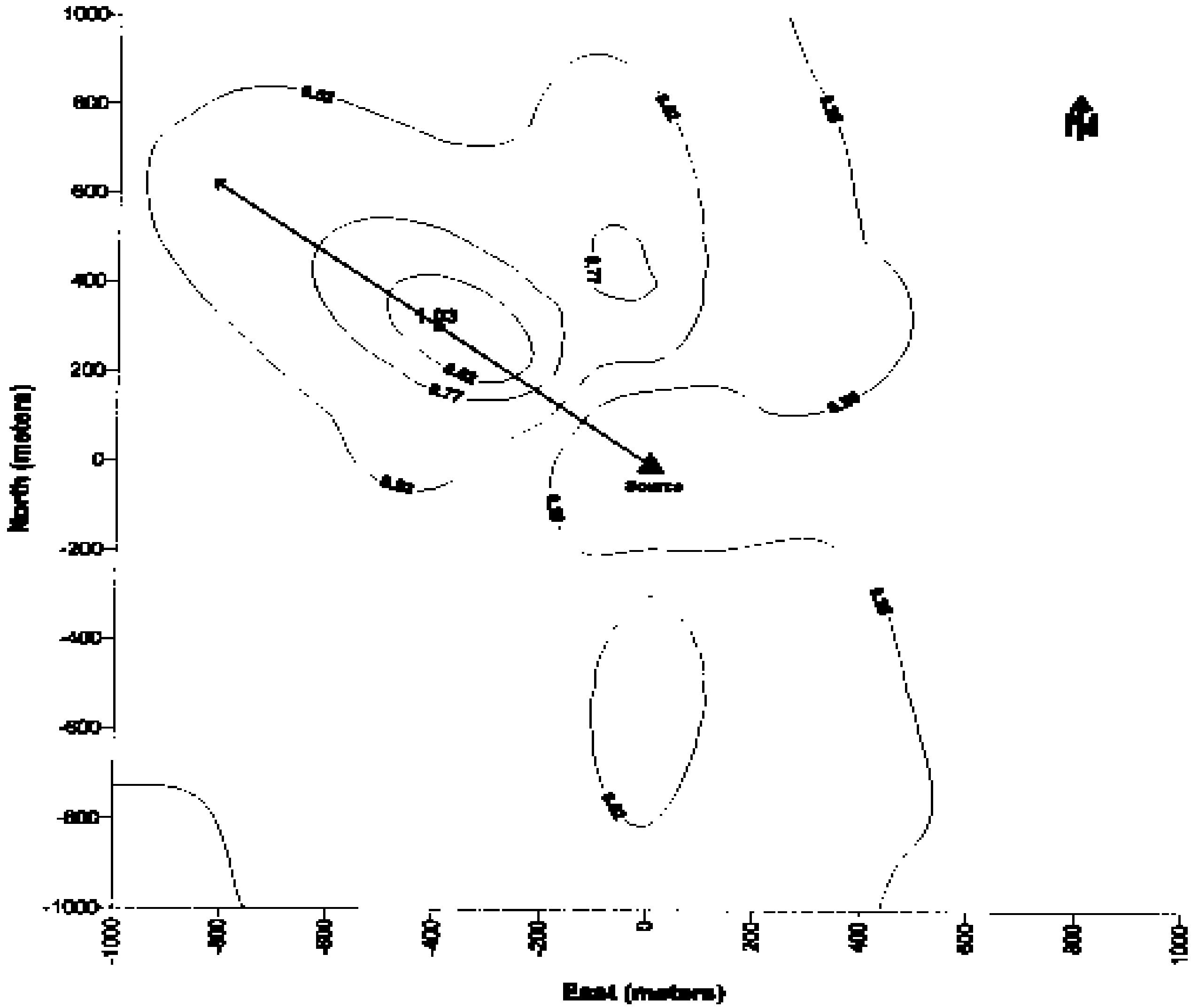
The vapor phase-specific inputs consist of gas scavenging coefficients only, since particle size distribution and density are not applicable to the vapor phase. Liquid and frozen gas scavenging coefficients for a 0.1 micron particle were utilized for the vapor phase modeling, as recommended in Section 3.7.2.6 the Draft SLHHRA Protocol. From the Jindal and Heinhold graph in the ISC3 User's Guide, the liquid scavenging coefficient for a 0.1 micron particle is 0.00017. For the base case runs, the frozen, or ice, scavenging coefficient is assumed to be one-third of that value, or 0.00006. The dry gas deposition algorithms in ISCST3 requires data that is currently not available for most SLHHRA COPCS. Therefore, only concentration, wet deposition, and wet depletion algorithms were invoked in ISCST3 for the vapor phase.

4.9 BASE CASE RESULTS

The results of the base case model runs are presented graphically in the figures at the end of this section with the direction of maximum impact identified for each type of output. The directions of maximum impact for concentration, dry deposition, and wet deposition are 307, 303, and 180 degrees, respectively. The base case model runs are then rerun using only these linear sets of grid nodes. The results of the linear grid base case model runs are presented in the sections describing the sensitivity analyses for the individual elements since these are the results used for comparison with alternative methods or values.

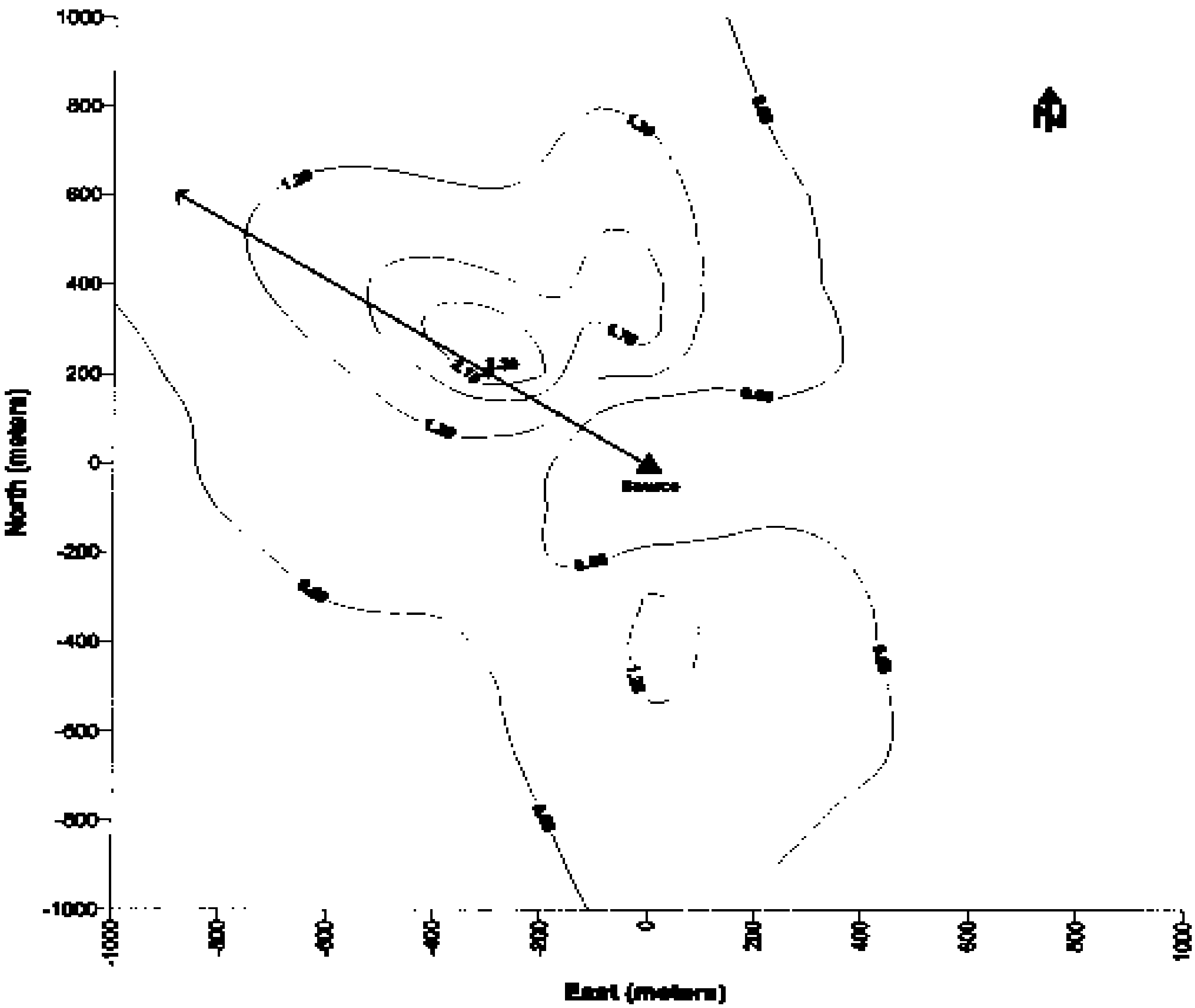
The modeling methodology for most of the priority and secondary elements is to modify the linear base case model runs to observe the effect of varying the inputs related to the elements. For a few elements (watershed size, watershed proximity, and polar versus Cartesian grid), the streamlined linear approach is not appropriate because two-dimensional spatial resolution is a necessary feature of the analysis. For other elements, including minimum Monin-Obukhov length, anthropogenic heat flux, and net radiation at ground level, a linear base case is appropriate but the use of rural dispersion coefficients is either not desirable or not applicable. Therefore, for these studies, element-specific base cases are developed. These base case model runs are discussed in the sections pertaining to these particular elements.

PARTICLE PHASE BASE CASE
5-YEAR AVERAGE CONCENTRATION
ug/m3/g/s



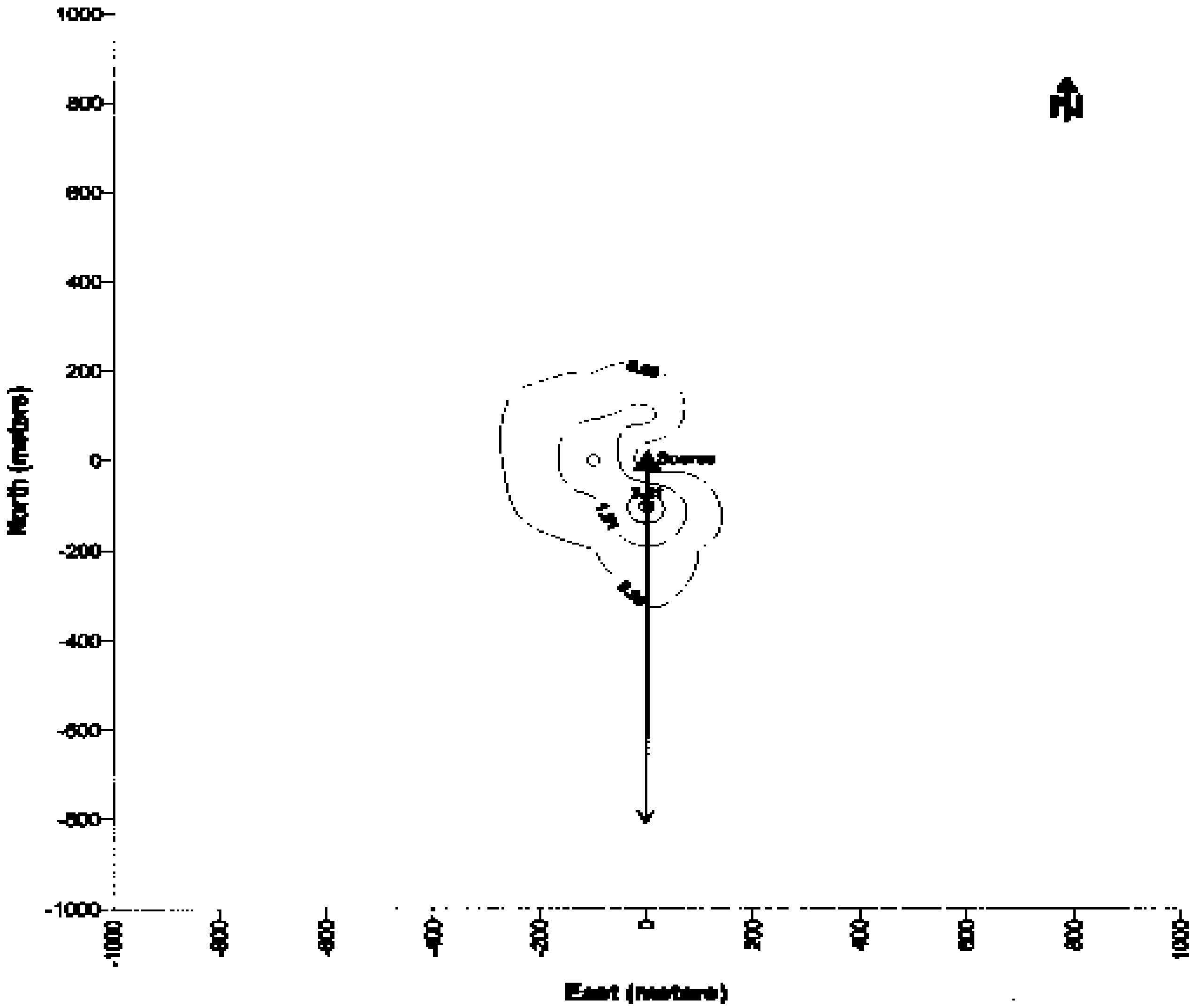
Notes:
Arrow depicts direction of maximum concentration
Isopleths represent 90%, 75%, 50%, and 25% of maximum concentration
Square indicates the location of maximum concentration
Triangle indicates source location

PARTICLE PHASE BASE CASE
5-YEAR CUMULATIVE DRY DEPOSITION
g/m2/g/s



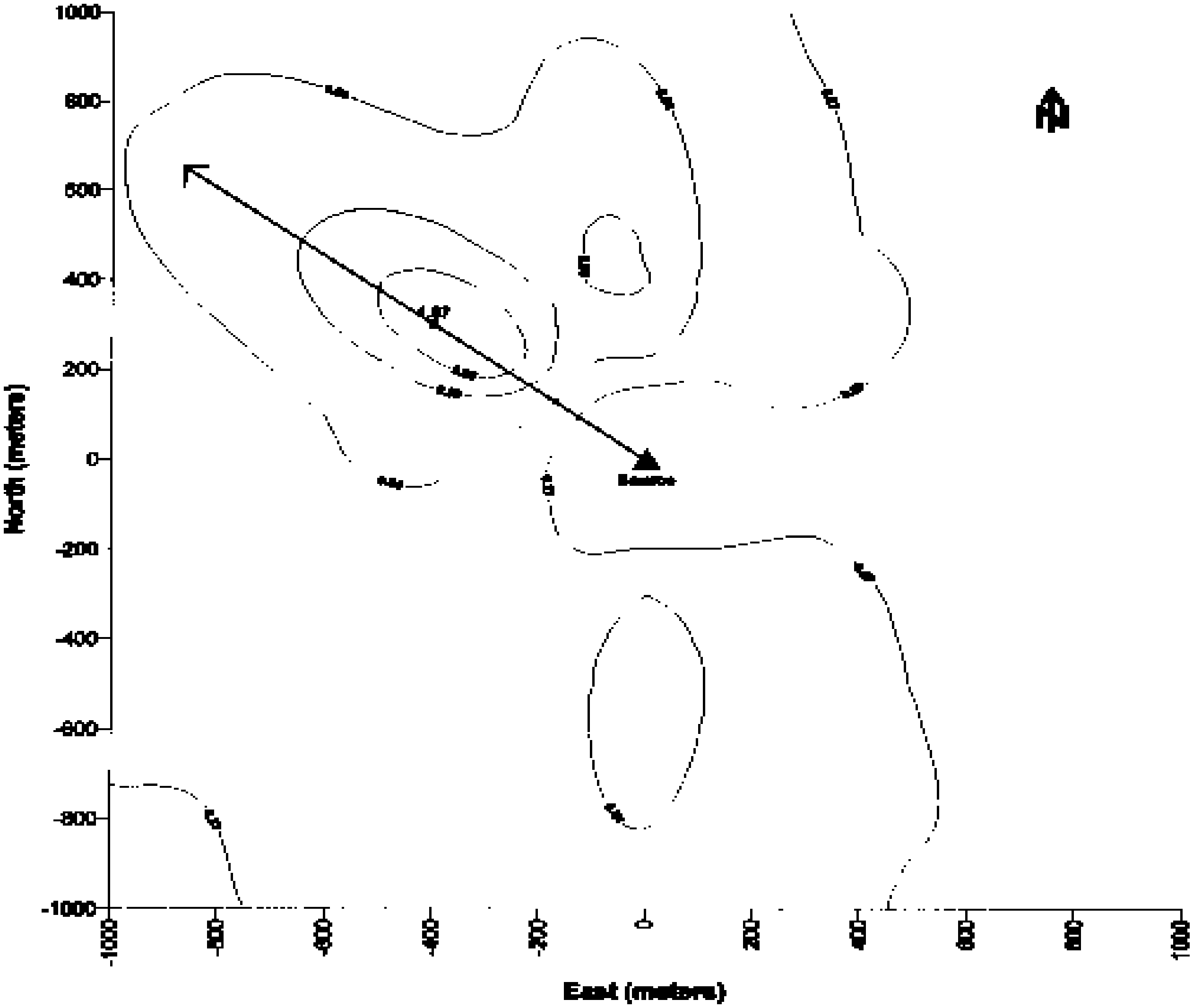
Note:
Arrow depicts direction of maximum dry deposition
Isopleths represent 90%, 75%, 50% and 25% of maximum dry deposition
Square indicates the location of maximum dry deposition
Triangle indicates source location

PARTICLE PHASE BASE CASE
5-YEAR CUMULATIVE WET DEPOSITION
g/m2/g/s



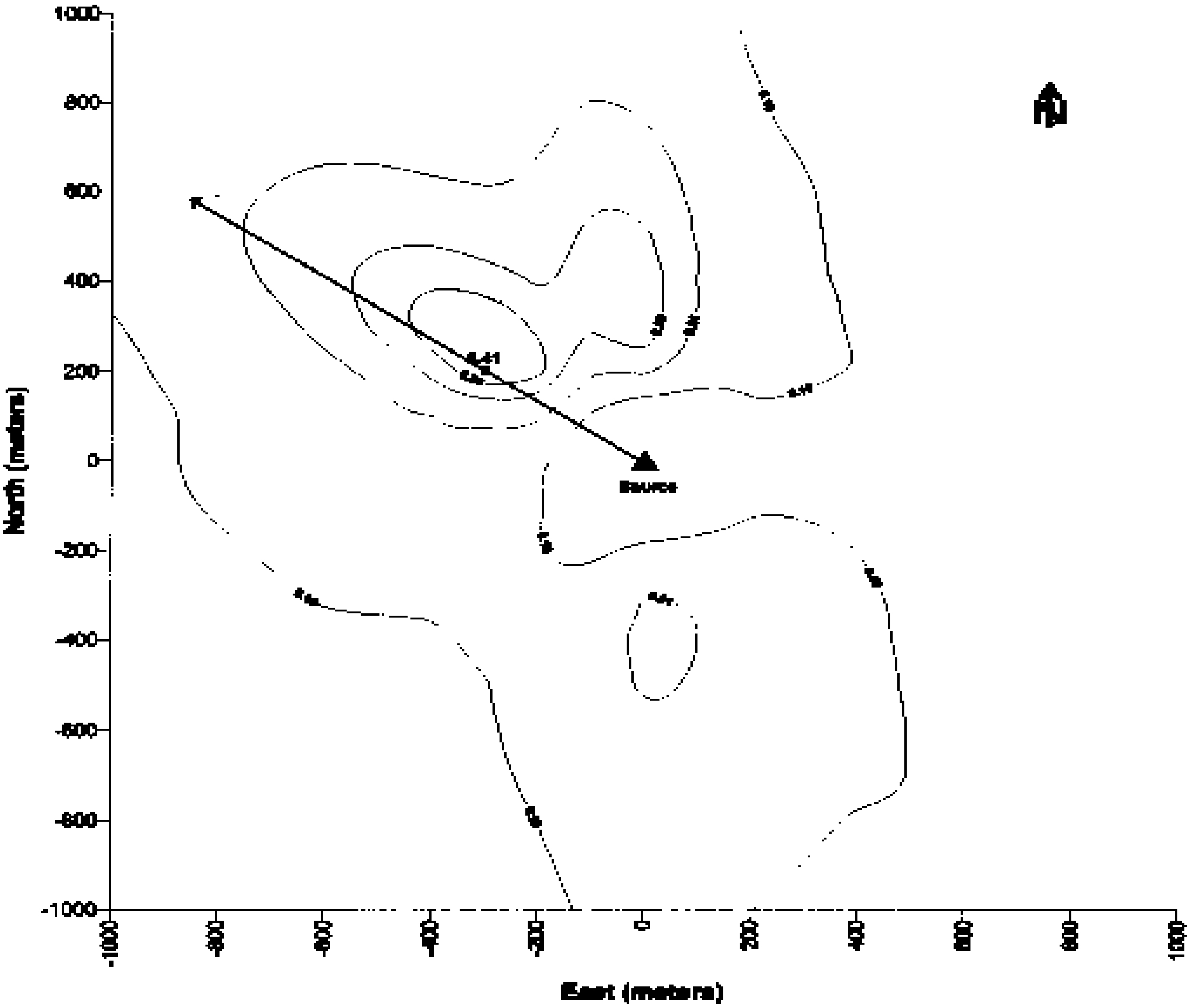
Notes:
Arrow depicts direction of maximum wet deposition
Isopleths represent 90%, 75%, 50% and 25% of maximum wet deposition
Square indicates location of maximum wet deposition
Triangle indicates source location

PARTICLE BOUND PHASE BASE CASE
5 YEAR AVERAGE CONCENTRATION
ug/m3/g/s

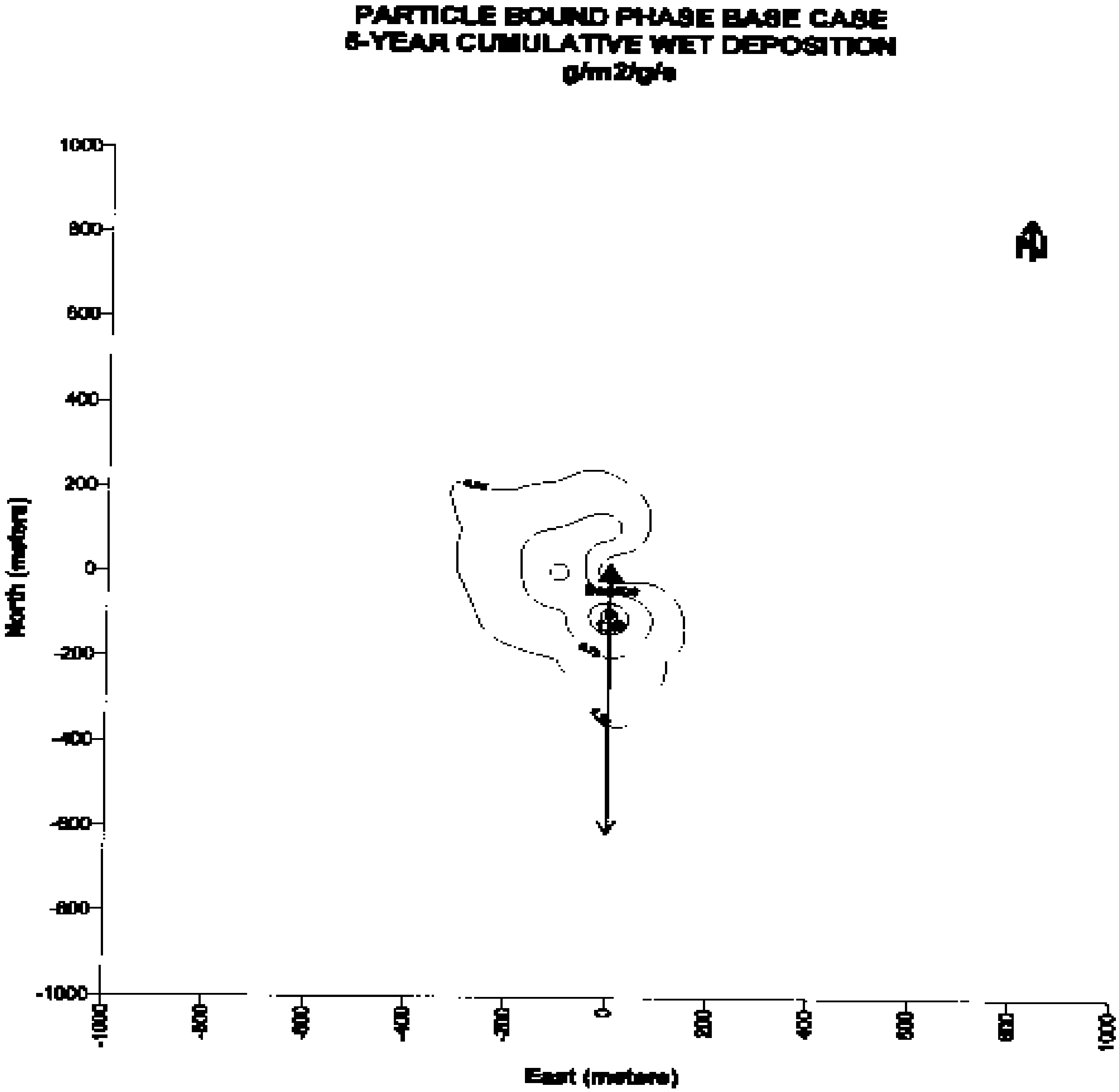


Notes:
Arrow depicts the direction of maximum concentration
Isopleths represent 90%, 75%, 50% and 25% of maximum concentration
Square indicates location of maximum concentration
Triangle indicates source location

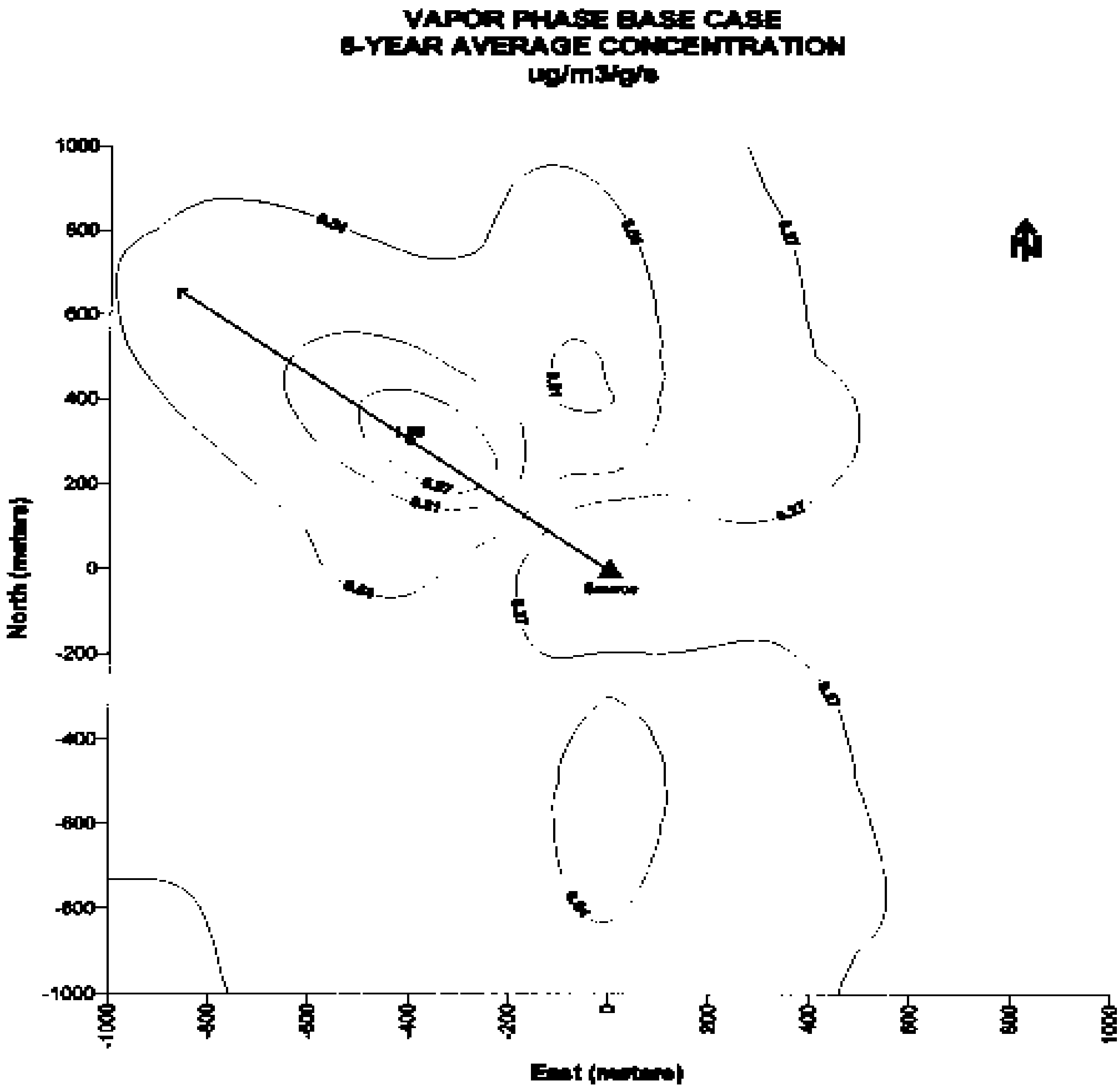
PARTICLE BOUND PHASE BASE CASE
5-YEAR CUMULATIVE DRY DEPOSITION
g/m2/g/s



Notes:
Arrow depicts the direction of maximum dry deposition
Isopleths indicate 90%, 75%, 50% and 25% of maximum dry deposition
Square indicates location of maximum dry deposition
Triangle depicts location of source

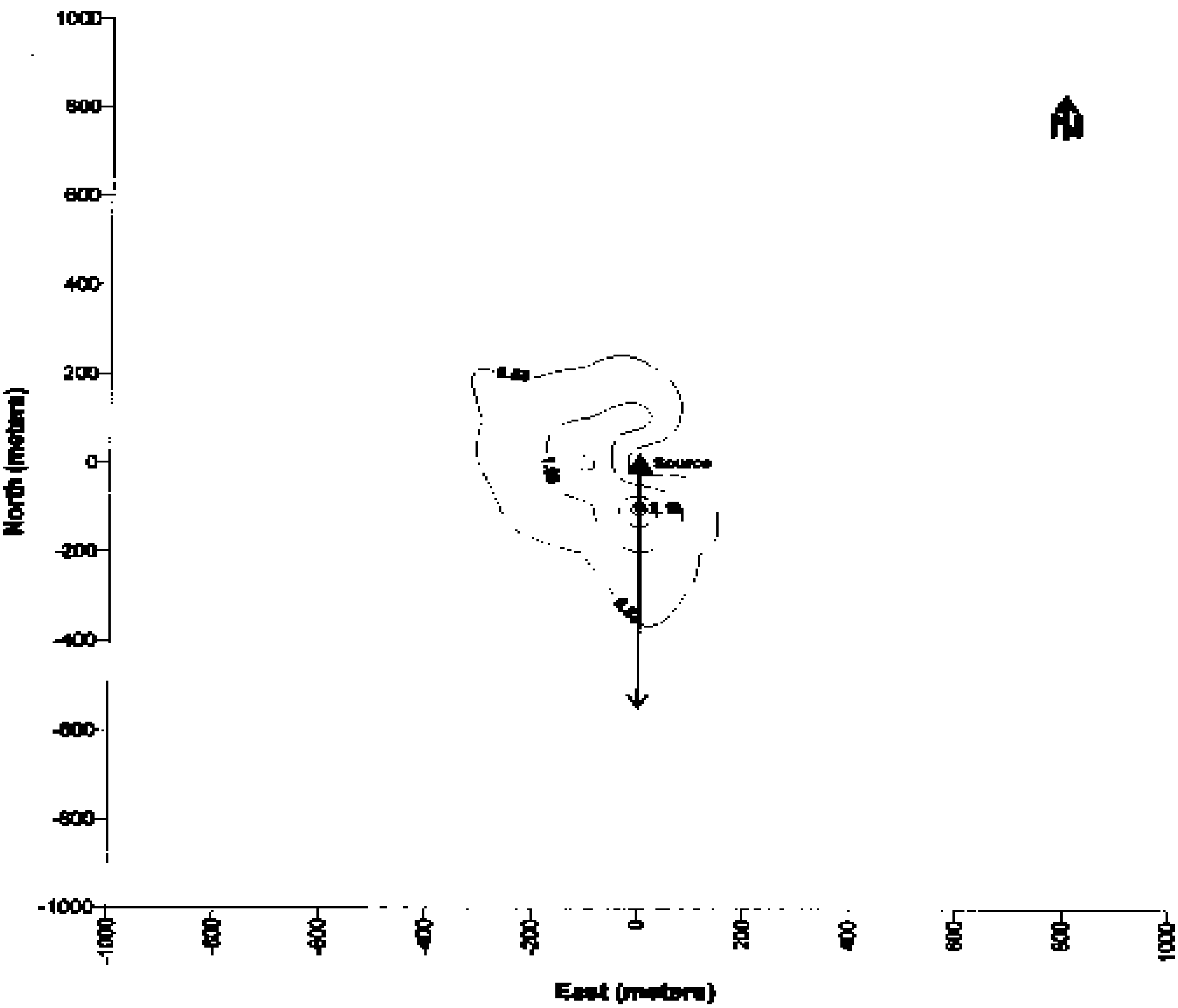


Notes:
Arrow depicts the direction of maximum wet deposition
Isopleths represent 90%, 75%, 50% and 25% of maximum wet deposition
Square indicates location of maximum wet deposition
Triangle indicates source location



Notes:
Arrow depicts direction of maximum concentration
Isopleths represent 90%, 75%, 50% and 25% of maximum concentration
Square indicates location of maximum concentration
Triangle indicates source location

VAPOR PHASE BASE CASE
5-YEAR CUMULATIVE WET DEPOSITION
g/m2/g/s



Notes:
Arrow depicts direction of maximum wet deposition
Isopleths represent 90%, 75%, 50% and 25% of maximum wet deposition
Square indicates location of maximum wet deposition
Triangle indicates source location

5. PRIORITY ELEMENTS STUDIES

5.1 ELEVATED VERSUS FLAT TERRAIN

5. 1.1 TECHNICAL OBJECTIVE

The primary objective of the elevated versus flat terrain element study is to determine what terrain elevations, if any, may be ignored without underestimating modeled impacts.

5.1.2 THEORETICAL BASIS

The ISCST3 model was developed to allow for any terrain elevation relative to stack base elevation. Terrain elevation is explicit in ISCST3 as the elevation of a grid node (referred to in ISCST3 as a 'receptor' elevation). The elevation of the receptor is subtracted from the height of the emitted COPC plume centerline to adjust the centerline down towards the ground. With plume centerline closer to the ground the dispersion equations compute higher ground-level concentrations and deposition rates. The dispersion curves are distributed normal (Gaussian) vertically and horizontally from plume centerline. With over 90% of plume mass within two standard deviations of centerline, a reasonable assumption for not including terrain elevations less than 10% of stack height may be appropriate. Similarly, it may be reasonable to ignore terrain elevations as much as 25% of stack height for high temperature plumes having plume rise above stack base tens to hundreds of meters.

5.1.3 METHODOLOGY

5.1.3.1 BASE CASE - FLAT TERRAIN METHOD

The base case model runs of concentration and deposition for particle, particle-bound, and vapor phases described in Section 4 are used for this analysis. The base case includes Protocol recommended methods and values, rural meteorology and dispersion coefficients, and a linear receptor grid in the direction of maximum impact with flat terrain option.

5.1.3.2 TEST CASE I - RECEPTOR ELEVATIONS AT 10% OF STACK HEIGHT

Test Case I is identical to the base case, except the elevated terrain heights option is invoked in ISCST3 and each receptor node in the linear receptor grid is assigned an elevation equal to 10% of the BIF stack height (60 feet x 0.10 = 6 feet).

5.1.3.3 TEST CASE 2 - RECEPTOR ELEVATIONS AT 25% OF STACK HEIGHT

Test Case 2 is identical to the base case, except the elevated terrain heights option is invoked in ISCST3 and each receptor node in the linear receptor grid is assigned an elevation equal to 25% of the BIF stack height (60 feet x 0.25 = 15 feet).

5.1.4 RESULTS

5.1.4.1 CONCENTRATION

The results of the elevated versus flat terrain sensitivity analysis of concentration are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized concentrations for the base case and both test cases.

For all phases (particle, particle-bound, and vapor), relative differences between the base case and the test cases are large close to the source. For example, at 100 meters from the source, concentrations for Test Case I (receptor elevations at 10% of stack height) and Test Case 2 (receptor elevations at 25% of stack height) are 1.9 and 4.8 times the base case concentration, respectively. The differences drop off significantly as distance from the source increases. At 600 meters from the source, Test Case I concentration is only 10% larger than the base case. At 1.7 kilometers, Test Case 2 concentration is only 10% larger than the base case. The differences continue to decrease with distance, and at 50 kilometers, the base case and test case results are virtually the same.

5.1.4.2 DRY DEPOSITION

The results of the elevated versus flat terrain sensitivity analysis of dry deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized dry deposition for the base case and both test cases.

For all phases (particle, particle-bound, and vapor), the results follow the same progression as for concentration. Relatively large differences occur close to the source with relative differences decreasing significantly with distance. For example, at 100 meters from the source dry deposition for Test Case 1 (receptor elevations at 10% of stack height) and Test Case 2 (receptor elevations at 25% of stack height) are 2.0 and 5.7 times the base case dry deposition at that same distance. At 550 meters from the source, Test Case 1 dry deposition is only 10% larger than the base case. At 1.0 kilometers, Test Case 2 dry deposition is only 10% larger than the base case. The differences continue to decrease with distance until at 50 kilometers the base case and test case results are virtually the same.

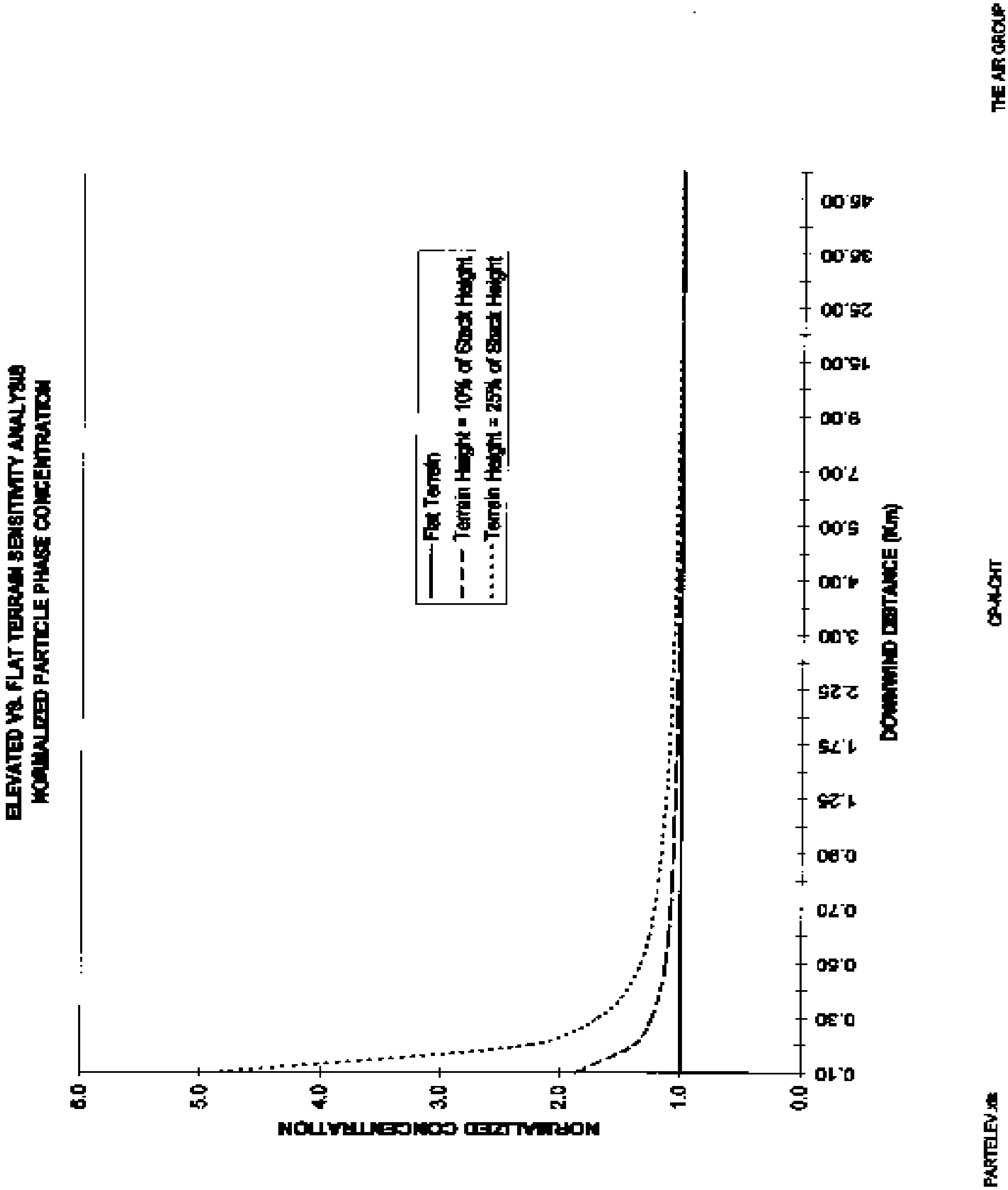
5.1.4.3 WET DEPOSITION

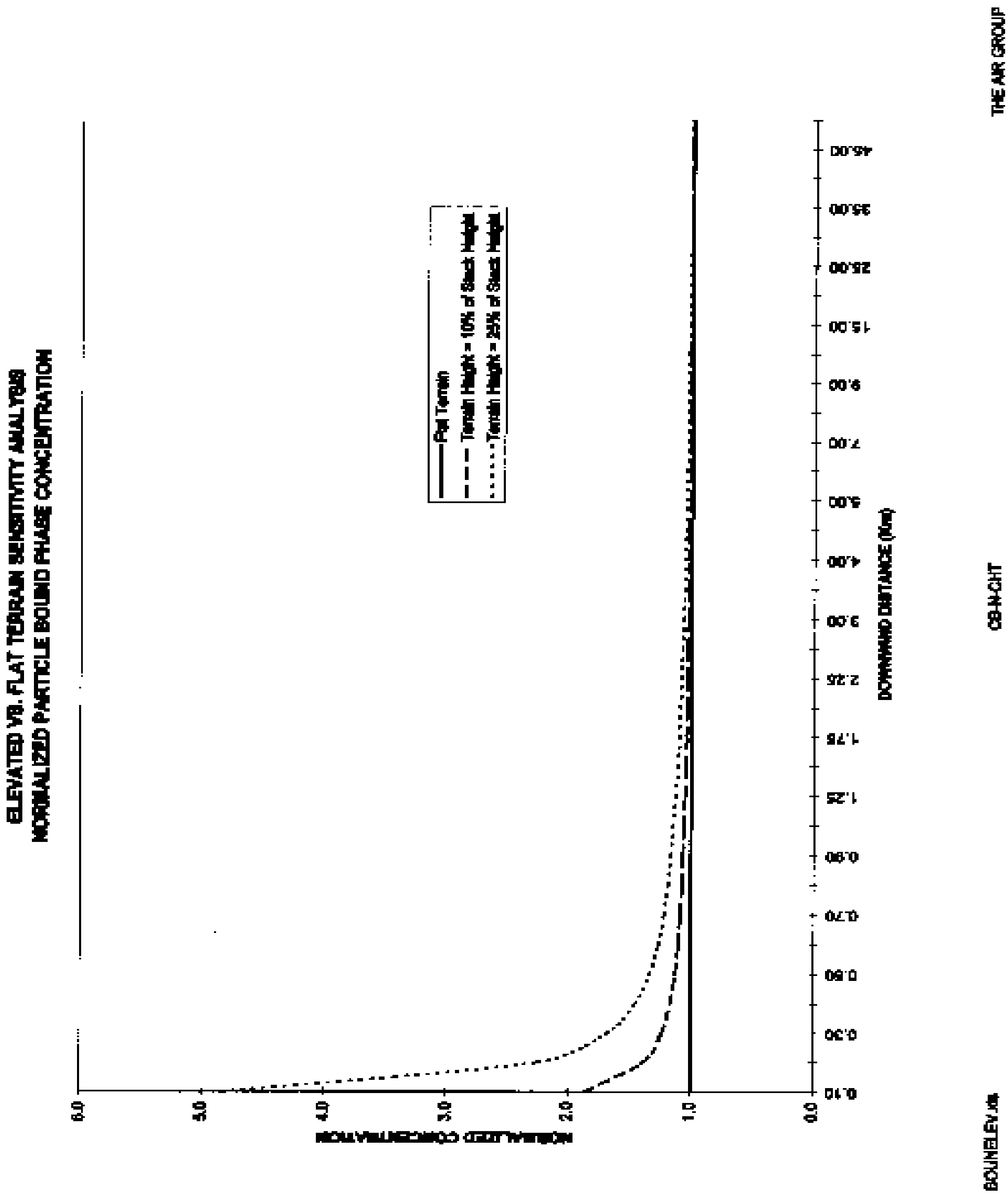
The results of the elevated versus flat terrain sensitivity analysis of wet deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized wet deposition for the base case and both test cases.

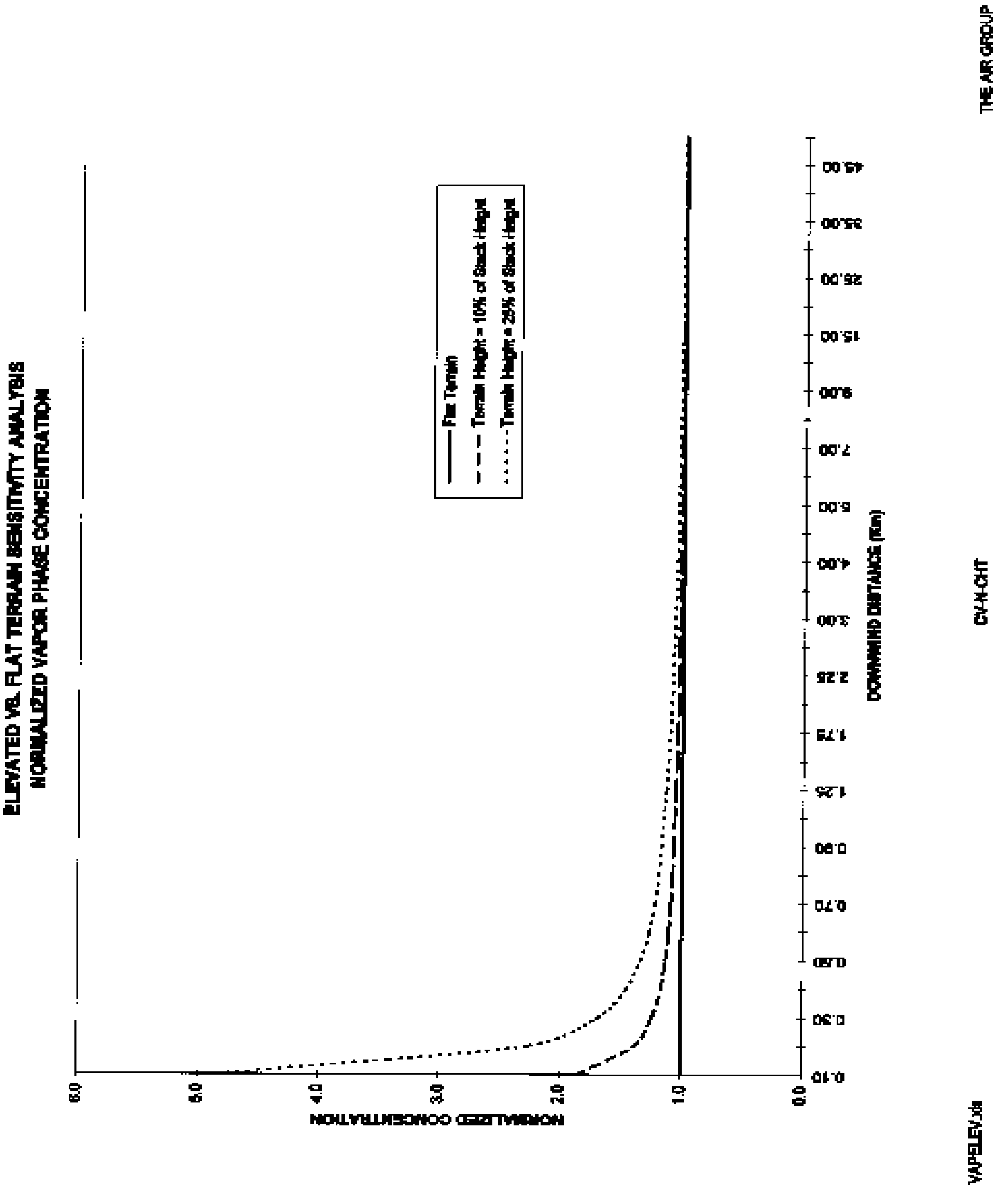
The results indicate that elevated terrain has no effect on wet deposition rates.

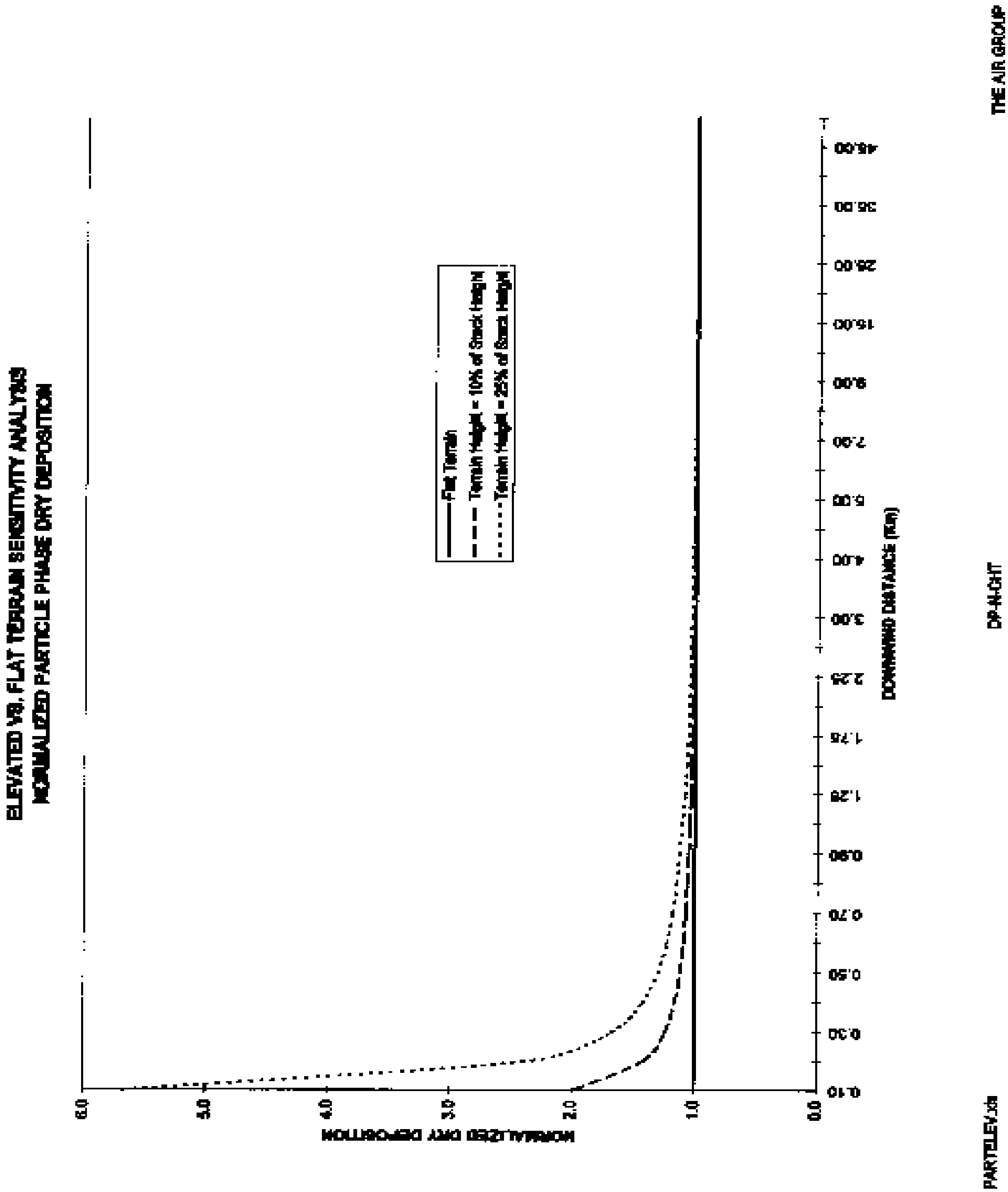
5.1.5 RECOMMENDATIONS

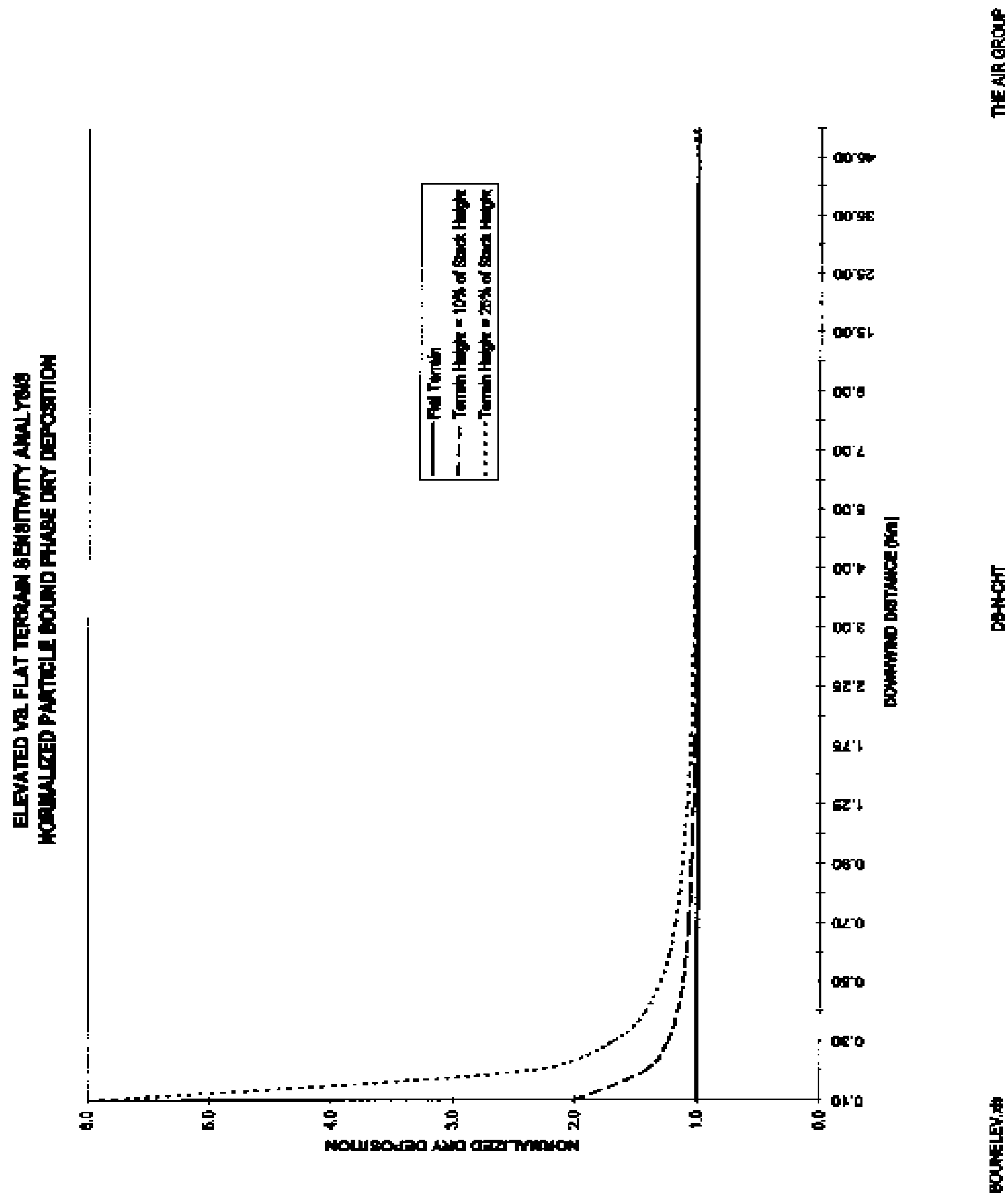
Based on the results of the elevated versus flat terrain analysis it is clear that elevated terrain cannot be ignored if it exists close to the sources being evaluated. At distances greater than 1 kilometer relative differences become more tolerable (less than 15%). Therefore, Section 3.2.1 of the Draft SLHHRA Protocol should at a minimum be modified to warn the modeler that concentration and dry deposition could be significantly underestimated close to the source (within 1 kilometer) by neglecting even relatively small terrain elevations above stack base. The current Protocol recommendation to always include any terrain is undisputed inside 1 kilometer from the source. Beyond I kilometer, terrain elevations less than 25% of stack height may be ignored with underestimates of concentration and dry deposition of 15% or less.

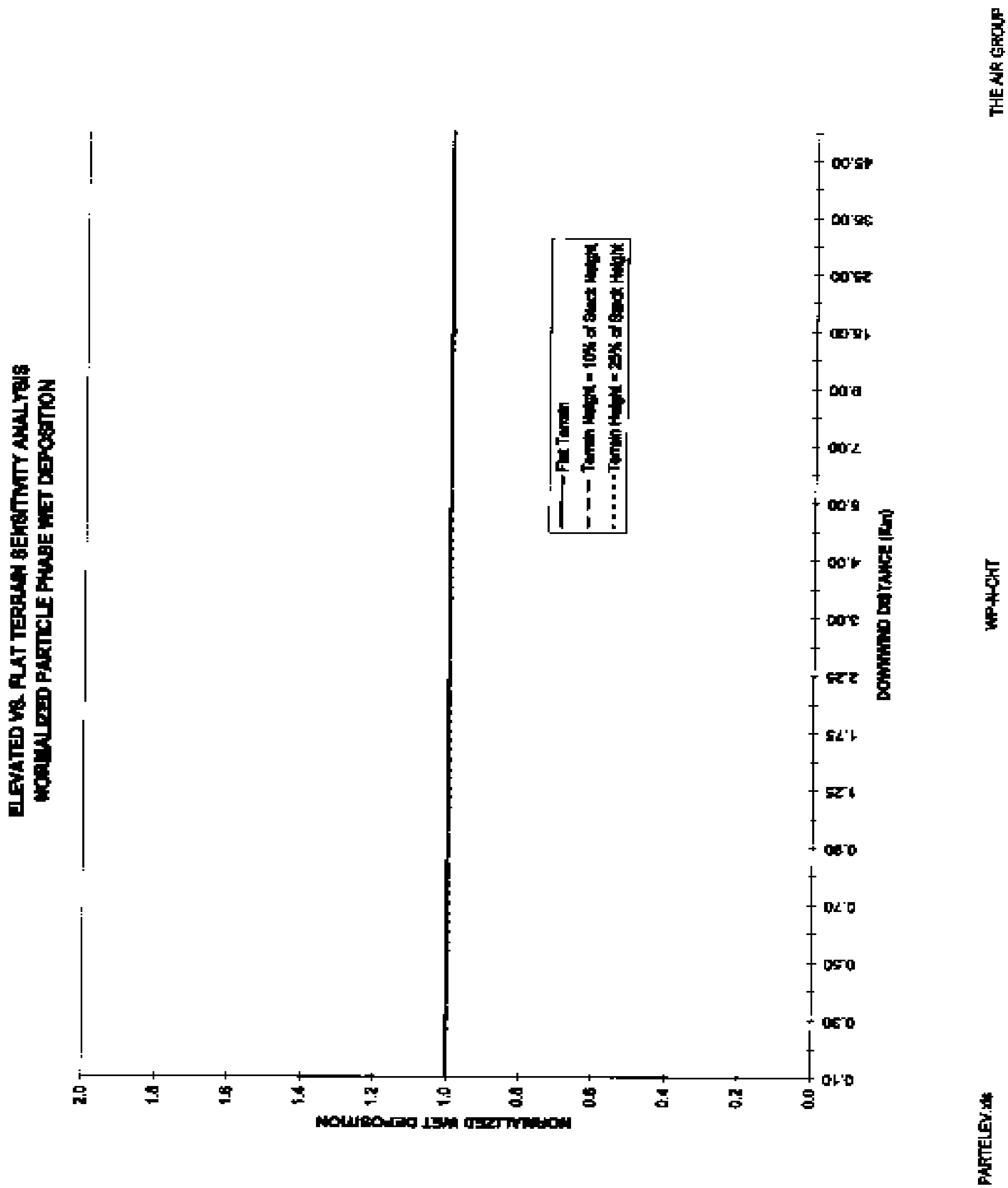

ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
CP-N-CHT
PARTELEV.xls

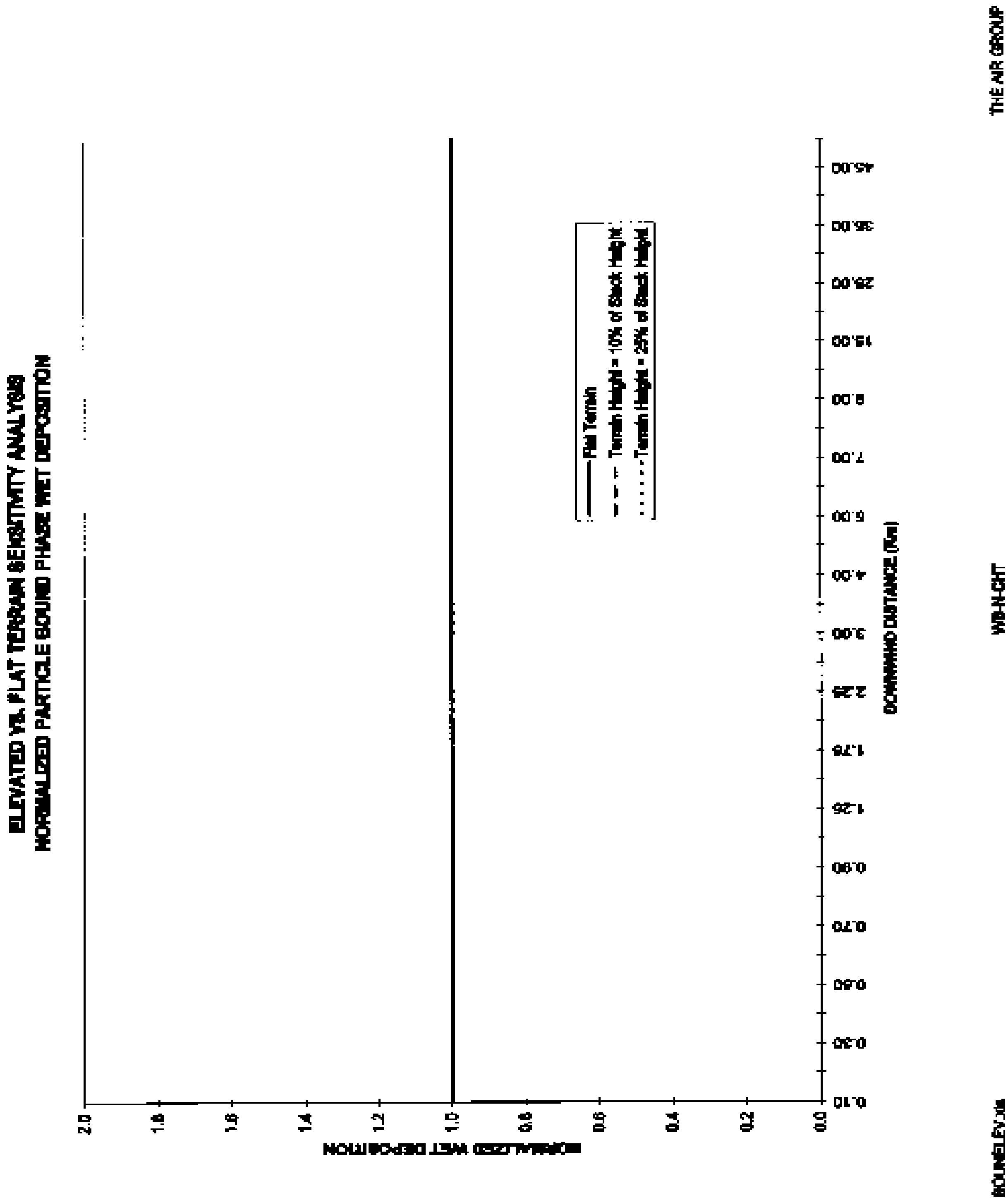

ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED CONCENTRATION
0.0
1.0
2.0
3.0
4.0
5.0
6.0
DOWNWIND DISTANCE (km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
CB-N-CHT
BOUNELEV.xls

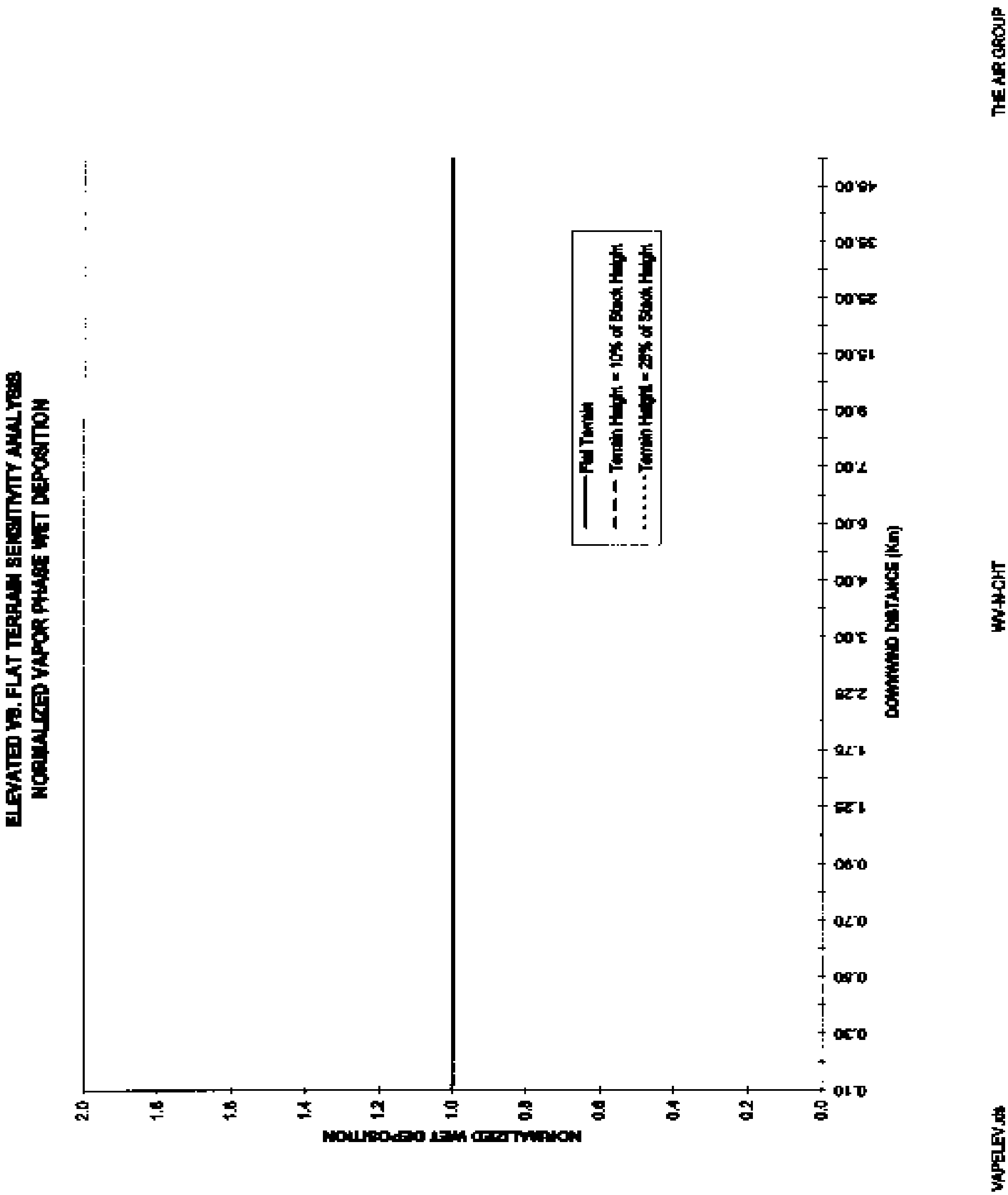

ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED CONCENTRATION
0.0
1.0
2.0
3.0
4.0
5.0
6.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
CV-N-CHT
VAPELEV.xls


ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED DRY DEPOSITION
0.0
1.0
2.0
3.0
4.0
5.0
6.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
DP-N-CHT
PARTELEV.xls


ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED DRY DEPOSITION
0.0
1.0
2.0
3.0
4.0
5.0
6.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP


ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
PARTELEV.xls


ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WB-N-CHT
SOLINELEV.xls



ELEVATED VS. FLAT TERRAIN SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Flat Terrain
Terrain Height = 10% of Stack Height
Terrain Height = 25% of Stack Height
NORMALIZED WET DEPOSITION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
THE AIR GROUP
HW-N-CHT
VAPELEV.xls

5.2 URBAN VERSUS RURAL

5.2.1 TECHNICAL OBJECTIVE

The primary objective of the urban versus rural sensitivity analysis is to determine whether a modeling analysis incorrectly performed using urban dispersion coefficients and assumptions in PCRAMMET and ISCST3 must be remodeled for rural parameters.

5.2.2 THEORETICAL BASIS

The urban or rural specification impacts several modeling algorithms. When preprocessing meteorological data, input parameters to PCRAMMET are specified according to urban or rural land use. The Guideline on Air Quality Models recommends Auer's method classifying land use within 3 kilometers according to vegetation, structures or population density. Urban locations have more available sensible heat from solar surface heating and anthropogenic combustion sources that destabilize the surface layer of air causing mixing of the COPC plume gases to the ground close to the source. The layer of surface air is further destabilized by mechanical turbulence from buildings and structures and lack of surface water for cooling or latent heat storage. These destabilizing factors in urban environments are reflected explicitly in the calculation of Monin-Obukhov length (L), surface roughness length at the application site, and friction velocity. These three parameters computed by PCRAMMET are read into ISCST3 to drive the computation of dry deposition rates. Concentrations and dry deposition are affected by urban designation in the ISCST3 use of the McElroy-Pooler adjustment to the dispersion coefficients, modification to the plume rise equations, and utilization of the urban mixing heights from PCRAMMET computed heights.

5.2.3 METHODOLOGY

5.2.3.1 BASE CASE - RURAL METEOROLOGY AND DISPERSION

The base case model runs described in Section 4 are used as the base case for this analysis. The base case includes Protocol recommended methods and values, rural meteorology and dispersion coefficients, and a linear receptor grid in the direction of maximum impacts with flat terrain.

5.2.3.2 TEST CASE I - URBAN METEOROLOGY AND DISPERSION

Test Case 1 is identical to the base case model runs, except the dispersion option is changed to urban and the Houston meteorological data is reprocessed with typical "urban" parameters, rather than typical "rural" parameters, as follows:

PARAMETER	VALUE	COMMENTS AND REFERENCES
Minimum Monin-Obukhov Length	50 m	Compact Residential, Industrial (Protocol, 3.6)
Anemometer Height	6.1 m	Houston IAH NWS station
Surface Roughness at Measurement Site	0.10 m	Grassland, summer (Protocol, 3.6)
Surface Roughness at Application Site	1.0 m	Urban areas (Protocol, 3.6)
Noon-time Albedo	0.16	Urban, summer (Protocol, 3.6)
Bowen Ratio	2.0	Urban, avg. moisture (Protocol, 3.6)
Anthropogenic Heat Flux	20 W/m^2	Southern urban city (Protocol, 3.6)
Fraction of Net Radiation Absorbed	0.27	Urban areas (Protocol, 3.6)

5.2.4 RESULTS

5.2.4.1 CONCENTRATION

The results of the urban versus rural sensitivity analysis of concentration are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized concentrations for the base case and both test cases.

For all phases (particle, particle-bound, and vapor), the urban concentrations are much larger than the rural concentrations close to the source, with the differences dropping off dramatically as distance from the source increases. For example: at 100, 200, and 300 meters from the source, concentrations for the urban case are greater than the rural case be a factor of 1 17, 5.5, and 2.0, respectively. At 400 meters from the source, the urban concentration is equal to the rural concentration. As distance increases beyond 400 meters, the urban values drop below the rural values and gradually decrease to a minimum of approximately 32% of rural at about 10 kilometers from the source. The urban concentrations then increase relative to rural values to a value of 37% of rural concentration at a distance of 50 kilometers.

5.2.4.2 DRY DEPOSITION

The results of the urban versus rural sensitivity analysis of dry deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized dry deposition for the base case and both test cases.

For both applicable phases (particle and particle-bound), the results follow the same progression as for concentration, urban dry deposition is significantly higher than rural close to the source, with relative differences decreasing significantly with distance. For example: at 100, 200, and 300 meters from the source, concentrations for the urban case are greater than the rural case be a factor of 375, 9.5, and 3.3, respectively. At 800 meters from the source, the urban dry deposition is equal to the rural dry deposition. As distance increases beyond 800 meters, the urban values drop below the rural values and gradually decrease to a minimum of approximately 69% of rural at about 3 kilometers from the source. The urban dry depositions then increase relative to rural values and begin to exceed rural dry deposition again at distance of 20 kilometers, reaching a concentration of 1.34 times the rural concentration at 50 kilometers from the source.

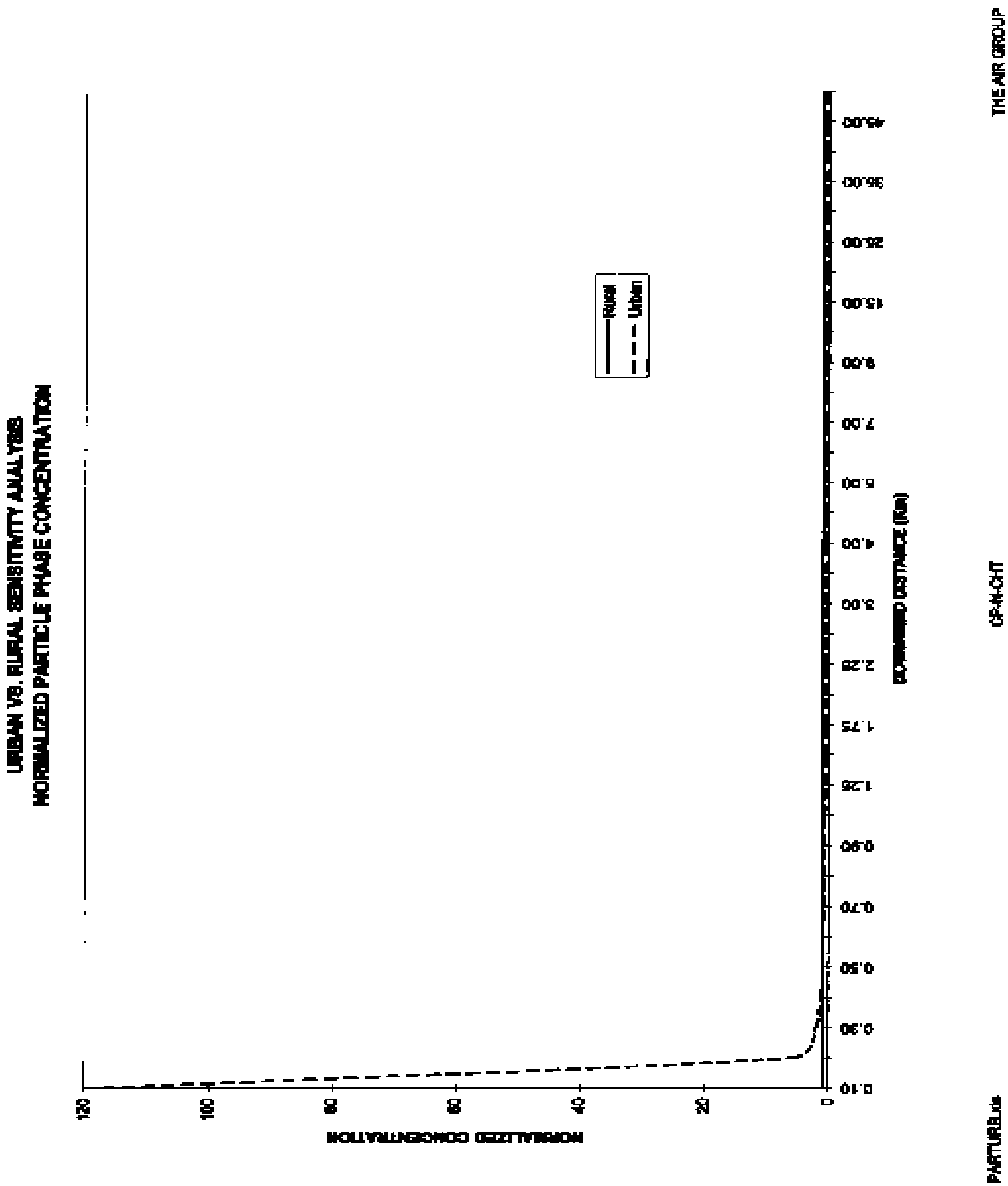
5.2.4.3 WET DEPOSITION

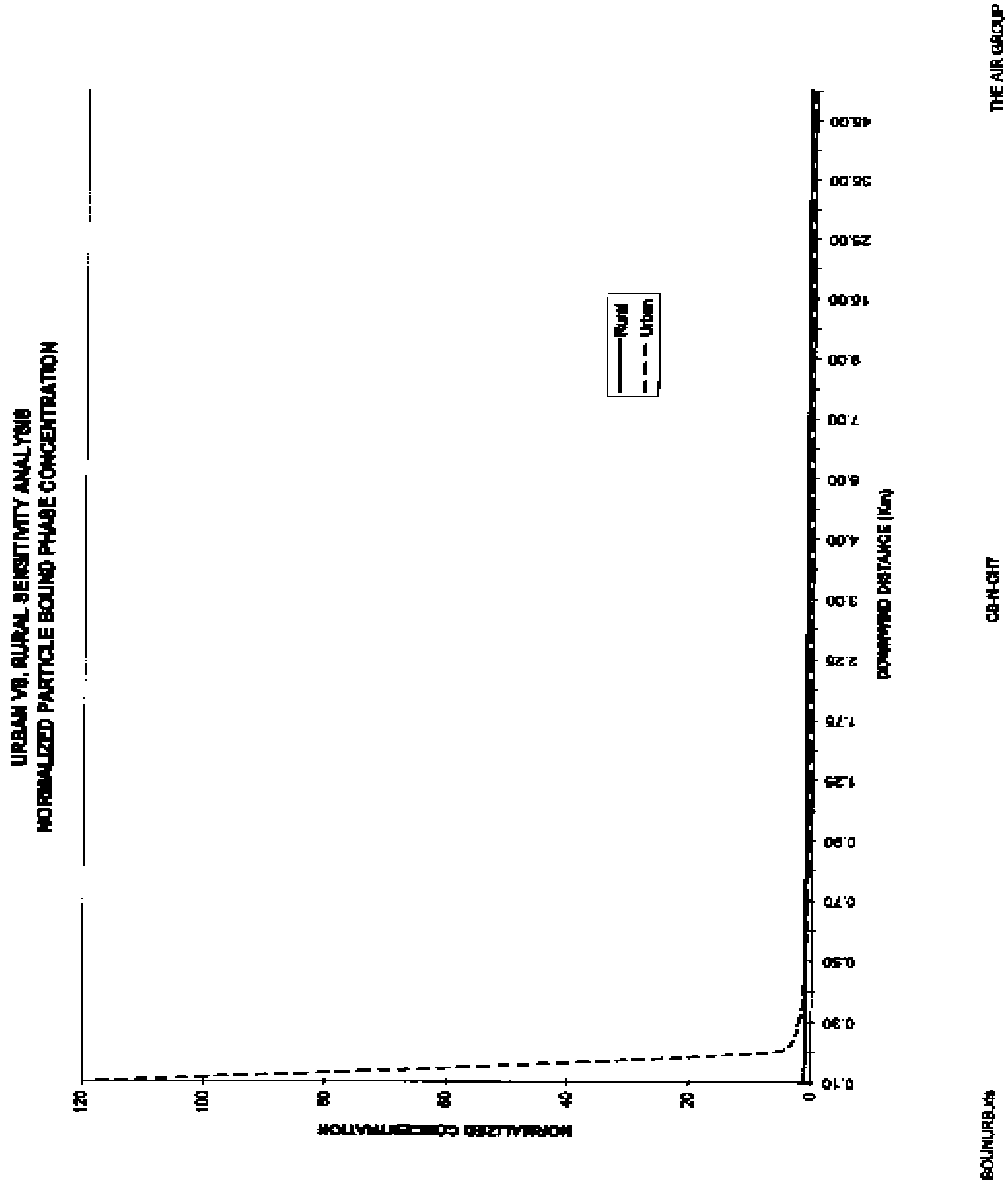
The results of the urban versus rural sensitivity analysis of wet deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized wet deposition for the base case and both test cases.

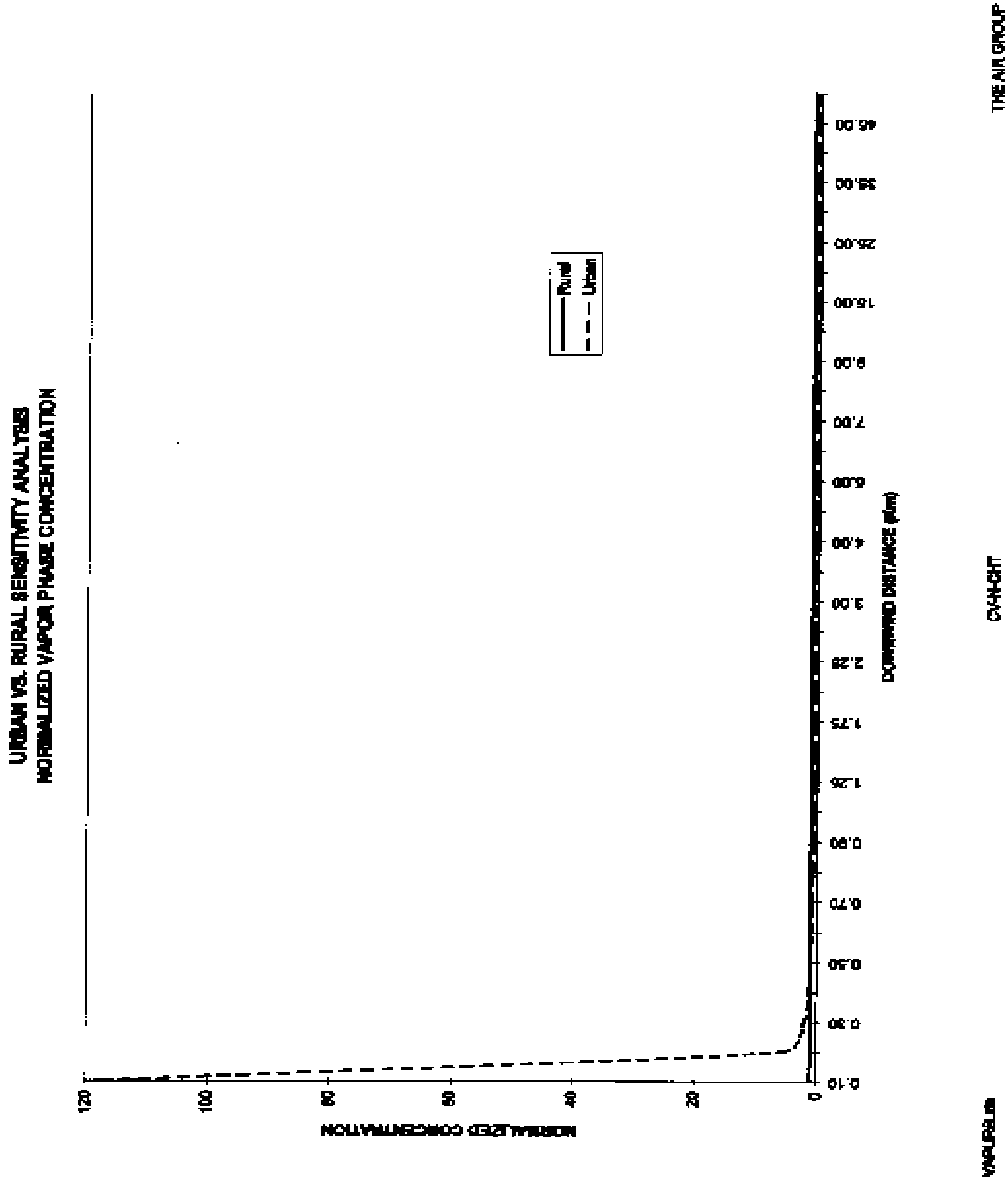
Close to the source, urban wet deposition rates are approximately 20% lower than rural wet deposition rates. As distance increases, urban wet deposition rates gradually increase relative to rural and begin to exceed rural wet deposition rates at approximately 5 kilometers. Urban continues to increase relative to rural until approximately 15 kilometers from the source, where it reaches a maximum normalized wet deposition of between 1.02 and 1.05, depending on the emission phase . Urban values then decrease to below rural values again at approximately 25 kilometers from the source. At 50 kilometers, the urban values range from 88% to 94% of the rural case, depending on the phase.

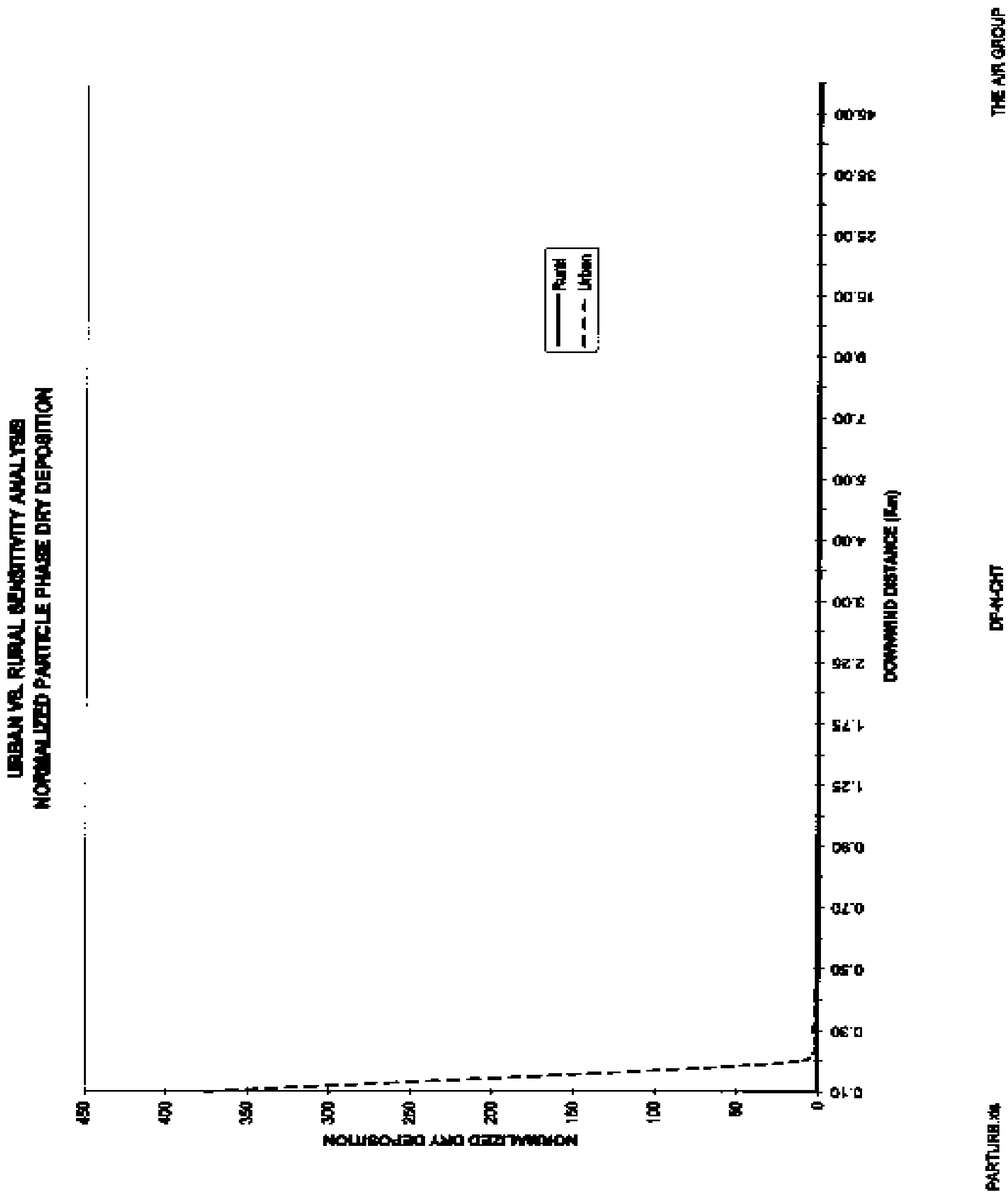
5.2.5 RECOMMENDATIONS

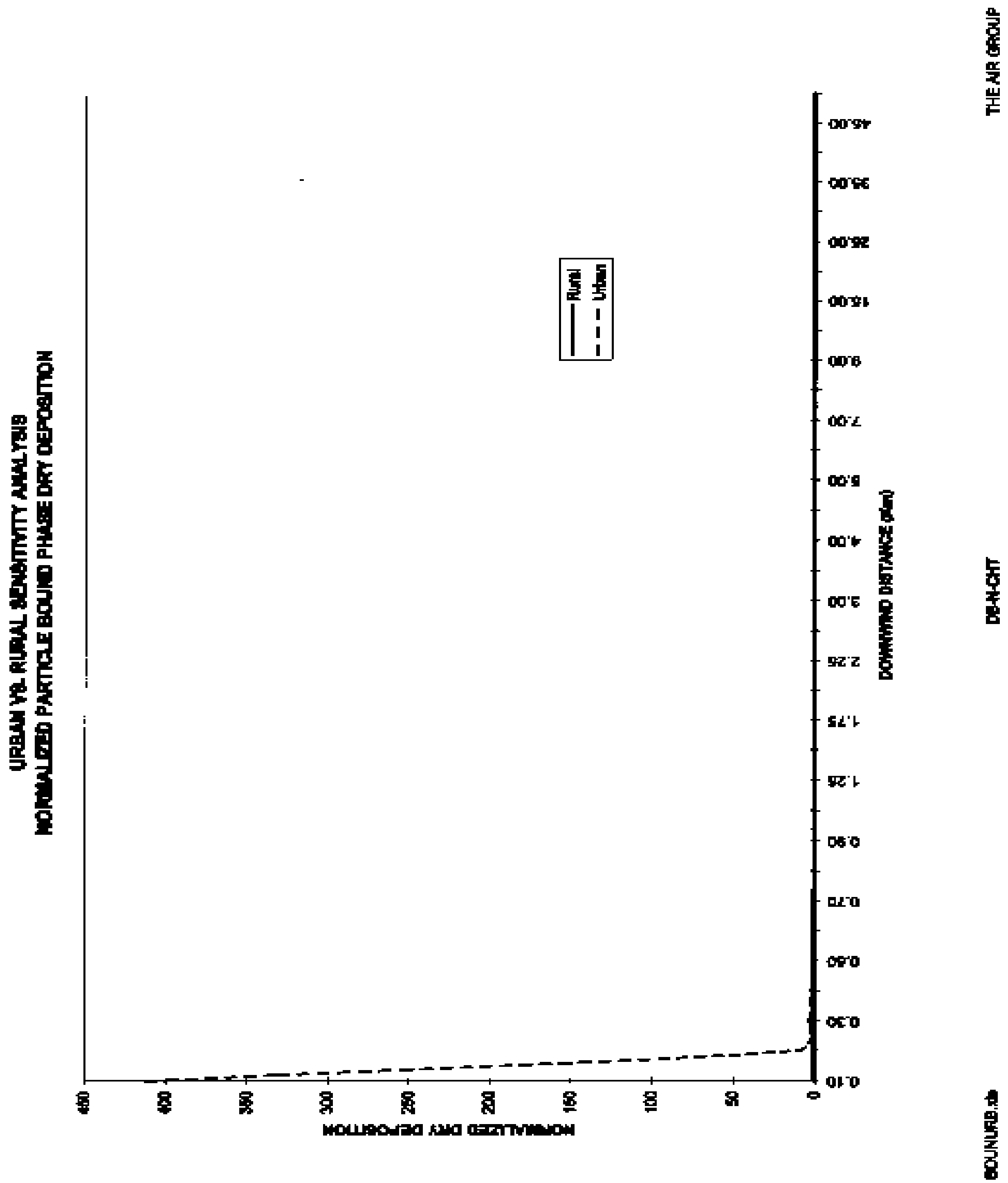
Based on the results of the urban versus rural analysis, it is clear that the choice of dispersion option and the corresponding changes in meteorological data processing have a significant effect on modeled concentrations and dry deposition rates. Differences are less significant for wet deposition. Therefore, the modeler should be careful to determine the most appropriate dispersion option for a particular site. Not only does the choice affect the dispersion coefficients used by the ISCST3 model, but other parameters related to the met data are also affected, each of which has an effect on the model output. Due to the great sensitivity of modeled impacts to the choice of dispersion coefficients, EPA should consider developing a more definitive method for determining whether a site should be classified as urban or rural. Also, Section 3.2.2.1 of the Draft SLHHRA Protocol should at a minimum advise the modeler to perform a detailed Auer land use analysis including aerial photographs and visual observation of current land use surrounding the site if it is not obvious whether the site should be classified as urban or rural.

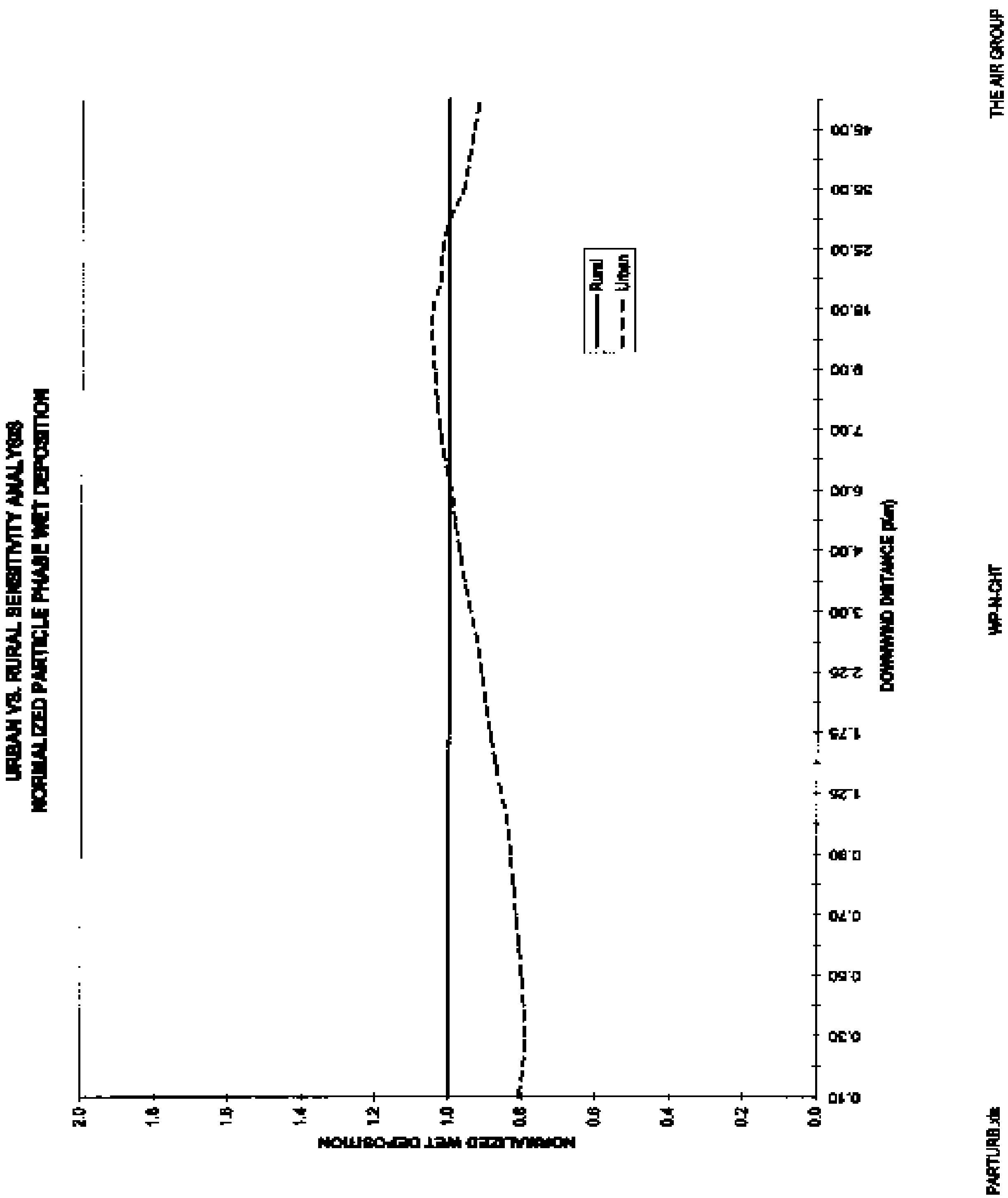

URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATION
Rural
Urban
NORMALIZED CONCENTRATION
0
20
40
60
80
100
120
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
CP-N-CHT

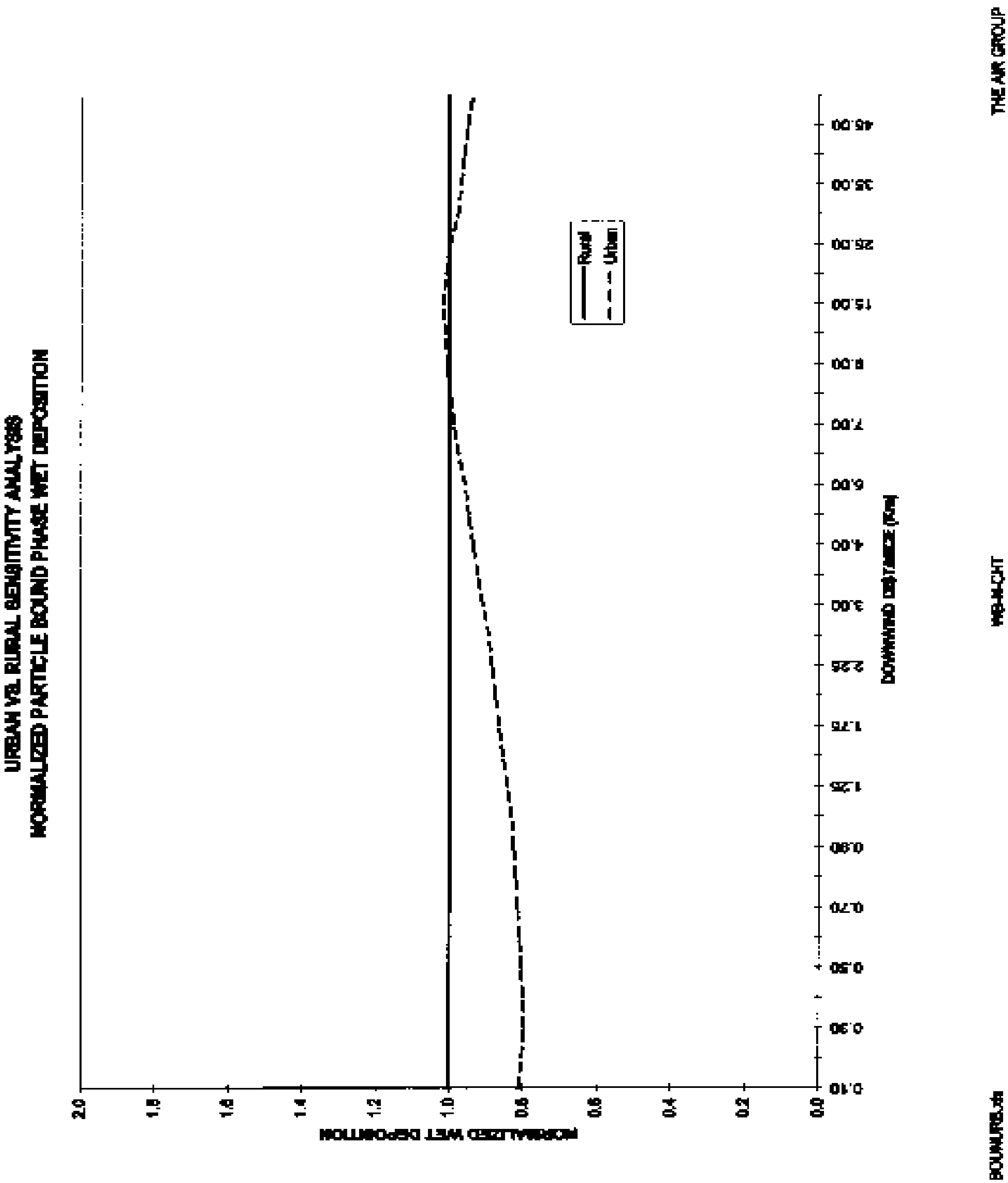

URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
Rural
Urban
NORMALIZED CONCENTRATION
0
20
40
60
80
100
120
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP

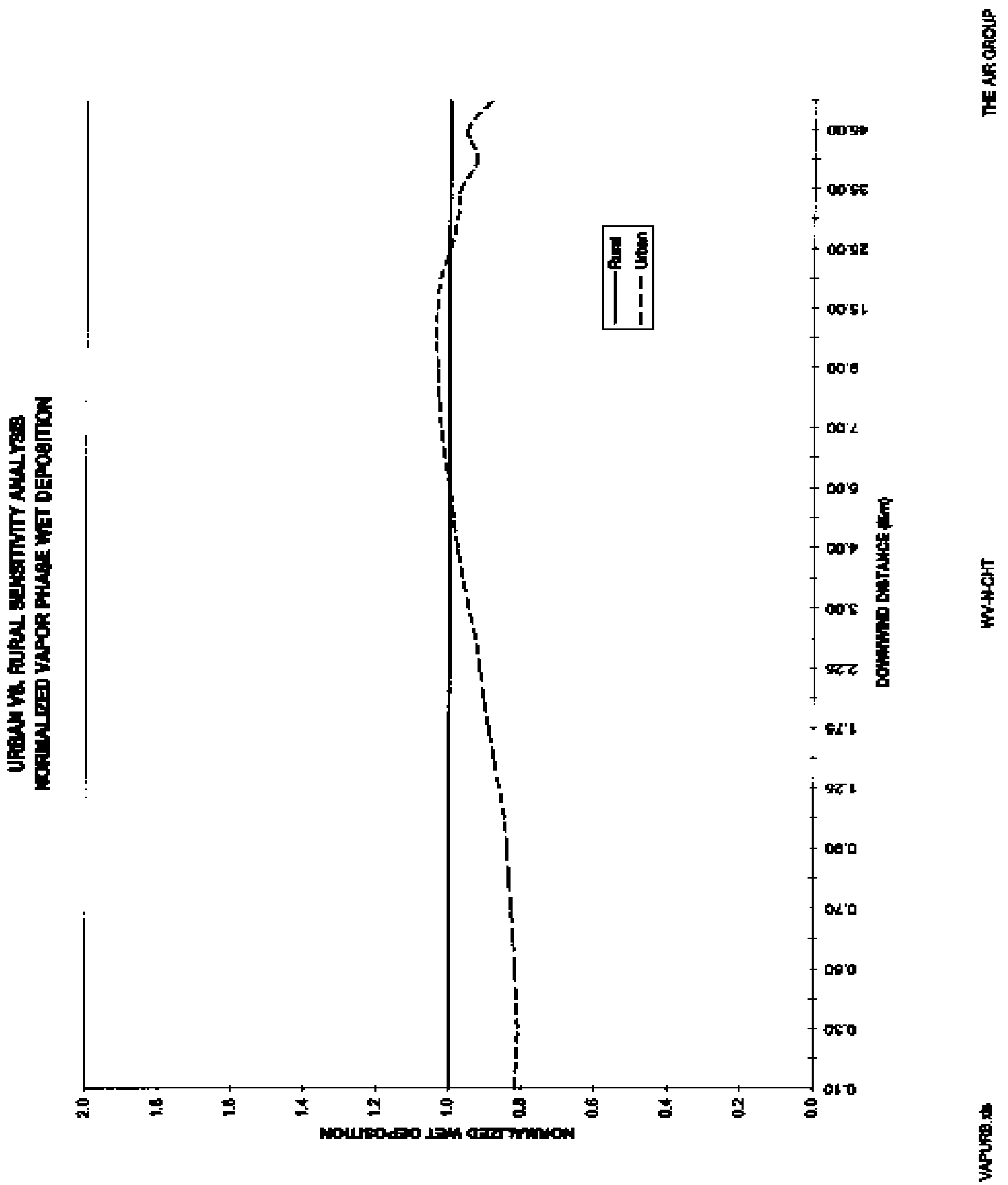

URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
Rural
Urban
DOWNWIND DISTANCE (km)
NORMALIZED CONCENTRATION
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
0
20
40
60
80
100
120
THE AIR GROUP


URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Rural
Urban
NORMALIZED DRY DEPOSITION
0
50
100
150
200
250
300
350
400
450
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
DP-N-CHT
PARTURB.xls


URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Rural
Urban
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (km)
0
50
100
150
200
250
300
350
400
450
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
DS-N-CHT


URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (km)
Rural
Urban
THE AIR GROUP
PARTURB.xls


URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Rural
Urban
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


URBAN VS. RURAL SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Rural
Urban
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (km)
THE AIR GROUP

5.3 SURFACE ROUGHNESS HEIGHT AT APPLICATION SITE

5.3.1 TECHNICAL OBJECTIVE

The method recommended in the Protocol for determining the appropriate surface roughness to use for a site is rigorous because dry deposition is very sensitive to the surface roughness value utilized in PCRAMMET. The objective of this study is to quantify the differences in model output that occur over the full range of surface roughness values identified by Sheih, Wesley, and Hicks (1979) (Section 3.2.2.2 of the Draft SLHHRA Protocol).

5.3.2 THEORETICAL BASIS

Surface roughness at the application site is specified explicitly as an input to PCRAMMET during preprocessing of meteorological data. In ISCST3, surface roughness at application site is used in the dry deposition algorithm to entrain particles into the lowest layer of air. The higher the surface roughness length, the sooner particles are removed from the air flow and deposited to the ground.

5.3.3 METHODOLOGY

5.3.3.1 BASE CASE - TYPICAL SURFACE ROUGHNESS HEIGHT

The base case model runs described in Section 4 are used as the base case for this analysis. The base case includes Protocol recommended methods and values, rural meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact, and the flat terrain option. The surface roughness at application site used in the base case is 0.1 meters, which represents surface roughness due to grassland during the summer.

5.3.3.2 TEST CASE I - MAXIMUM SURFACE ROUGHNESS HEIGHT

Test Case 1 is identical to the base case model runs, except that a surface roughness height at application site of 1.3 meters is used to develop the meteorological data. This roughness height is the maximum over the range of roughness heights and is representative of forests during the summer.

5.3.3.3 TEST CASE 2 - MINIMUM SURFACE ROUGHNESS HEIGHT

Test Case 2 is identical to the base case model runs, except that a surface roughness height at application site of 0.001 meters is used to develop the meteorological data. This roughness height is within in the lower range of potential values and is representative of grassland in the winter or a water surface.

5.3.4 RESULTS

5.3.4.1 CONCENTRATION

The results of the surface roughness at application site sensitivity analysis of concentration are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized concentrations for the base case and both test cases.

For the particle and particle-bound phases, relative differences between the base case and the test cases are small. Concentrations for both test cases stay within 20% of the base case for all distances modeled. Particle phase concentrations using the maximum surface roughness (Test Case 1) are approximately two to three percent lower than base case concentrations within 300 meters of the source. Relative impacts gradually decrease out to 25 kilometers to a minimum Test Case 1 normalized concentration of 0.83. Then Test Case 1 concentrations increase slightly to a normalized concentration of 0.84 at 50 kilometers. Particle-bound phase concentrations using the minimum surface roughness (Test Case 2) are approximately two to three percent higher than base case concentrations within 300 meters of the source. Normalized concentrations gradually increase to a maximum of 1.26 at 35 kilometers, then begin to drop off slightly to a normalized concentration of 1.12 at 50 kilometers.

For the vapor phase, concentrations are unaffected by the variation in surface roughness.

5.3.4.2 DRY DEPOSITION

The results of the surface roughness at application site sensitivity analysis of dry deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized dry deposition for the base case and both test cases.

The results indicate that surface roughness at the application site can have a dramatic effect on modeled dry deposition rates. For both the particle and particle-bound phases, normalized dry deposition rates using the maximum surface roughness height (Test Case 1) are three orders of magnitude (1000 times) higher than the base case deposition rates at a distance of 100 meters from the source. Normalized rates then drop dramatically to approximately 700% at 300 meters from the source. Normalized dry deposition rates then decrease gradually to a minimum of approximately 0.9 and 1.21 at 45 kilometers for particle phase and particle bound phase, respectively.

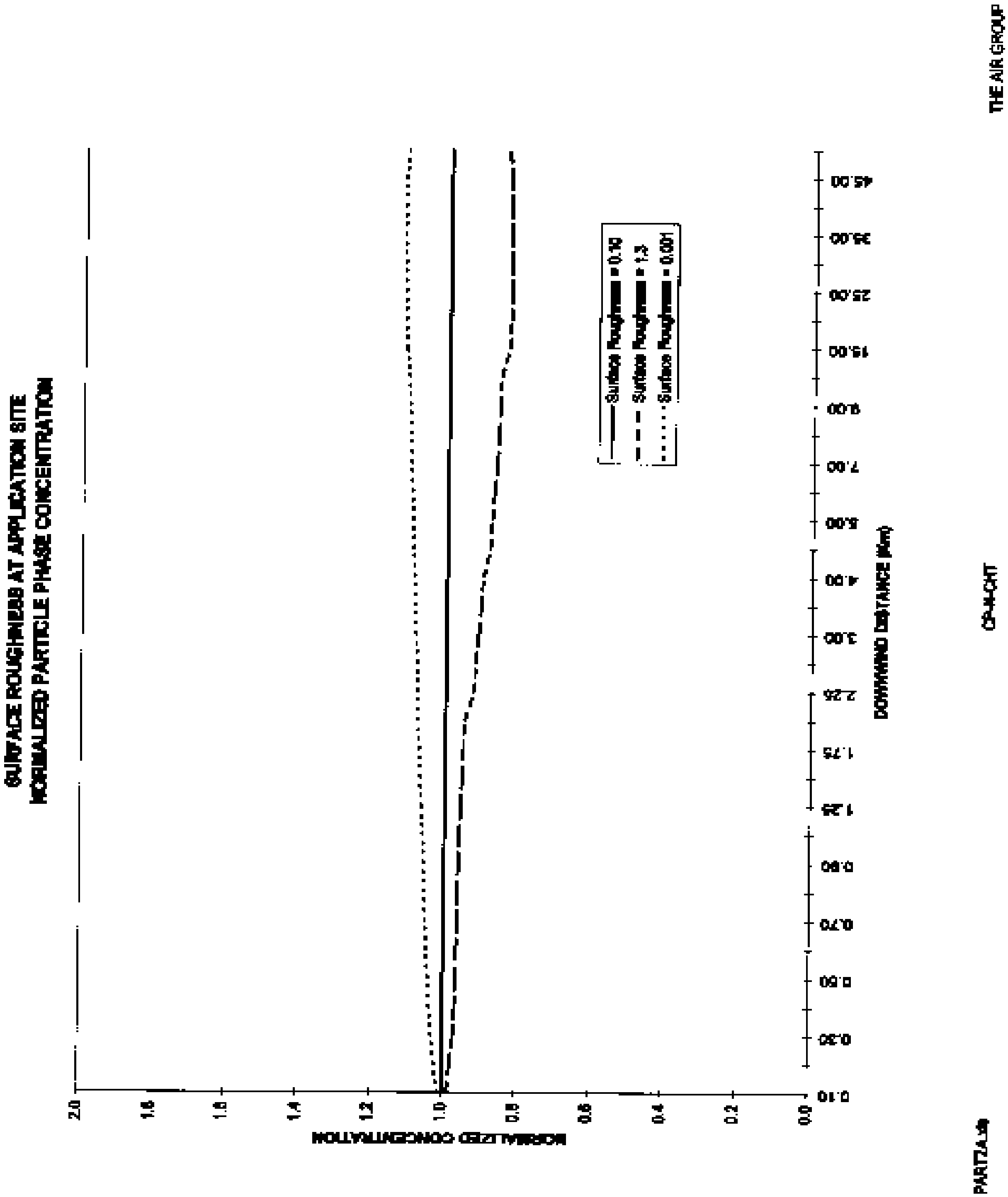
5.3.4.3 WET DEPOSITION

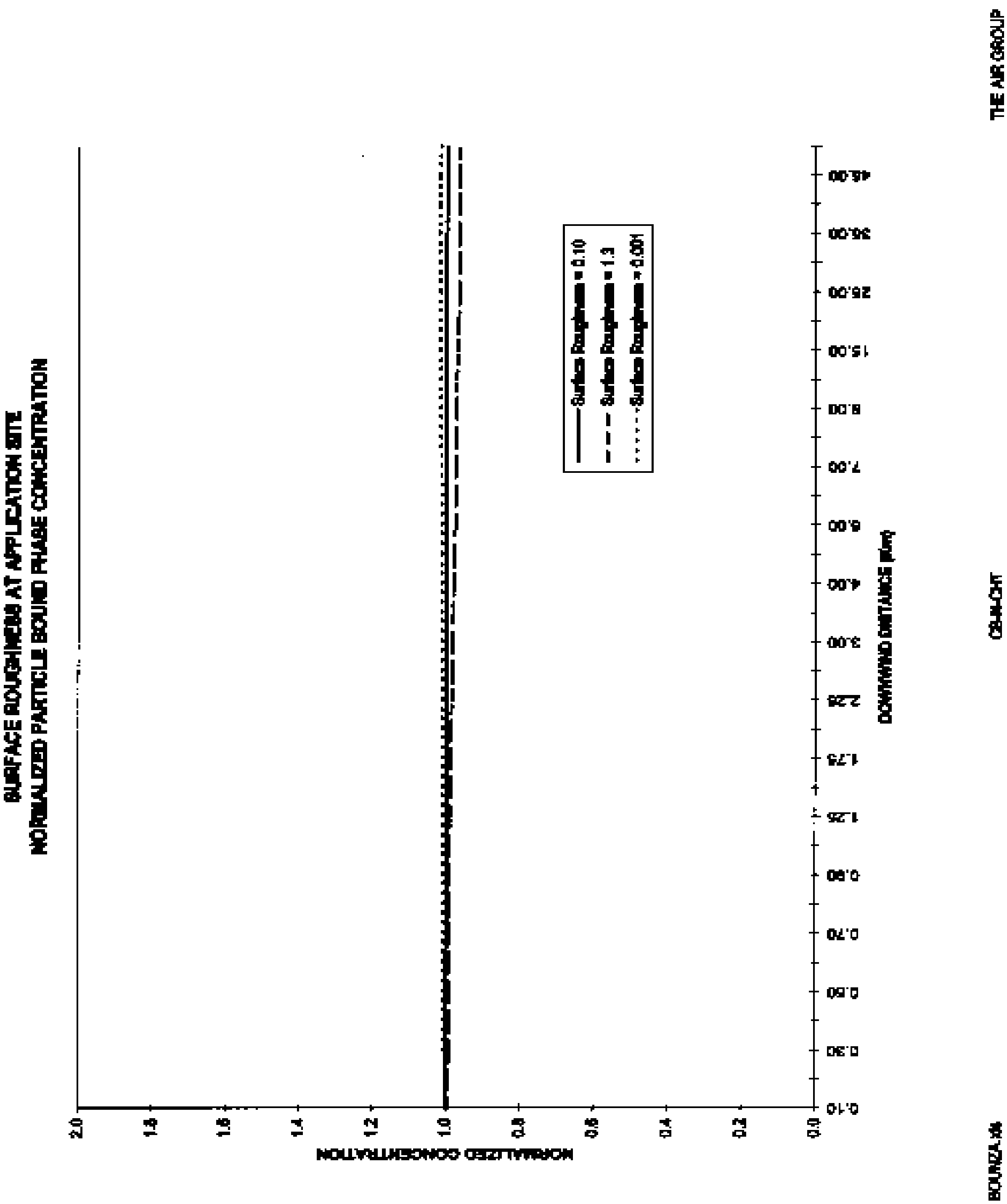
The results of the surface roughness at application site sensitivity analysis of wet deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized wet deposition for the base case and both test cases.

The normalized wet deposition curves are very similar to the normalized concentration curves. As with concentration, particle phase and particle-bound phase wet deposition values are within 20% of the base case results at all modeled distances, with the maximum surface roughness (Test Case 1) producing lower wet deposition than the base case and minimum surface roughness (Test Case 2) producing higher wet deposition than the base case.

5.3.5 RECOMMENDATIONS

Dry deposition rates are extremely sensitive to the surface roughness at the application site that is utilized in processing the meteorological data. One consideration for future development is revising ISCST3 to allow for direction and distance specific values for surface roughness. The most value is for estimating dry deposition rates. In the interim, it is important for EPA to standardize the method of determining surface roughness for equitable application across facilities. The Auer method accomplished this standardization for determining urban or rural land use. The Protocol method biasing the average surface roughness by wind direction probability is valid for representing surface roughness in the predominant wind flow directions. However, as the interested receptor or watershed may occur in any direction from the source, an areal average without wind direction consideration may be more appropriate.


SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED PARTICLE PHASE CONCENTRATION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
CP-N-CHT


SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
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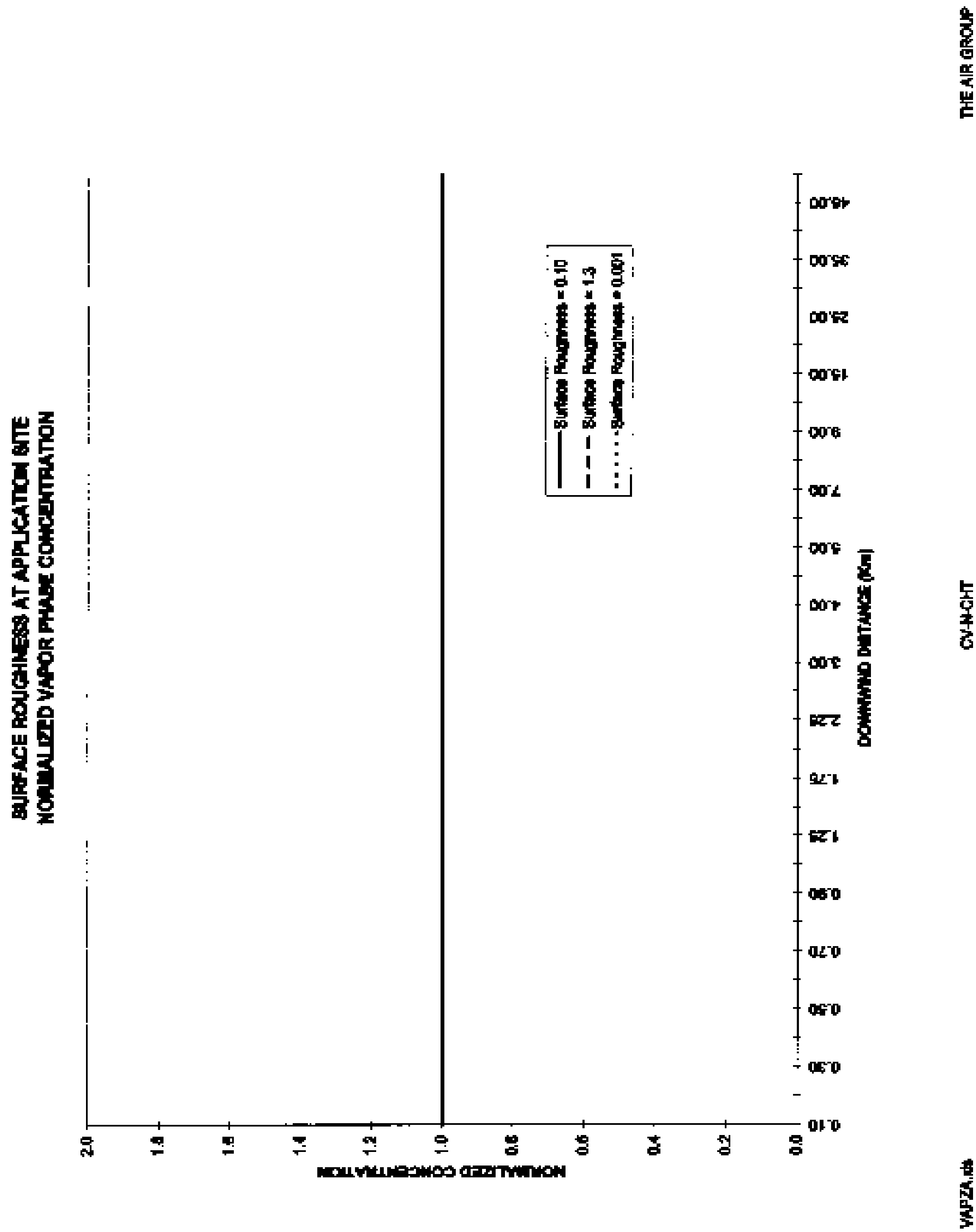
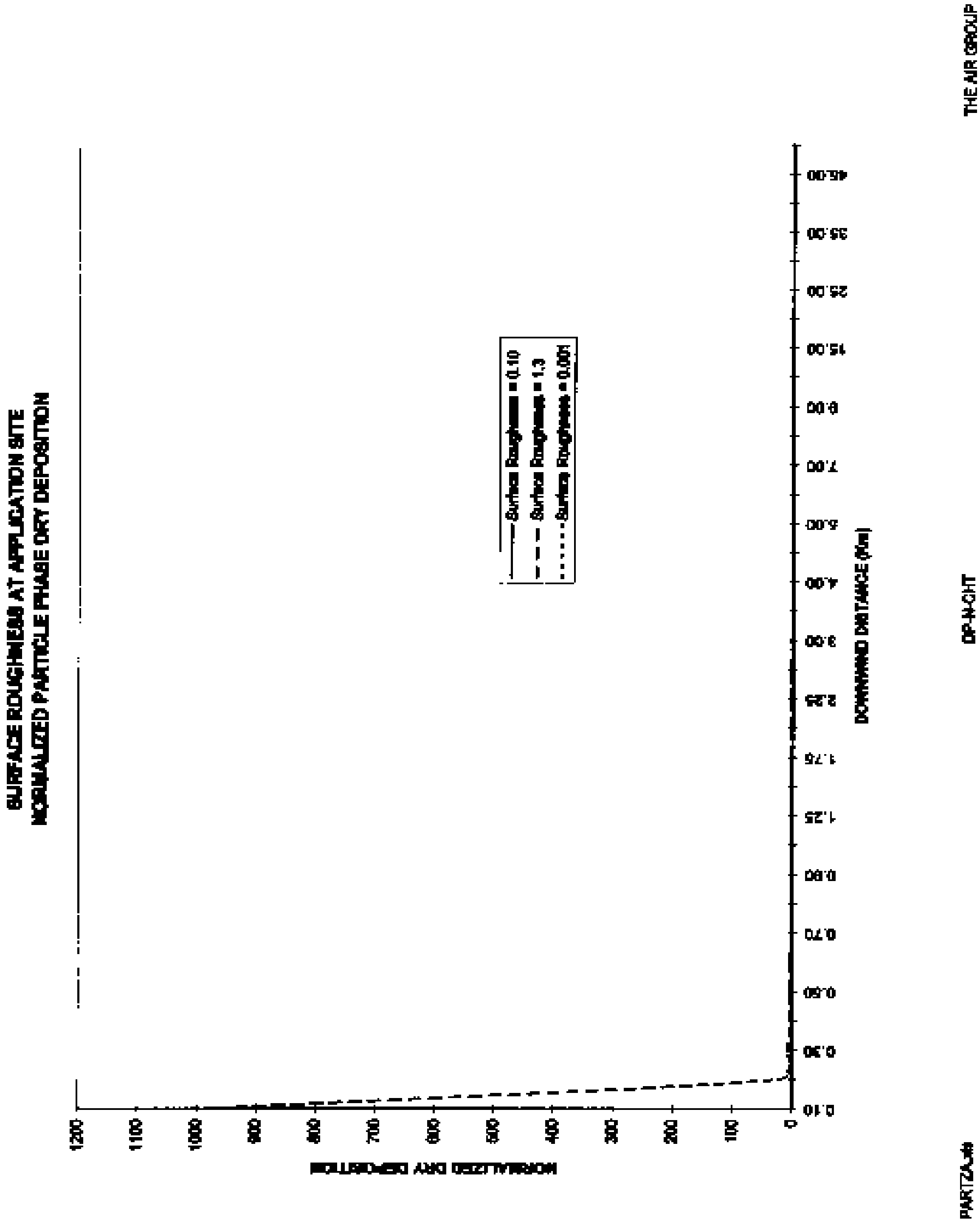
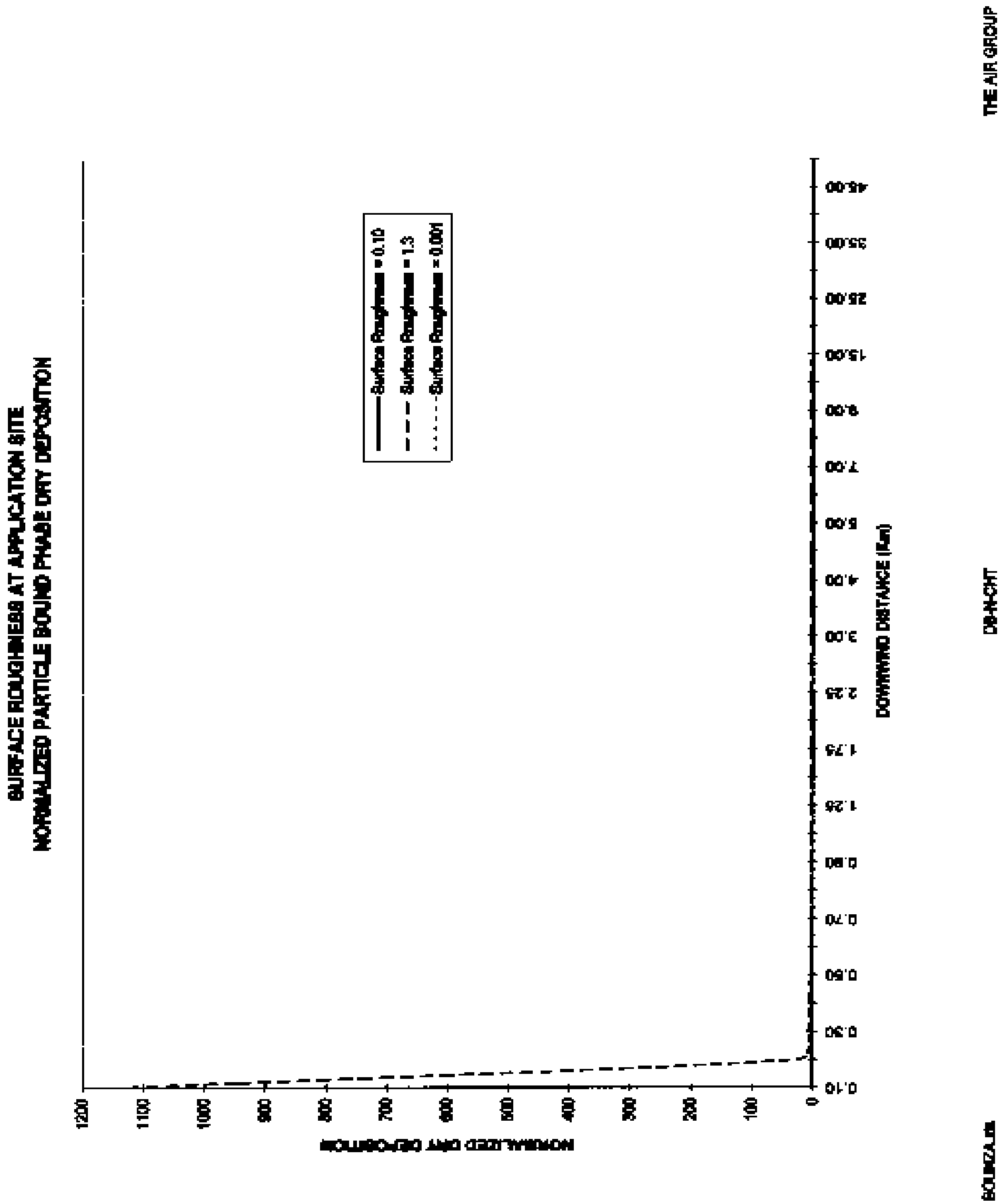
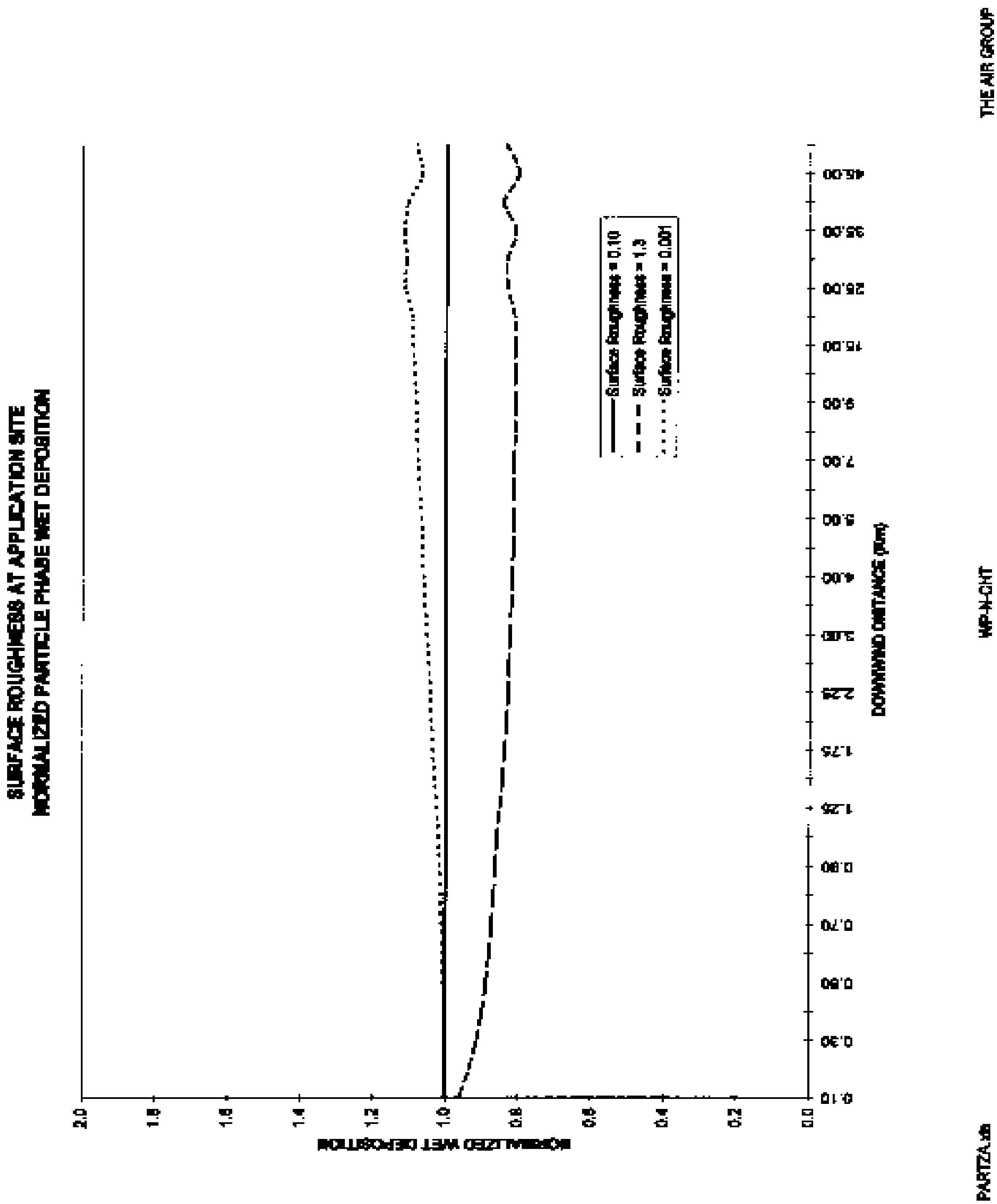
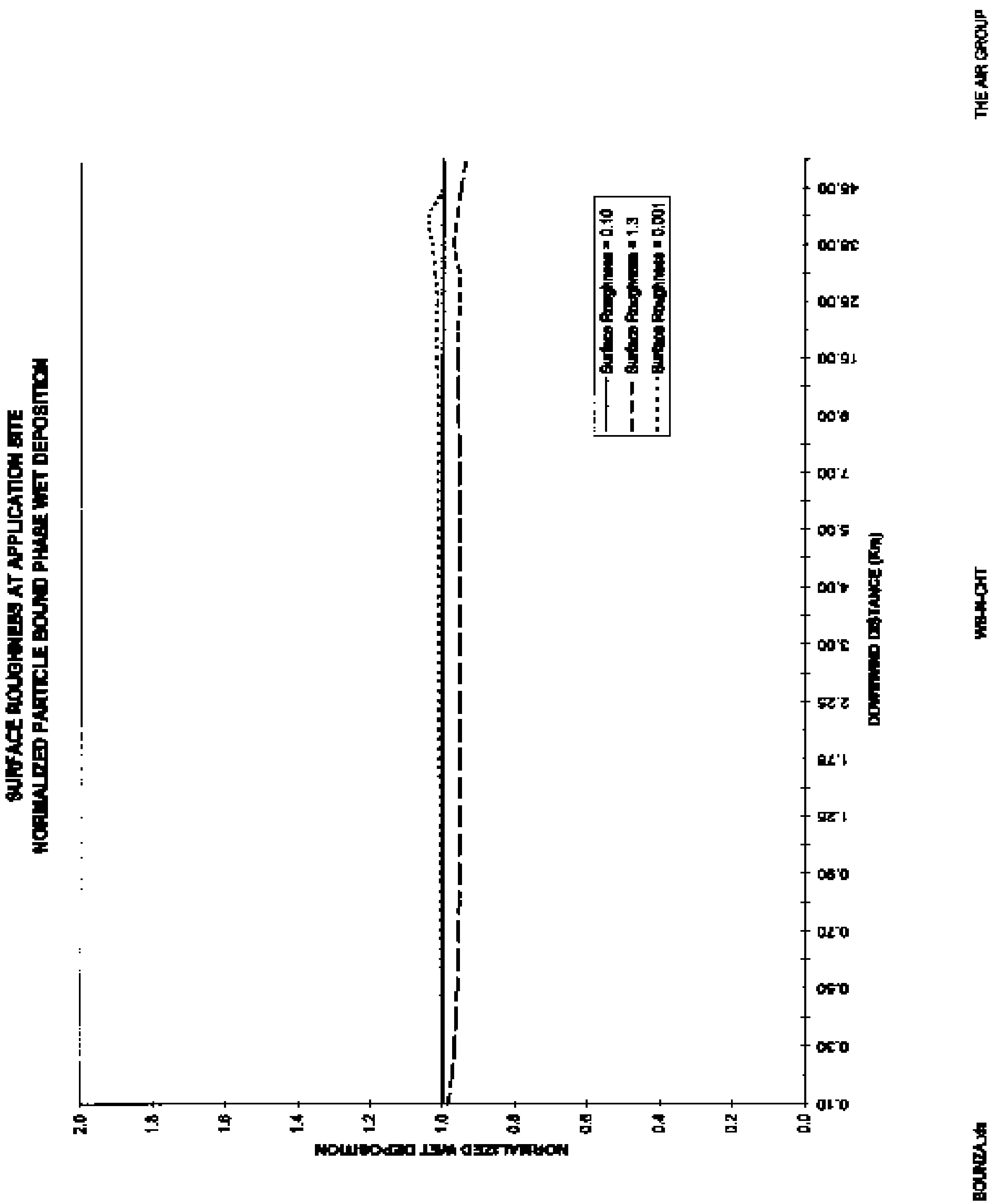
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (km)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP

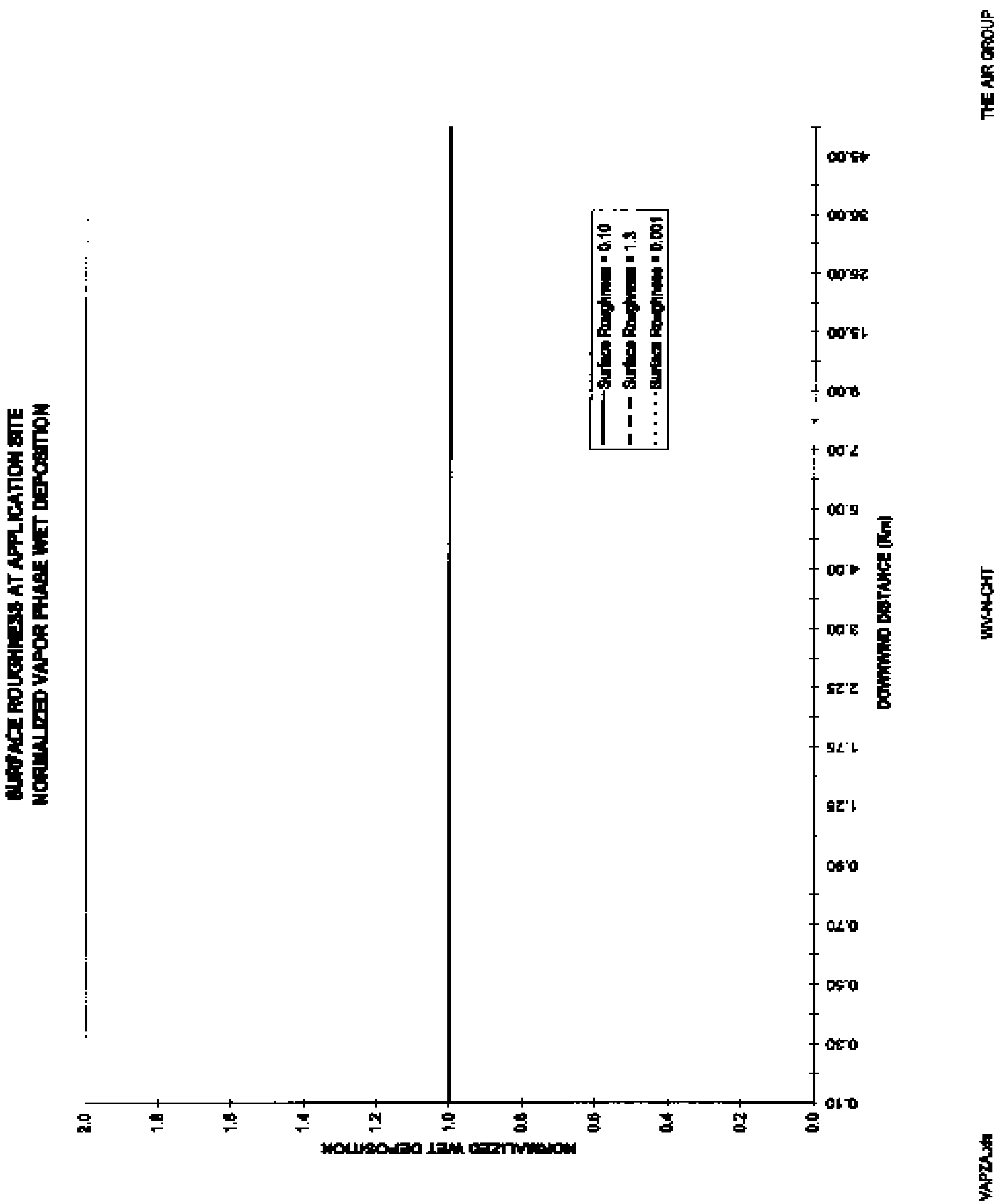

SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED VAPOR PHASE CONCENTRATION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED CONCENTRATION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
THE AIR GROUP
CV-N-CHT
VAPZA.xls


SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
DP-N-CHT
PARTZA.#


SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED PARTICLE PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
THE AIR GROUP
WP-N-CHT
PARTZA.xls


SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
THE AIR GROUP


SURFACE ROUGHNESS AT APPLICATION SITE
NORMALIZED VAPOR PHASE WET DEPOSITION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP

5.4 WATERSHED SIZE AND PROXIMITY

5.4.1 TECHNICAL OBJECTIVE

The technical objective of the watershed size and proximity sensitivity analysis is to determine how sensitive modeled results are to changing assumptions about watershed size and location. Since concentrations are not utilized in the watershed component of the risk assessment analysis, only total deposition is evaluated as recommended in the Protocol.

5.4.2 THEORETICAL BASIS

The size selection of the watershed determines two offsetting characteristics of computing representative values for deposition into a water body. The larger the area selected, the more area for COPC to be deposited. However, since the deposition rate is averaged over the area of the watershed, a larger watershed area will have a diluting effect on deposition rates. The selection of an appropriate watershed size is determined by two key factors. First, select a watershed that covers an area that results in a COPC entering a pathway to a known receptor via drinking water or fish consumption. Within the watershed boundary, a conservative value for total deposition into the watershed would be at the single grid node with the highest deposition rate. As this value may be too conservative, an area average of multiple grid nodes may be more representative of deposition into the watershed. The trade-off begins as the area increases to include lower deposition rate grid nodes.

5.4.3 WATERSHED SIZE

5.4.3.1 METHODOLOGY

5.4.3.1.1 BASE CASE - TOTAL DEPOSITION FROM 10 KM X 10 KM WATERSHED GRID

A 10 km x 10 km watershed size is assumed. It is also assumed that the source is located in the center of the watershed. The base case model runs for this analysis utilize the same Protocol recommended methods and values used in the base case described in Section ??, including rural meteorology and dispersion coefficients with the flat terrain option. However, instead of a linear receptor grid in the direction of maximum impacts, the receptor grid modeled for the watershed size base case consists of 500 meter spaced Cartesian grid nodes extending out 5 kilometers in each direction from the source, resulting in a 10 km x 10 km grid. The base case total deposition rates are averaged over the entire watershed for comparison with the test cases because it is the average total deposition that is used in the watershed fate and transport calculations.

5.4.3.1.2 TEST CASE I - TOTAL DEPOSITION FROM I KM X I KM WATERSHED GRID

Test Case 1 consists of calculating the average total deposition over a much smaller area than the base case. A 1 km x 1 km, 500 meter spaced grid surrounding the maximum total deposition value is chosen for Test Case 1. Note that no additional model runs are necessary to perform the Test Case 1 analysis, since the 1 km x 1 km grid is a subset of the 10 km x 10 km grid modeled for the base case.

5.4.3.1.3 TEST CASE 2 - MAXIMUM TOTAL DEPOSITION OVER ENTIRE WATERSHED

Test Case 2 is simply an evaluation of the total deposition rate at the maximum grid node value compared to the base case and Test Case I average total deposition rates.

5.4.3.2 RESULTS

The results of the watershed size sensitivity analysis which present the plotted total deposition rates for each of the phases (particle, particle-bound, and vapor) are plotted in the figures at the end of this section. Tables in Appendix A compare absolute and normalized total deposition for the base case and both test cases. A comparison of the total deposition rates calculated by the three different methods (base case, Test Case 1, and Test Case 2) are presented below, in units of g/m^2/g/s:

PHASE	BASE CASE: Average Deposition Over 10 X 10 Km Grid	TEST CASE 1: Average Deposition Over I X I Km Grid	TEST CASE 2: Maximum Deposition Within Watershed
PARTICLE	0.12	0.90	2.03
PARTICLE-BOUND	0.03	0.19	0.47
VAPOR	0.02	0.15	0.39

Test Case 1 deposition rates are between 600% and 800% higher than the base case. Test Case 2 deposition rates are 1600% to 2000% higher than the base case.

5.4.3.3 RECOMMENDATIONS

For large watersheds located close to the COPC source, the method of using maximum total deposition rate over the entire watershed grossly over-estimates deposition and the ultimate risk associated with the pathways pertaining to watersheds. The method of modeling a 1 kilometer by 1 kilometer grid at the location of maximum impacts for computing the average total deposition also significantly over-predicts the average total deposition over a large watershed when the watershed is located close to the source being modeled. Therefore, the modeler should be careful to evaluate average total deposition over an appropriately large watershed area in order to produce representative estimates of total deposition.

5.4.4 WATERSHED PROXIMITY

5.4.4.1 METHODOLOGY

5.4.4. 1.1 BASE CASE - WATERSHED LOCATED I KILOMETER FROM THE SOURCE

The base case for the watershed proximity analysis consists of modeling a 2 km x 2 km watershed located I kilometer from the source using a Cartesian grid and 500 meter spacing. All other inputs to the base case model runs are identical to those described in Section 4. As with the watershed size sensitivity analysis, total deposition rates are determined for this watershed using three different methods: 1) average total deposition calculated over the entire grid; 2) average total deposition calculated over a smaller 1 km x 1 kin grid that includes the maximum modeled total deposition rate; and 3) maximum total deposition rate within the entire grid.

5.4.4.1.2 TEST CASE 1 - WATERSHED LOCATED 10 KILOMETERS FROM SOURCE

Test Case 1 consists of modeling a 2 km x 2 km watershed located 10 kilometers from the source using a Cartesian grid with 500 meter spacing. Other than the location of the watershed grid, all other inputs to the Test Case I model runs are identical to the base case.

5.4.4.2 RESULTS

The results of the watershed proximity sensitivity analysis are provided in the figures at the end of this section which present the plotted total deposition rates for each of the phases (particle, particle-bound, and vapor).

Average total deposition rates calculated using the three different methods are presented below, in units of $g/m^2/g/s$:

BASE CASE

WATERSHED GRID LOCATED 1 KILOMETER FROM SOURCE

PHASE	Avg. Deposition Over 2 Km x 2 Km Grid	Avg. Deposition Over 1 x 1 Km Grid	Maximum Deposition Within Watershed
PARTICLE	0.291	0.438	0.914
PARTICLE-BOUND	0.067	0.100	0.203
VAPOR	0.030	0.045	0.085

TEST CASE 1

WATERSHED GRID LOCATED 10 KILOMETERS FROM SOURCE

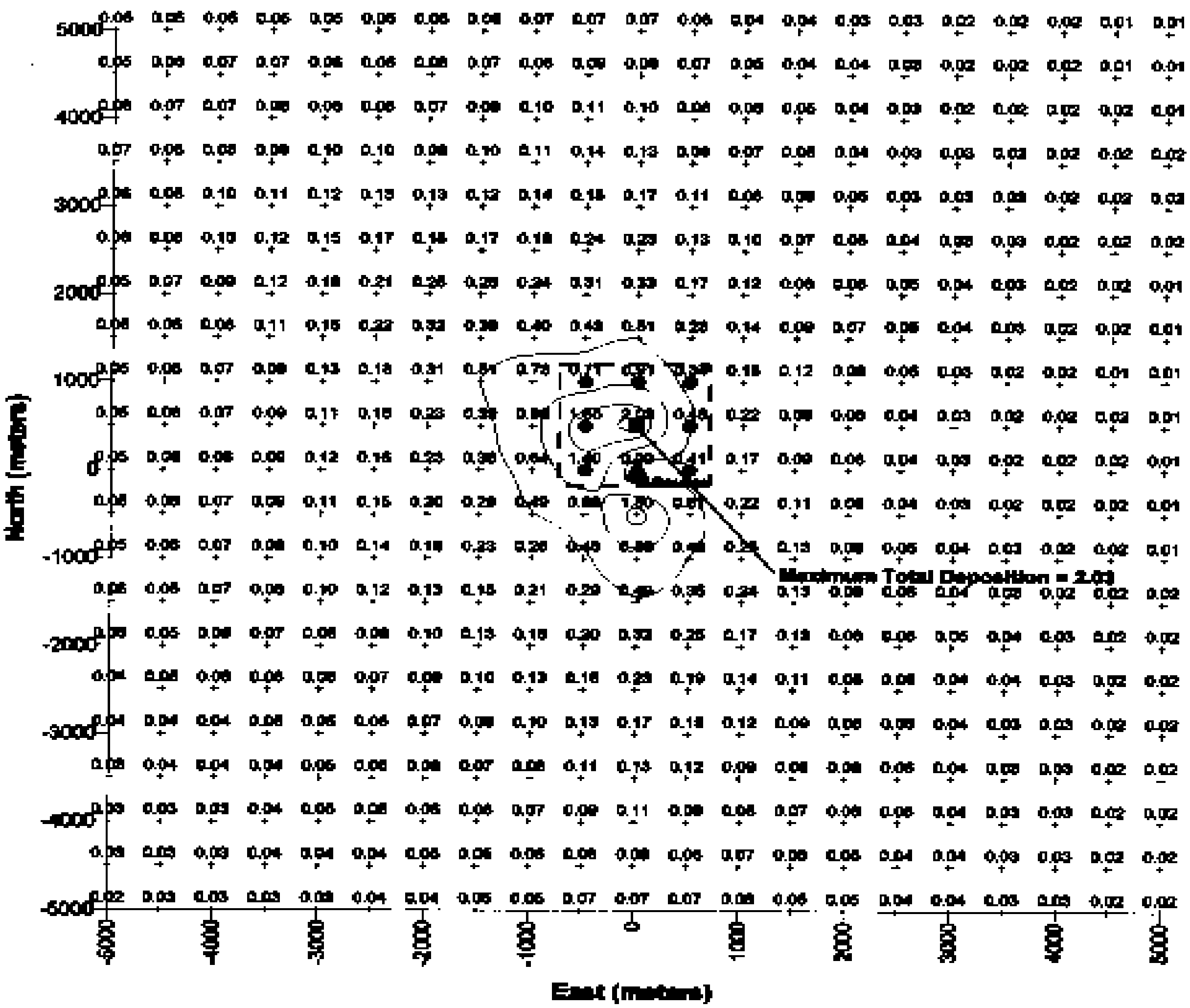
PHASE	Avg. Deposition Over 2 Km x 2 Km Grid	Avg. Deposition Over 1 x 1 Km Grid	Maximum Deposition Within Watershed
PARTICLE	0.017	0.019	0.021
PARTICLE-BOUND	0.005	0.005	0.006
VAPOR	0.002	0.002	0.003

For the watershed located 10 kilometers from the source, the average total deposition calculated over either the whole 2 km x 2 km watershed grid or the 1 km x 1 km grid surrounding the maximum value is only IO% to 20% lower than the maximum total deposition rate. In contrast, for the watershed located I kilometer from the source the average total deposition calculated over the 2 km x 2 km watershed grid is approximately 70% lower than the maximum total deposition. The average total deposition calculated over the 1 km x 1 km grid surrounding the maximum value is 33% lower than the maximum total deposition rate.

5.4.4.3 RECOMMENDATIONS

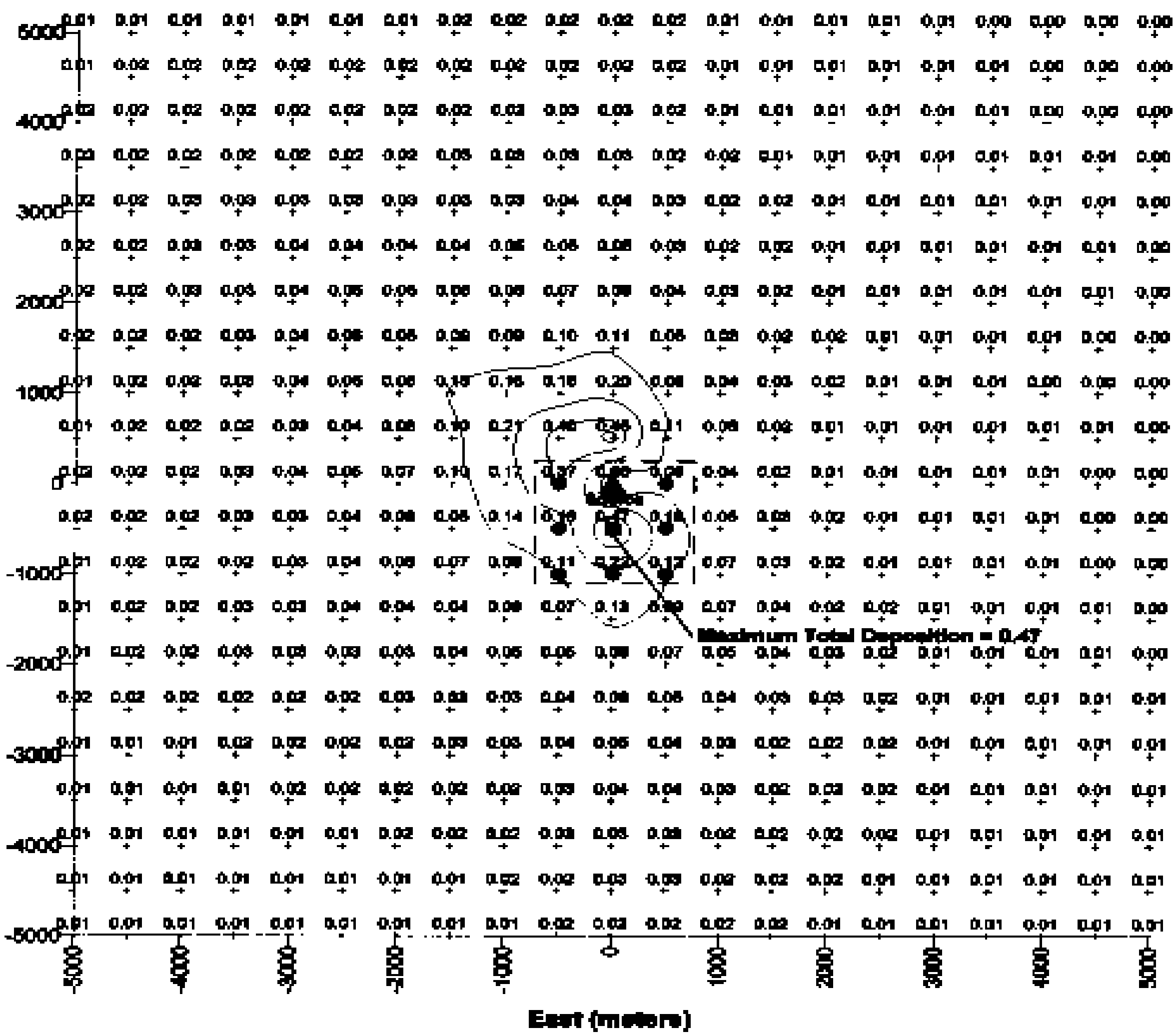
For watersheds located close to the sources being modeled, the method of choosing the maximum total deposition rate over the entire watershed could grossly over-estimate ultimate risk associated with the pathways that pertain to watersheds. However, for watersheds located at distances of 10 kilometers or greater from the source there is negligible difference in average deposition rates calculated by the three methods. Therefore, a remote watershed could be modeled using a small receptor grid at the nearest portion of the watershed to the sources being modeled without significantly over-predicting average total deposition rates.

WATERSHED SIZE SENSITIVITY ANALYSIS
10 KM X 10 KM WATERSHED AREA
PARTICLE PHASE TOTAL DEPOSITION
g/m2/g/s



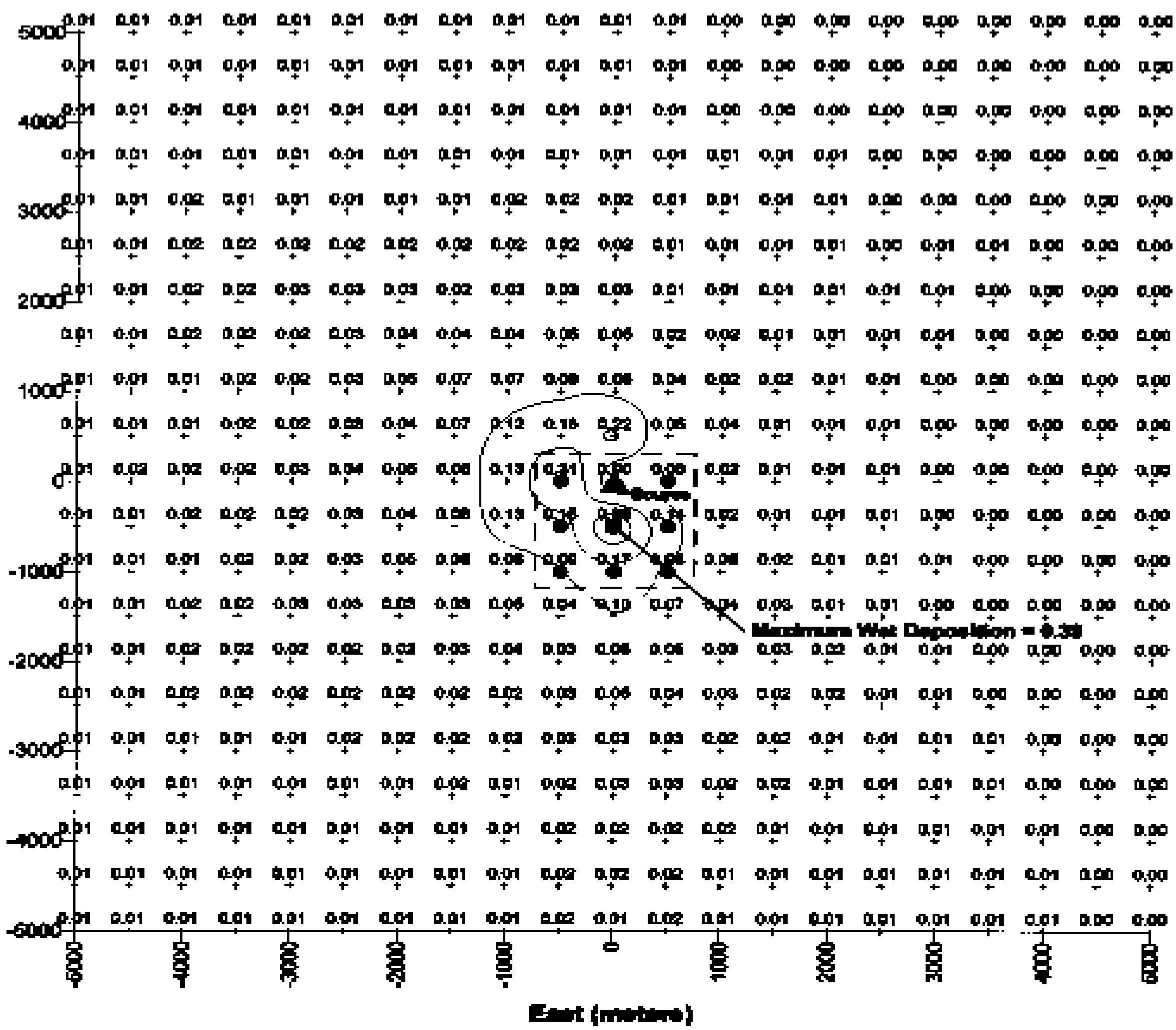
Legend:
Triangle indicates source location
Square indicates location of maximum total deposition
Circles indicate 8-point grid around maximum deposition
Crosses indicate 10 km x 10 km grid nodes
Isopleths represent 90%, 75%, 50%, and 25% of maximum deposition

WATERSHED SIZE SENSITIVITY ANALYSIS
10 KM X 10 KM WATERSHED AREA
PARTICLE BOUND PHASE TOTAL DEPOSITION
g/m2/g/s

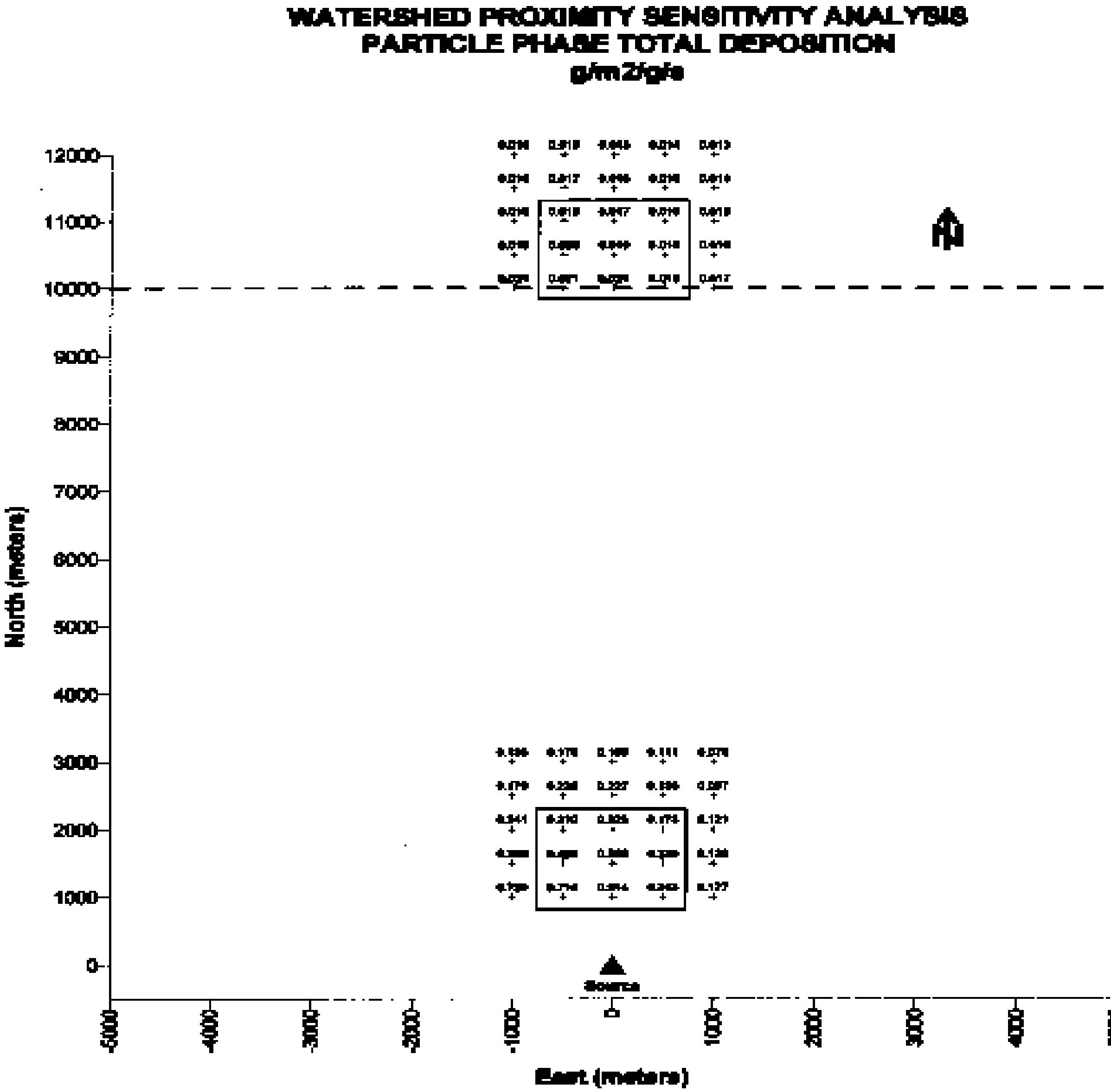


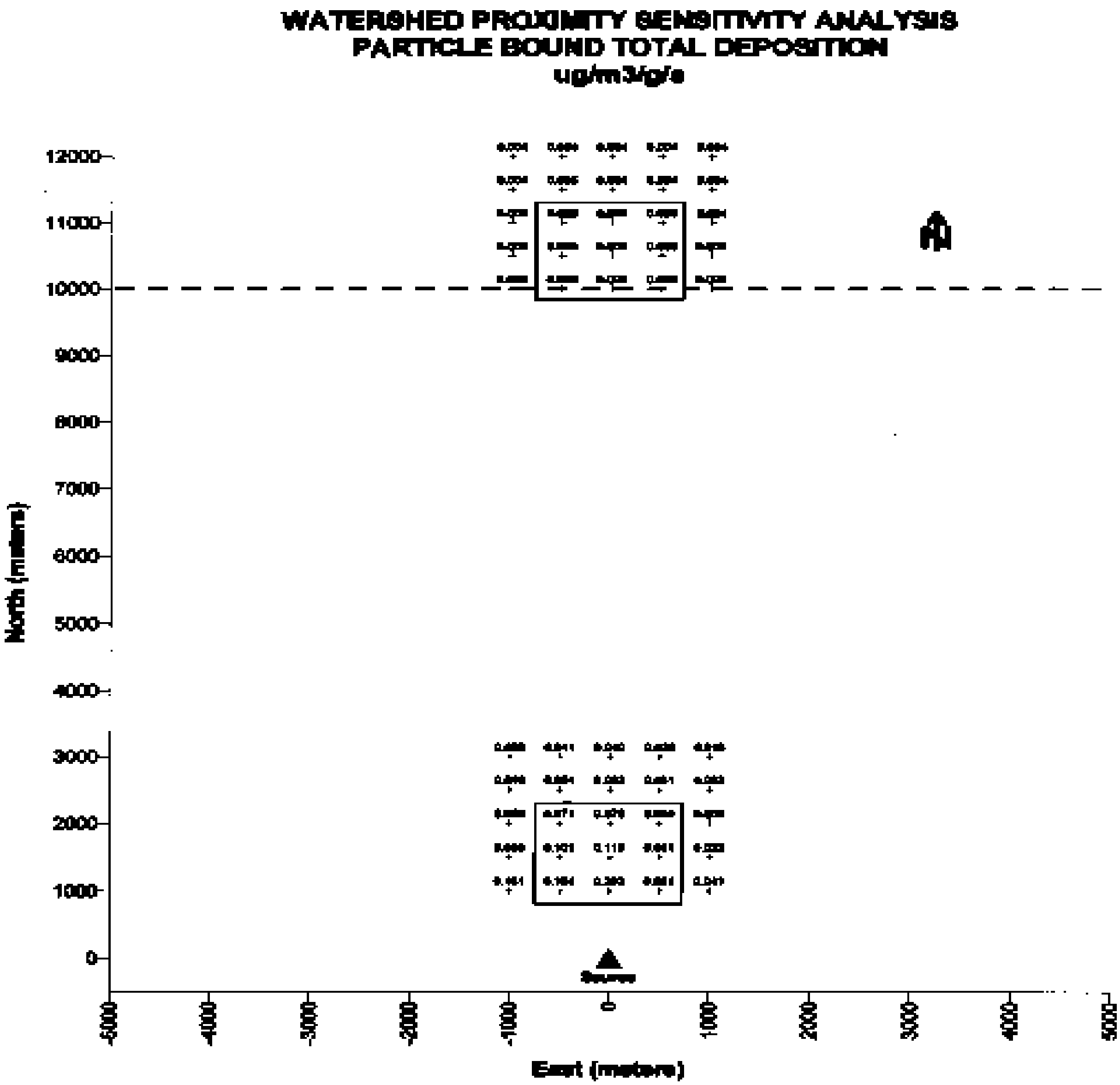
Legend:
Triangle indicates source location
Square indicates location of maximum total deposition
Circles indicate 9-point grid around maximum deposition
Crosses indicate 10Km x 10Km grid nodes
Isopleths represent 90%, 75%, 50%, and 25% of maximum deposition

WATERSHED SIZE SENSITIVITY ANALYSIS
10 KM X 10 KM WATERSHED AREA
VAPOR PHASE WET DEPOSITION
g/m2/g/s



Legend:
Triangle indicates source location
Square indicates location of maximum wet deposition
Circles indicate 9-point grid around maximum deposition
Crosses indicate 10 km x 10 km grid nodes
Isopleths represent 90%, 75%, 50%, and 25% of maximum deposition


WATERSHED PROXIMITY SENSITIVITY ANALYSIS
PARTICLE PHASE TOTAL DEPOSITION
g/m2/g/s
North (meters)
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
N
Source
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
East (meters)


WATERSHED PROXIMITY SENSITIVITY ANALYSIS
PARTICLE BOUND TOTAL DEPOSITION
ug/m3/g/s
North (meters)
East (meters)
Source
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
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-5000
-4000
-3000
-2000
-1000
0
1000
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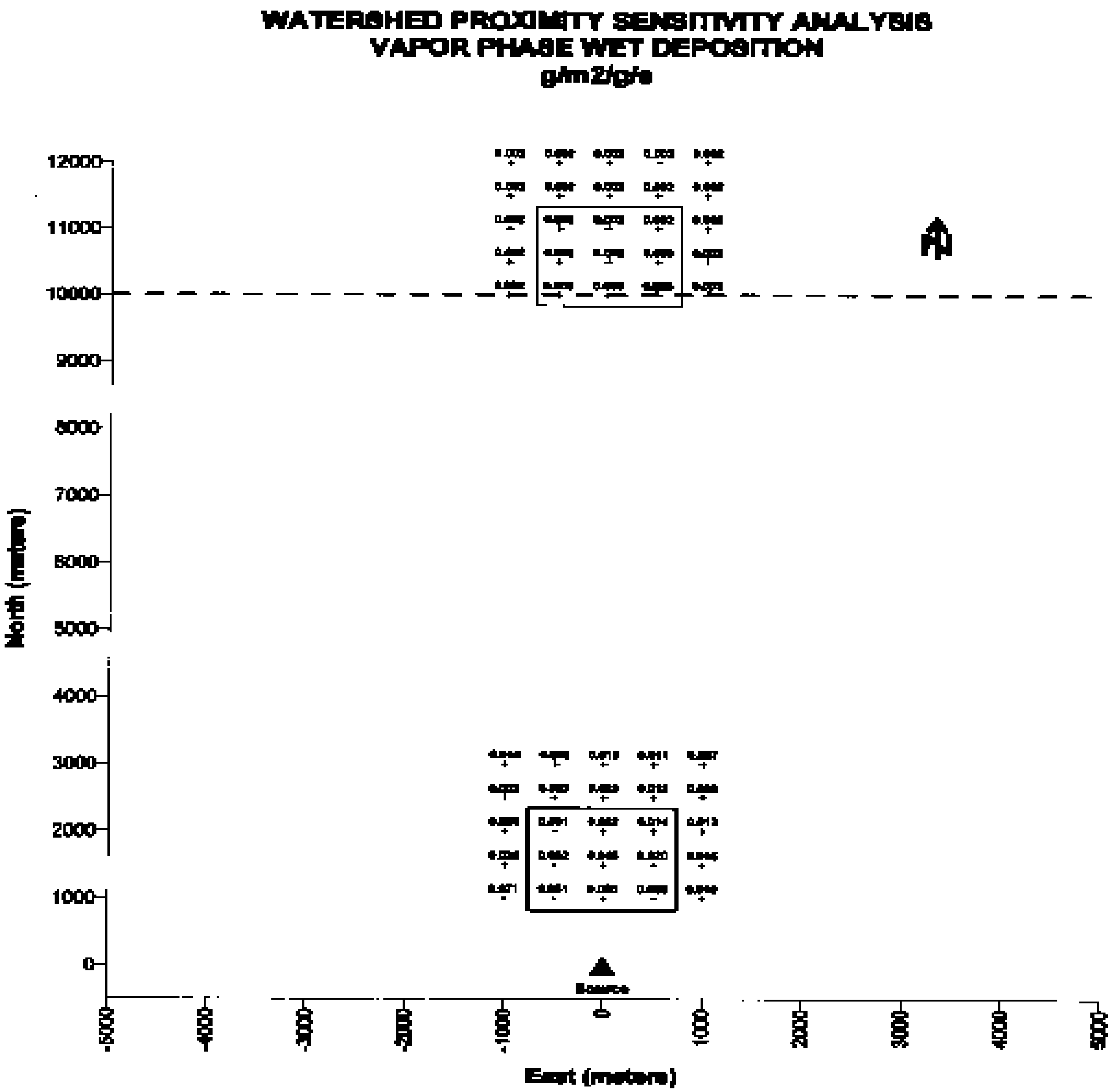
3000
4000
5000


WATERSHED PROXIMITY SENSITIVITY ANALYSIS
VAPOR PHASE WET DEPOSITION
g/m2/g/s
North (meters)
East (meters)
Source
N
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000

5.5 ANEMOMETER HEIGHT

5.5.1 TECHNICAL OBJECTIVE

Most anemometers are installed at a height of 10 meters above local ground level at NWS primary stations. However, some stations in the primary network are installed at the old Federal Aviation Administration standard level of 20 feet (6.1 meters). Even others are at different heights for various reasons. All anemometer heights are documented by the National Climate Data Center (NCDC) in Asheville, North Carolina, in the Local Climate Data (LCD) summaries for each station. If a modeler does not verify anemometer height and incorrectly assumes it is 10 meters, this sensitivity analysis identifies the potential magnitude of errors in the model results.

5.5.2 THEORETICAL BASIS

Anemometer height is used in ISCST3 to calculate the wind speed each hour at stack top for each modeled stack. The measured wind speed at anemometer height is extrapolated to the estimated wind speed at stack top height based on a wind speed profile that exponentially increases wind speed with height and stability class. The wind speed at stack top is explicit in the concentration equation as inversely proportional to concentration. The wind speed at stack top is implicit in the computation of plume rise. The wind speed used in PCRAMMET to compute stability class is the measured wind speed and not the stack top wind speed so that errors will not change the computed stability category.

5.5.3 METHODOLOGY

In EPA Region 6, perhaps the most used meteorological data is Houston Intercontinental Airport (IAH) NWS station. Houston NWS station has a non-standard anemometer height of 20 feet (6.1 meters). Inexperienced modelers sometimes incorrectly assume that the Houston anemometer height is 10 meters. Therefore, the base case and test cases use different combinations of these heights in the meteorological preprocessing and ISCST3 input file to represent realistic scenarios that easily could occur for sites in the Houston area.

5.5.3.1 BASE CASE - 6.1 METER ANEMOMETER HEIGHT IN BOTH MET AND ISCST3

The base case model runs described in Section 4 are the base case for this analysis. The base case includes Protocol recommended methods and values, rural meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact with flat terrain option. An anemometer height of 6.1 meters (20 ft.) is specified in PCRAMMET and ISCST3.

5.5.3.2 TEST CASE I - 6.1 M. ANEMOMETER HEIGHT IN MET, 10 M. IN ISCST3

Test Case 1 is identical to the base case model runs, except that the anemometer height in the ISCST3 is set at 10 meters rather than the actual height of 6.1 meters. The anemometer height specified in PCRAMMET is left at 6.1 meters. This represents a situation where the meteorological preprocessing is perfon-ned by a different (and more knowledgeable) person than the modeler who performs the ISCST3 set up and model runs. This realistic scenario occurs because the State of Texas prepares and makes available to the modeling community the meteorological data for use in modeling sites in Texas.

5.5.3.3 TEST CASE 2 - 10 METER ANEMOMETER HEIGHT IN BOTH MET AND ISCST3

Test Case 1 is identical to the base case model runs, except that the anemometer height is set at 10 meters in both PCRAMMET and ISCST3. This represents the scenario where the same person who processes the met data also performs the modeling and that person did not realize that the Houston IAH station has an uncommon anemometer height.

5.5.4 RESULTS

5.5.4.1 CONCENTRATION

The results of the anemometer height sensitivity analysis of concentration are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized concentrations for the base case and both test cases.

For all phases and at all distances from the source, the difference between the base case and test case concentrations are less than 20 percent. The normalized curves are very similar for all three phases. At 100 meters, the normalized concentrations for both test cases are about 16 percent lower than the base case. The test case concentrations gradually increase relative to base case concentrations until they equal the base case at approximately 700 meters from the source. They continue to rise gradually beyond 700 meters, reaching a maximum 13 to 15 percent higher than the base case at 40 to 50 kilometers from the source.

5.5.4.2 DRY DEPOSITION

The results of the anemometer height sensitivity analysis of dry deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized dry deposition for the base case and both test cases.

For both the particle and particle-bound phases, the normalized curve for Test Case 1 begins at 100 meters from the source with a value of 84% (16 percent lower than the base case) and follows the same progression as for concentration. The normalized curve for Test Case 2 begins at 100 meters from the source with a value of 74% for the particle phase (26 percent lower than base case) and 72% for the particle-bound phase. The curve gradually rises to maximum of 97% for particle phase and 100% for particle-bound phase at 50 kilometers.

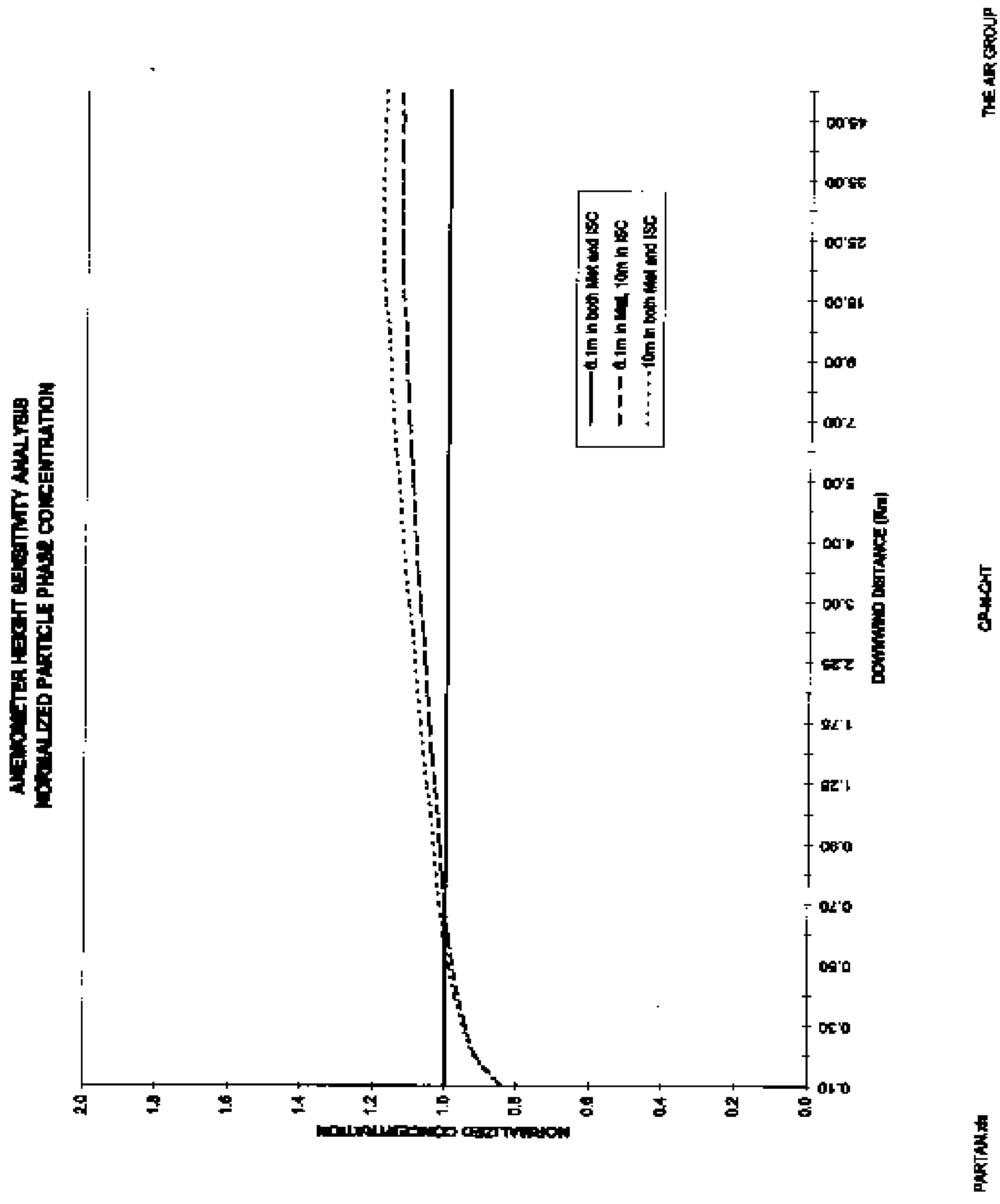
5.5.4.3 WET DEPOSITION

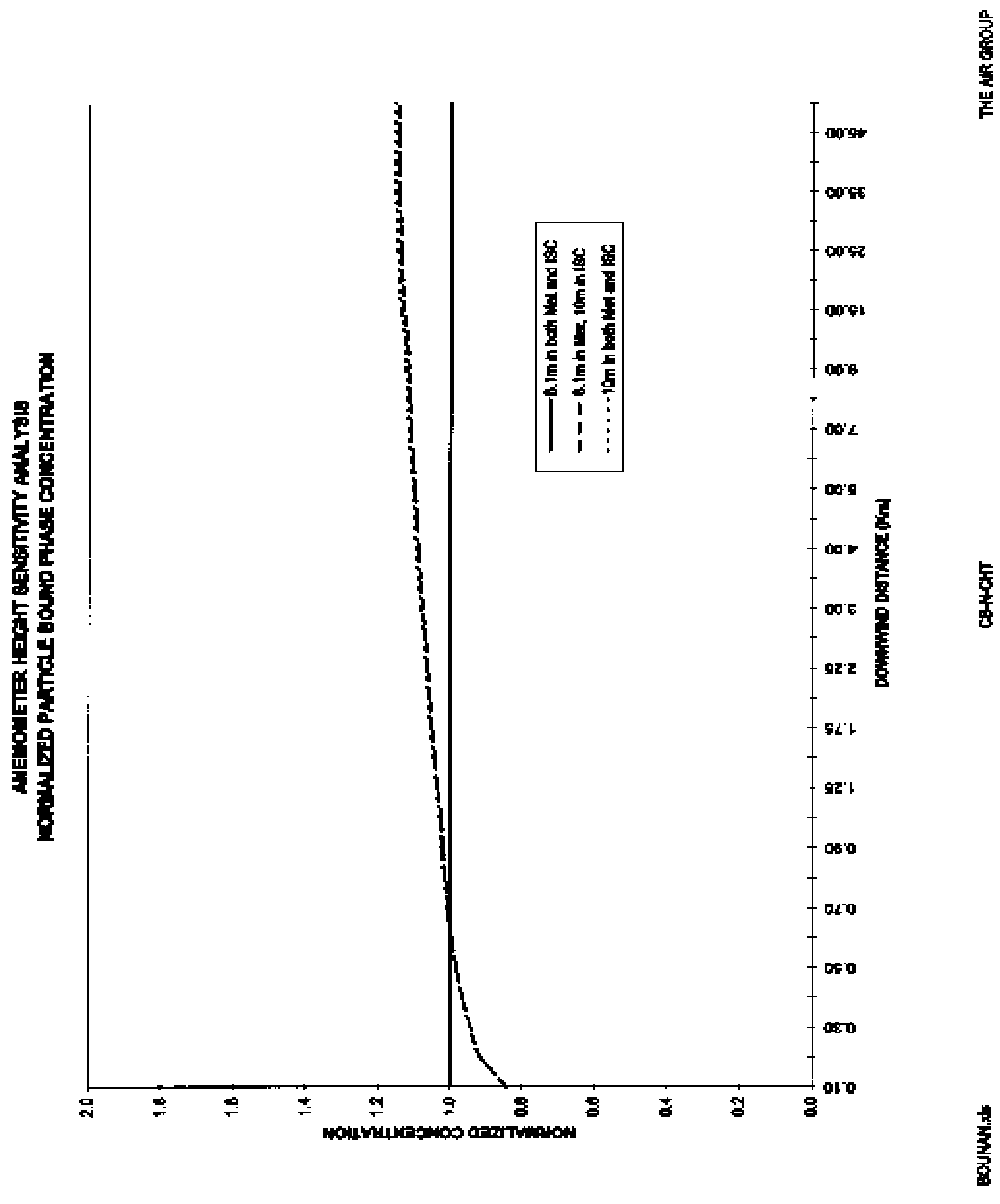
The results of the anemometer height sensitivity analysis of wet deposition are presented in the figures at the end of this section. Tables in Appendix A compare absolute and normalized wet deposition for the base case and both test cases.

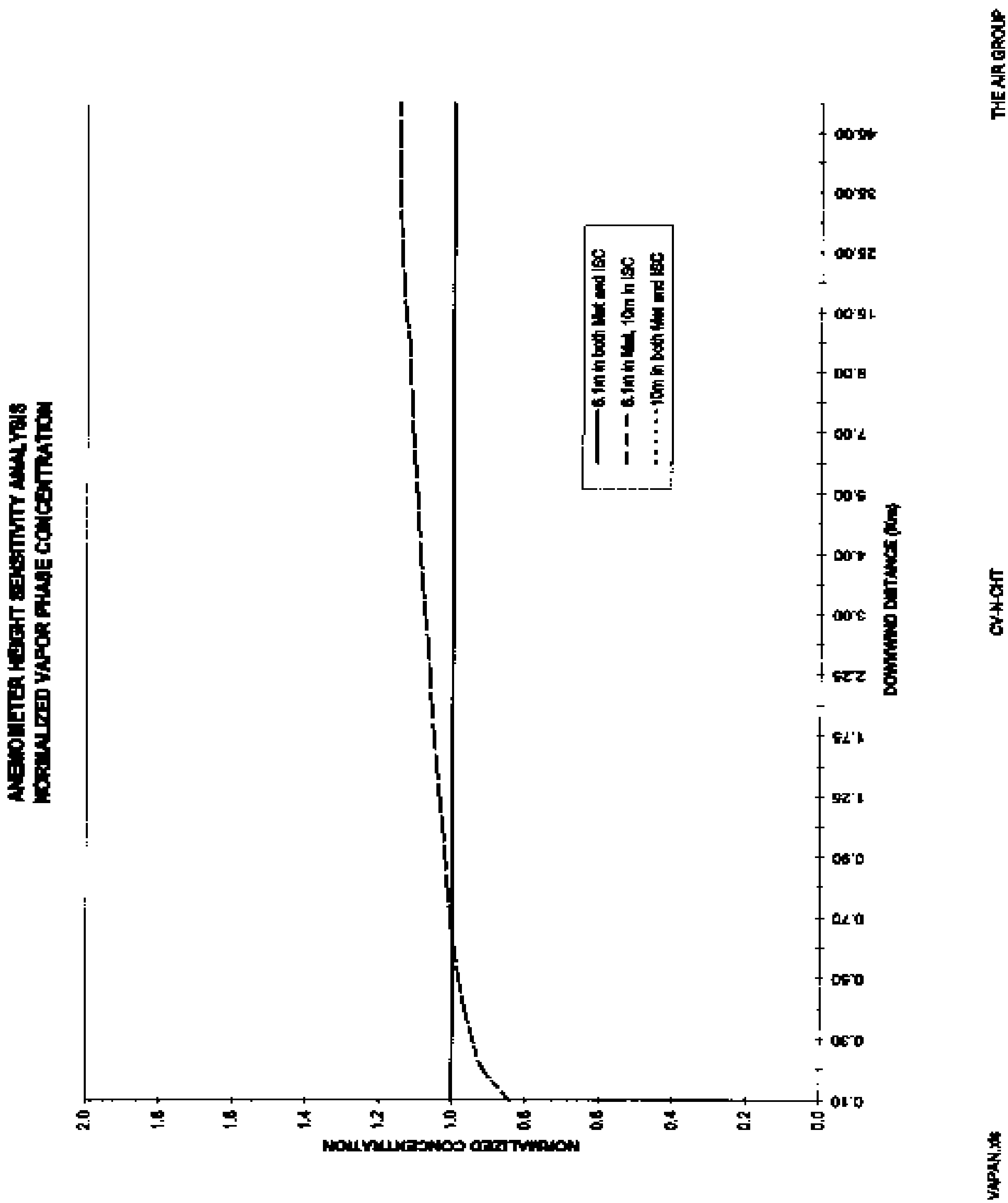
For all three phases, the normalized curves for both Test Case I and Test Case 2 begin at 100 meters from the source with a value of approximately 107% (7 percent higher than base case), gradually decreasing to 100% at 10 to 30 kilometers depending on phase. The curves then diverge either slightly above or slightly below the base case curve.

5.5.5 RECOMMENDATIONS

Concentrations from the test cases are under-predicted by as much as 17% compared to the base case. Wet deposition rates are over-predicted by as much as 7%. Dry deposition rates are the most affected with modeled results under-predicted by as much as 26% compared to the base case. The anemometer height effect on modeled results is more pronounced close to the source. The differences in modeled results noted above appear to be large enough to warrant remodeling if the modeler uses a higher anemometer height than the actual anemometer height. Especially modeling with the higher anemometer height under-predicts the impacts at most locations, except for wet deposition.


ANEMOMETER HEIGHT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATION
0.1m in both Met and ISC
0.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
CP-NIGHT
PARTAN.##


ANEMOMETER HEIGHT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
0.1m in both Met and ISC
0.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


ANEMOMETER HEIGHT SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
6.1m in both Met and ISC
6.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED CONCENTRATION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
8.00
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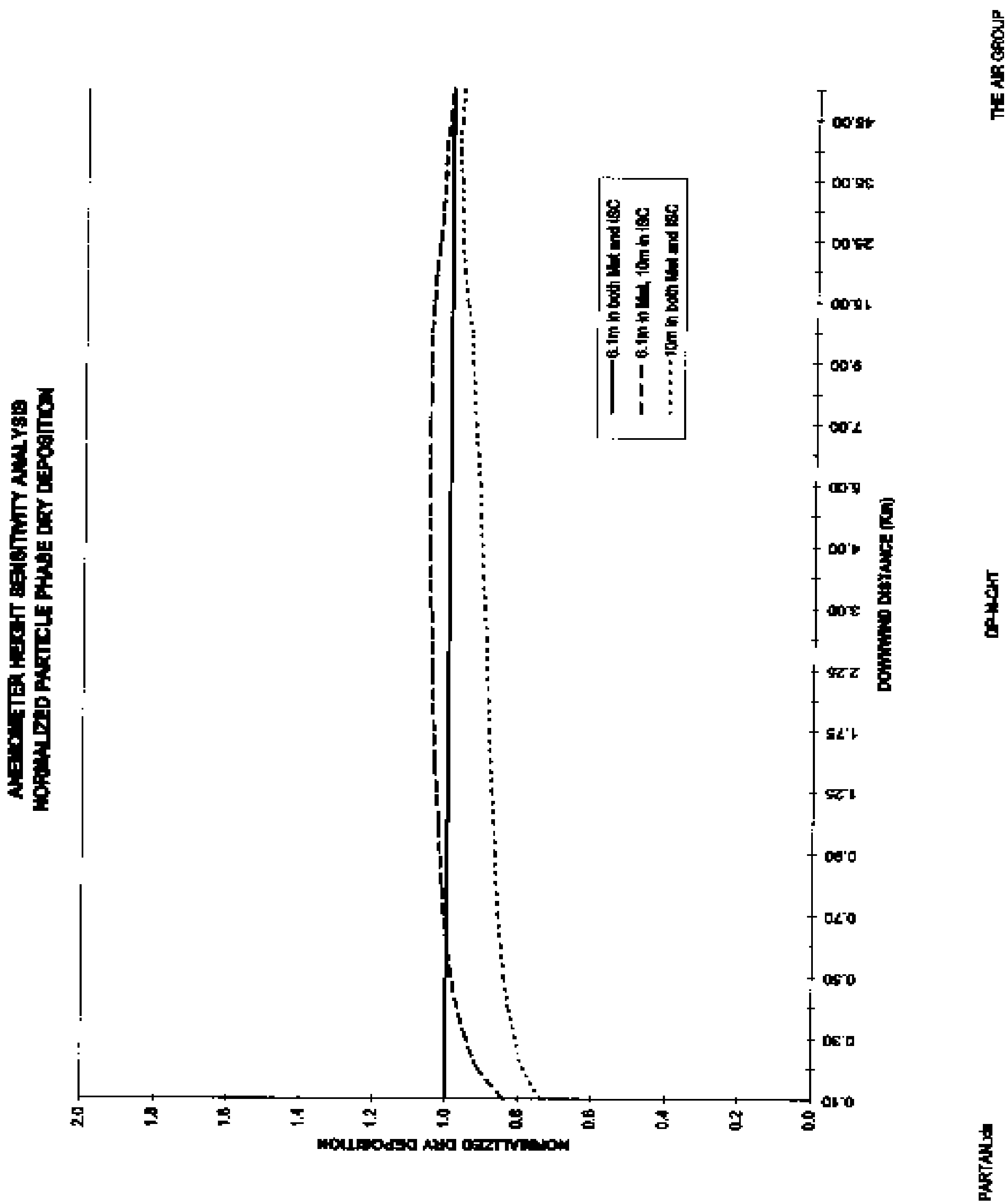
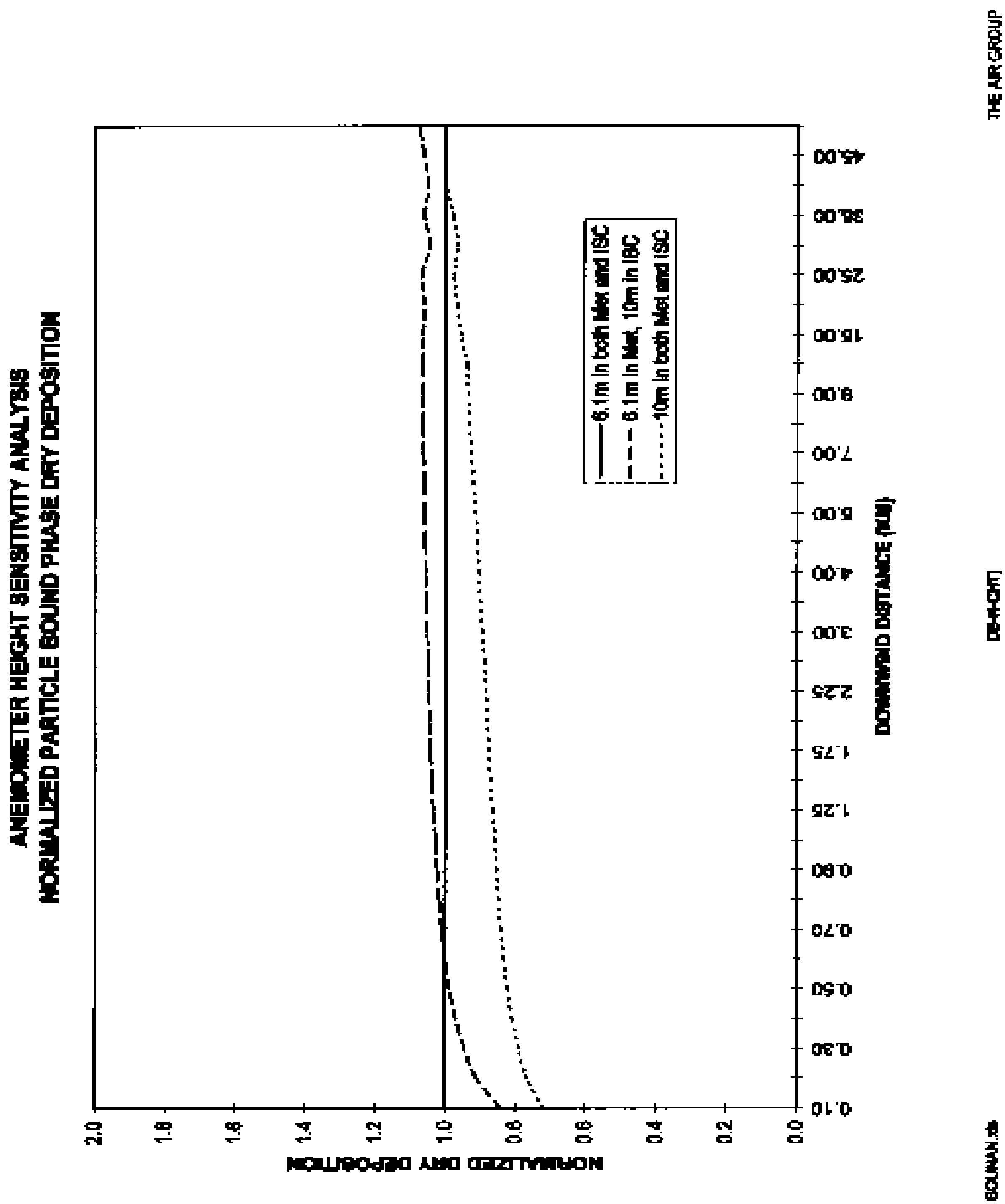
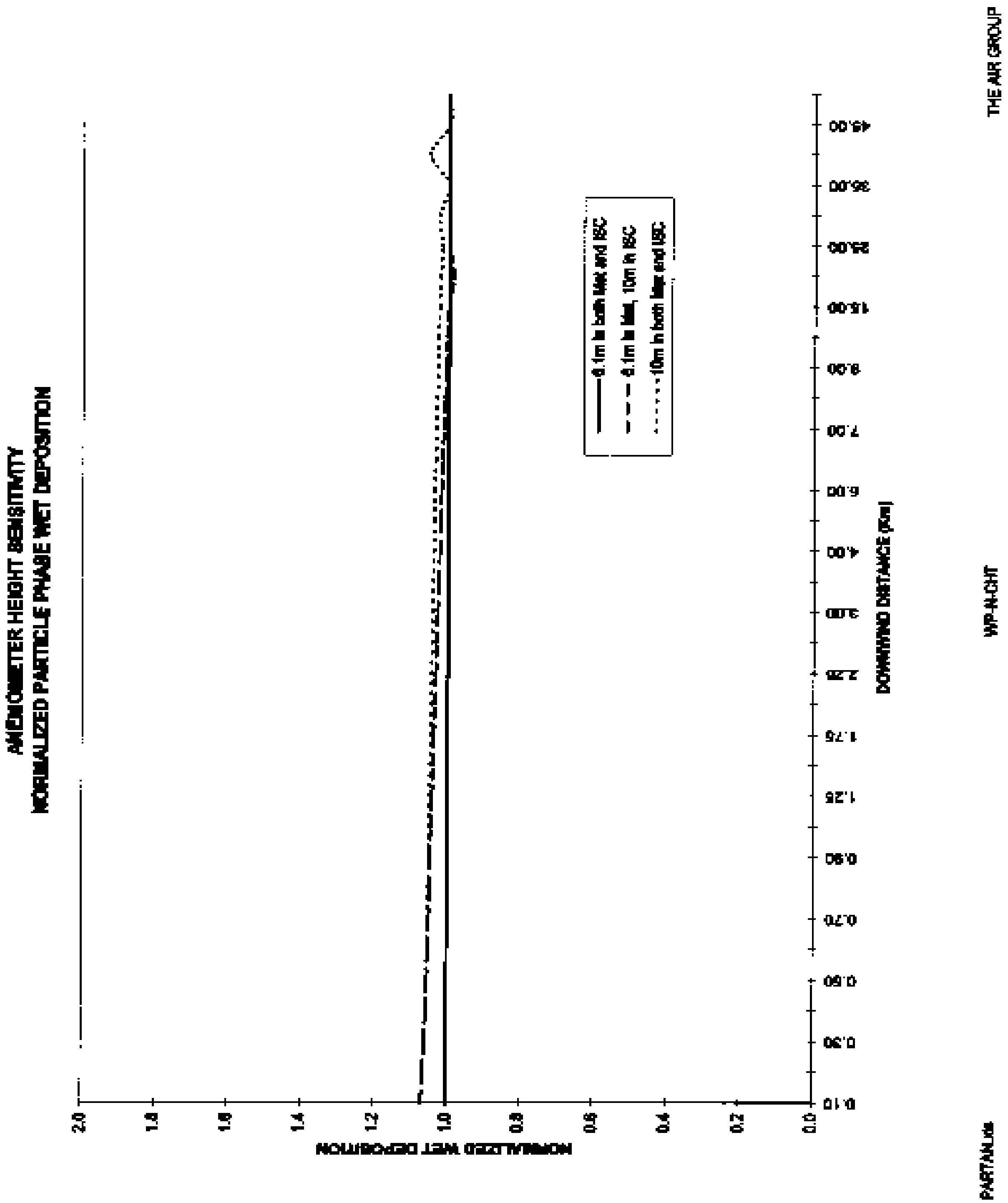
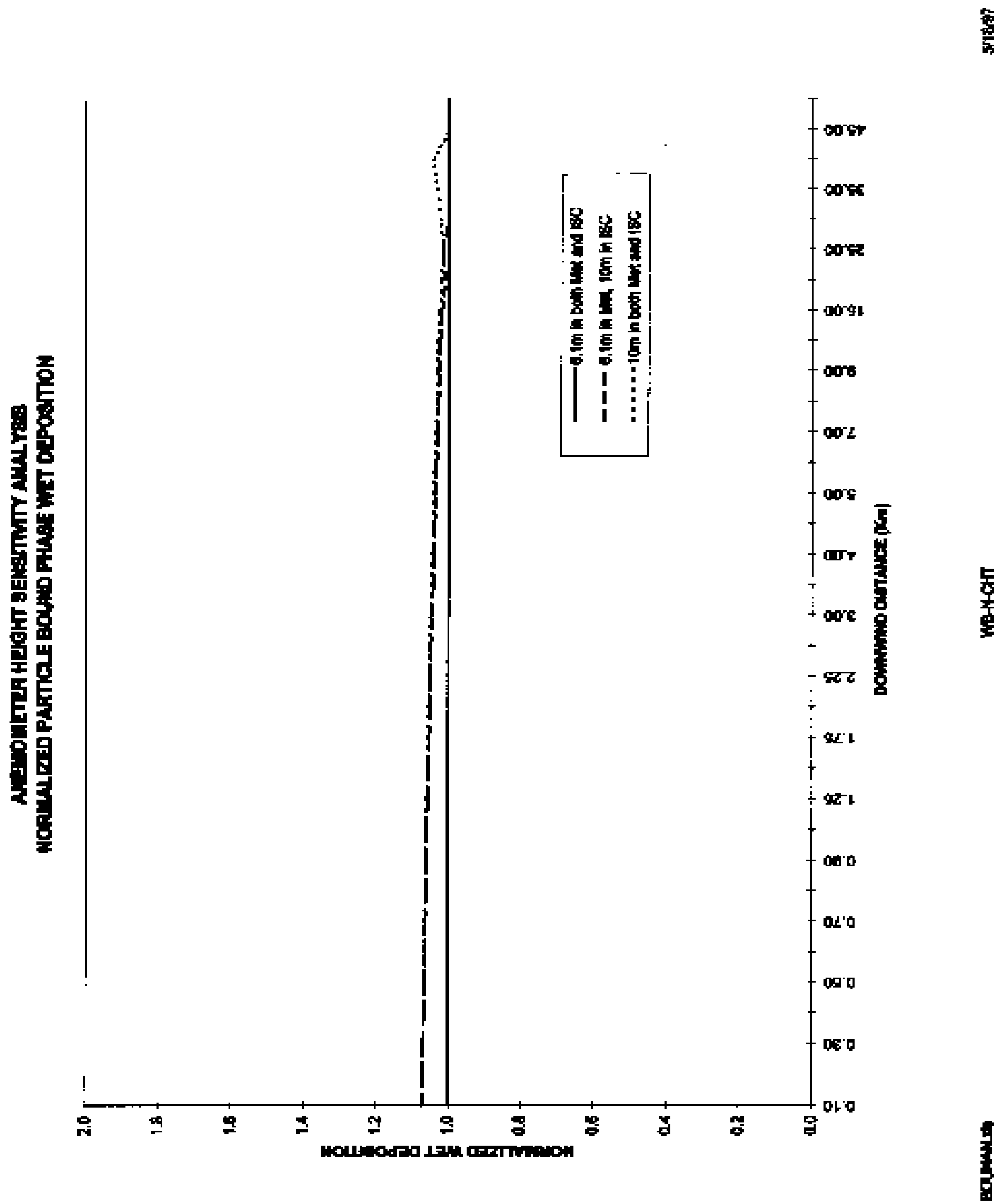
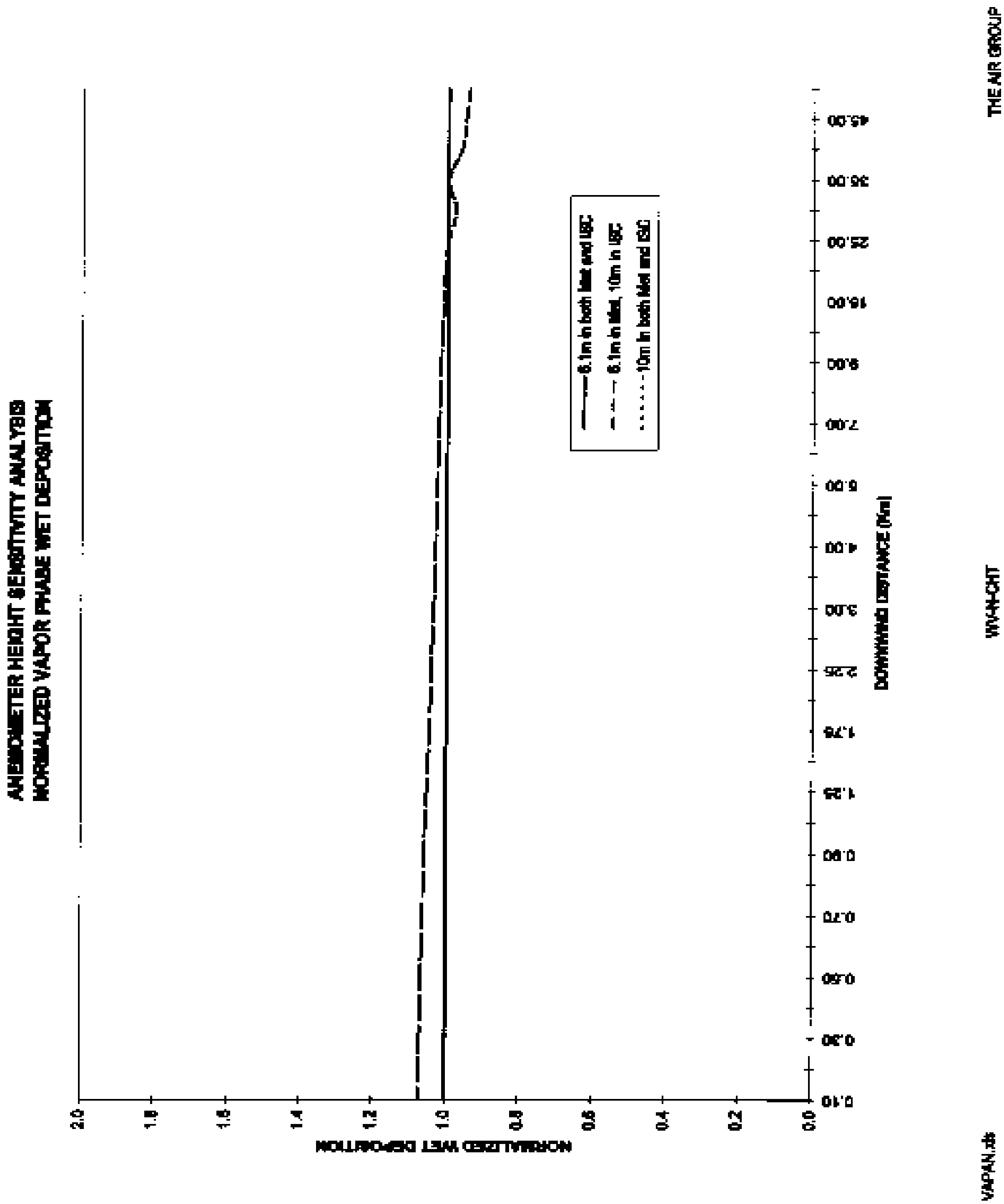
35.00
45.00
THE AIR GROUP
VAPAN.xls


ANEMOMETER HEIGHT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
6.1m in both Met and ISC
6.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


ANEMOMETER HEIGHT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
6.1m in both Met and ISC
6.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (KM)
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP


ANEMOMETER HEIGHT SENSITIVITY
NORMALIZED PARTICLE PHASE WET DEPOSITION
0.1m in both Met and ISC
0.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WP-N-CHT
PARTAN.xls


ANEMOMETER HEIGHT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
6.1m in both Met and ISC
6.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
5/18/97


ANEMOMETER HEIGHT SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
6.1m in both Met and ISC
6.1m in Met, 10m in ISC
10m in both Met and ISC
NORMALIZED WET DEPOSITION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
WV-N-CHT
VAPAN.xls

5.6 PARTICLE SIZE DISTRIBUTION AND DENSITY

5.6.1 TECHNICAL OBJECTIVE

The technical objective of the particle size and density sensitivity analysis is to determine the sensitivity of ISCST3 results to variations in particle size and density. This study also attempts to provide answers to the following questions related to particle size and density: 1) How many size categories are required to produce representative results? 2) What particle sizes are most sensitive? 3) How much resolution is required for the small particle versus the large particle sizes? 4) Can a typical particle density be specified as a default value, or is a stack-specific determination of particle density required?

5.6.2 THEORETICAL BASIS

Particle size is explicit in the deposition equations for dry particles. ISCST3 computes a terminal velocity for each particle size to determine fall rate. The particles fall out of the plume at this terminal velocity. Terminal velocity is a function of particle diameter and density. The gravitational force is balanced by the air resistance (viscosity) on the falling particle. For mathematical simplification, ISCST3 assumes all particles are spherical. The larger the particle, the higher the terminal velocity and deposition rate. The denser the particle, the higher the terminal velocity. Small particles in the range of 1.0 micrometer (micron) have very low terminal velocities and effectively are suspended in air. Larger 10 micron particles have a significant increase in terminal velocity that results in deposition near the emission source. The sensitivity of the equations to particle sizes between 1.0 and 10 micron has not been evaluated in the literature.

5.6.3 METHODOLOGY

5.6.3.1 BASE CASE

The particle and particle-bound phase model runs described in Section 4 are used as the base case for the particle size and density analyses. The vapor phase is not evaluated in these analyses because there is currently not sufficient site-specific data available to adequately model dry deposition for the vapor phase. The base case model runs are based on Protocol recommended methods and parameters, including particle size parameters specified in Table 3-1 of the Draft Protocol, a default density of 1.0 g/cm , and wet scavenging coefficients obtained from the graph in ISC3 User's Guide (U.S. EPA 1995b). The frozen scavenging coefficients are assumed to be one-third of liquid scavenging coefficients as recommended in Section 3.7.2.6 of Draft SLHHRA Protocol. The base case inputs for particle size and density for particle and particle-bound are summarized in the tables on the following page.

5.6.3.2 NUMBER OF PARTICLE SIZE CATEGORIES ANALYSIS

5.6.3.2.1 TEST CASE I - SIX (6) PARTICLE SIZE CATEGORIES

Test Case 1 is identical to the base case, except that all inputs are consolidated into six particle size categories rather than the nine categories used in the base case. The phase-specific inputs used in Test Case 1 are summarized in the following tables.

5.6.3.2.2 TEST CASE 2 - THREE (3) PARTICLE SIZE CATEGORIES

Test Case 2 is identical to the base case, except that all inputs are consolidated into three particle size categories rather than the nine categories used in the base case. The phase-specific inputs used in Test Case 2 are in the following tables.

PARTICLE PHASE BASE CASE MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Dia. (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
Mass Fraction	.224	.076	.082	.105	.103	.073	.104	.105	.128
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE-BOUND PHASE BASE CASE MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
SA Fraction	.488	.1656	.1290	.0915	.0499	.0231	.0224	.0146	.0149
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	

NUMBER OF PARTICLE SIZE CATEGORIES ANALYSIS
PARTICLE PHASE TEST CASE 1 MODEL INPUTS

Size Category	1	2	3	4	5	6
Mean Diameter (microns)	0.70	1.10	2.80	4.60	8.1	12.5
Mass Fraction	.300	.082	.157	.124	.104	.233
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.5E-4	.6E-4	2.0E-4	3.IE-4	5.2E-4	6.7E-4
Ice Scavenging Coefficient	0.2E-4	0.2E-4	0.7E-4	1.0E-4	1.7E-4	2.2E-4

NUMBER OF PARTICLE SIZE CATEGORIES ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 1 MODEL INPUTS

Size Category	1	2	3	4	5	6
Mean Diameter (microns)	.70	1.10	2.80	4.60	8.10	12.5
SA Fraction	.667	.132	.100	.048	.023	.030
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.5E-4	.6E-4	2.0E-4	3.1E-4	5.2E-4	6.7E-4
Ice Scavenging Coefficient	0.2e-4	0.2e-4	0.7e-4	1.0e-4	1.7e-4	2.2e-4

NUMBER OF PARTICLE SIZE CATEGORIES ANALYSIS
PARTICLE PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3
Mean Diameter (microns)	0.70	3.60	12.5
Mass Fraction	.382	.281	.337
Density (g/cm^3)	1.0	1.0	1.0
Liquid Scavenging Coefficient	.5E-4	2.6E-4	6.7E-4
Ice Scavenging Coefficient	0.2E-4	0.9E-4	2.2E-4

NUMBER OF PARTICLE SIZE CATEGORIES ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3
Mean Diameter (microns)	.70	3.60	12.5
SA Fraction	.783	.166	.052
Density (g/cm^3)	1.0	1.0	1.0
Liquid Scavenging Coefficient	.5E-4	2.6E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.9E-4	2.2E-4

5.6.3.3 PARTICLE SIZE RESOLUTION ANALYSIS

5.6.3.3.1 TEST CASE I - HIGH RESOLUTION FOR SMALL PARTICLE SIZES

Test Case 1 is identical to the base case, except that higher resolution (more particle size categories) is given for the smaller particle size range and lower resolution (fewer particle size categories) is given for large particle size range. The total number of categories is the same as in the base case. The phase-specific inputs are summarized in the tables on the following pages.

5.6.3.3.2 TEST CASE 2 - HIGH RESOLUTION FOR LARGE PARTICLE SIZES

Test Case 2 is identical to the base case, except that higher resolution (more particle size categories) is given for the larger particle size range and lower resolution (fewer particle size categories) is given for the smaller particle size range. The total number of categories is the same as the base case. The phase-specific inputs are summarized in the following tables.

PARTICLE SIZE RESOLUTION ANALYSIS
PARTICLE PHASE TEST CASE 1 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.1	.5	1.0	1.5	2.0	2.5	3.0	3.6	
Mass Fraction	.05	.20	.12	.07	.05	.03	.04	.03	.41
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	1.6E-4	.5E-4	.5E-4	0.8E-4	1.3E-4	2.0E-4	2.2E-4	2.6E-4	5.2E-4
Ice Scavenging Coefficient	.5E-4	.2E-4	.2E-4	.3E-4	.4E-4	.7E-4	.7E-4	.9E-4	1.7E-4

PARTICLE SIZE RESOLUTION ANALYSIS
PARTICLE-BOUND PHASE TEST CASE I MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.1	.5	1.0	1.5	2.0	2.5	3.0	3.6	8.1
SA Fraction	.425	.340	.102	.040	.021	.010	.011	.007	.043
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	1.6E-4	.5E-4	.5E-4	0.8E-4	1.3E-4	2.0E-4	2.2E-4	2.6E-4	5.2E-4
Ice Scavenging Coefficient	.5E-4	.2E-4	.2E-4	.3E-4	.4E-4	.7E-4	.7E-4	.9E-4	

PARTICLE SIZE RESOLUTION ANALYSIS
PARTICLE PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	1.1	3.6	5.0	7.0	9.0	11.0	13.0	15.0	20.0
Mass Fraction	.38	.21	.06	.08	.06	.05	.05	.03	.08
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	0.6E-4	2.6E-4	3.6E-4	4.8E-4	6.1E-4	6.7E-4	6.7E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	0.2E-4	0.9E-4	1.2E-4	1.6E-4	2.2E-4	2.2E-4	2.2E-4	2.2E-4	2.2E-4

PARTICLE SIZE RESOLUTION ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	1.1	3.6	5.0	7.0	9.0	11.0	13.0	15.0	20.0
SA Fraction	.771	.130	.027	.025	.015	.010	.009	.004	.009
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	0.6E-4	2.6E-4	3.6E-4	4.8E-4	6.1E-4	6.7E-4	6.7E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.9E-4	1.2E-4	1.6E-4	2.2E-4	2.2E-4	2.2E-4	2.2E-4	2.2E-4

5.6.3.4PARTICLE MASS DISTRIBUTION ANALYSIS

5.6.3.4.1 TEST CASE 1 - MAJORITY OF MASS IN SMALL PARTICLE RANGE

Test Case 1 is identical to the base case, except that the mass within each particle size category is redistributed such that 80% of the total mass lies within the small particle size range (3.6 micron diameter and below). The phase-specific inputs used in Test Case 1 are summarized in the following tables.

5.6.3.4.2 TEST CASE 2 - MAJORITY OF MASS IN LARGE PARTICLE RANGE

Test Case 2 is identical to the base case, except that the mass within each particle size category is redistributed such that 80% of the total mass lies within the large particle size range (3.6 micron diameter and above). The phase-specific inputs used in Test Case 2 are summarized in the following tables.

PARTICLE MASS DISTRIBUTION ANALYSIS
PARTICLE PHASE TEST CASE 1 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.1	2.0	3.6	5.5	8.1	12.5	15.0
Mass Fraction	.304	.103	.111	.142	.140	.036	.051	.051	.062
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE MASS DISTRIBUTION ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 1 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.1	2.0	3.6	5.5	8.1	12.5	15.0
SA Fraction	.513	.174	.136	.096	.052	.009	.009	.005	.006
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE MASS DISTRIBUTION ANALYSIS
PARTICLE PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.1	2.0	3.6	5.5	8.1	12.5	15.0
Mass Fraction	.092	.031	.034	.043	.160	.114	.162	.164	.200
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	

PARTICLE MASS DISTRIBUTION ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.1	2.0	3.6	5.5	8.1	12.5	15.0
SA Fraction	.362	.123	.096	.068	.140	.065	.063	.041	.042
Density (g/cm^3)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

5.6.3.5 PARTICLE DENSITY ANALYSIS

5.6.3.5.1 TEST CASE 1 - 0.5 G/CM^3 PARTICLE DENSITY

Test Case 1 is identical to the base case, except that a particle density of 0.5 g/cm^3 is used instead of the default density of 1.0 g/cm^3. The phase-specific inputs used in Test Case 1 are summarized in the following tables.

5.6.3.5.2 TEST CASE 2 - 1.5 G/CM^3 PARTICLE DENSITY

Test Case 2 is identical to the base case, except that a particle density of 1.5 g/cm^3 is used instead of the default density of 1.0 g/cm^3. The phase-specific inputs used in Test Case 2 are summarized in the following tables.

5.6.3.5.3 TEST CASE 3 - 2.0 G/CM^3 PARTICLE DENSITY

Test Case 3 is identical to the base case, except that a particle density of 2.0 g/cm^3 is used instead of the default density of 1.0 g/cm^3 . The phase-specific inputs used in Test Case 3 are summarized in the following tables.

PARTICLE DENSITY ANALYSIS
PARTICLE PHASE TEST CASE 1 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
Mass Fraction	.224	.076	.082	.105	.103	.073	.104	.105	.128
Density (g/cm^3)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE DENSITY ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 1 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
SA Fraction	.488	.1656	.1290	.0915	.0499	.0231	.0224	.0146	.0149
Density (g/CM^3)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE DENSITY ANALYSIS
PARTICLE PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
Mass Fraction	.224	.076	.082	.105	.103	.073	.104	.105	.128
Density (g/cm^3)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE DENSITY ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 2 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
SA Fraction	.488	.1656	.1290	.0915	.0499	.0231	.0224	.0146	.0149
Density (g/cm^3)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE DENSITY ANALYSIS
PARTICLE PHASE TEST CASE 3 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
Mass Fraction	.224	.076	.082	.105	.103	.073	.104	.105	.128
Density (g/cm^3)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

PARTICLE DENSITY ANALYSIS
PARTICLE-BOUND PHASE TEST CASE 3 MODEL INPUTS

Size Category	1	2	3	4	5	6	7	8	9
Mean Diameter (microns)	.35	.70	1.10	2.00	3.60	5.50	8.10	12.5	15.0
SA Fraction	.488	.1656	.1290	.0915	.0499	.0231	.0224	.0146	.0149
Density (g/cm^3)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Liquid Scavenging Coefficient	.7E-4	.5E-4	.6E-4	1.3E-4	2.6E-4	3.9E-4	5.2E-4	6.7E-4	6.7E-4
Ice Scavenging Coefficient	.2E-4	.2E-4	.2E-4	.4E-4	.9E-4	1.3E-4	1.7E-4	2.2E-4	2.2E-4

5.6.4 RESULTS

5.6.4.1 NUMBER OF PARTICLE SIZE CATEGORIES ANALYSIS

5.6.4. 1.1 CONCENTRATION

The results of the number of particle size categories sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute concentration and normalized concentration versus downwind distance are presented in Appendix A for all cases. Using either three or six categories of particulate sizes results in variations in concentration of less than 3% from the base case of nine categories.

5.6.4.1.2 DRY DEPOSITION

The results of the number of particle size categories sensitivity analysis in terms of normalized dry deposition versus downwind distance are presented in figures at the end of this section.

Tables of absolute dry deposition and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

Using either three or six categories of particulate sizes results in variations in dry deposition of less than 7% from the base case of nine categories.

5.6.4.1.3 WET DEPOSITION

The results of the number of particle size categories sensitivity analysis in ten-ns of normalized wet deposition (test case wet deposition divided by base case wet deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute wet deposition and normalized wet deposition versus downwind distance are presented in Appendix A for all cases. Using either three or six categories of particulate sizes results in variations in wet deposition of less than 10% from the base case of nine categories.

5.6.4.2 PARTICLE SIZE RESOLUTION ANALYSIS

5.6.4.2.1 CONCENTRATION

The results of the particle size resolution sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized concentration versus downwind distance are presented in Appendix A for all cases.

Only small variations of concentration occur due to skewing of the particle size resolution toward either small or larger particles. For the particle phase, there is virtually no variation (less than 1%) in concentration out to a distance of 500 meters. The maximum variation occurs at 50 kilometers from the source, where higher resolution for small particles produced 10% higher concentrations than the base case. The particle-bound phase concentrations show even less variation than particle phase concentrations.

5.6.4.2.2 DRY DEPOSITION

The results of the particle size resolution sensitivity analysis in terms of normalized dry deposition (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

Dry deposition has the greatest sensitivity to particle size resolution. Higher resolution for the smaller particles produces approximately 20% to 40% lower dry deposition rates than the base case for most downwind distances, depending on the phase. For the particle phase, higher resolution for large particles produced virtually no variations from the base case. Yet, for the particle-bound phase, higher resolution for large particles produced approximately 20% higher dry deposition rates than the base case.

5.6.4.2.3 WET DEPOSITION

The results of the particle size resolution sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case wet deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

Particle size resolution variations produced variations of up to 20% compared to the base case. For the particle phase, higher resolution for small particles produced lower wet deposition rates than the base case, and higher resolution for large particles produced higher wet deposition rates than the base case for most downwind distances. For particle-bound phase both test cases produced higher wet deposition rates than the base case for most distances.

5.6.4.3 PARTICLE MASS DISTRIBUTION ANALYSIS

5.6.4.3.1 CONCENTRATION

The results of the particle mass distribution sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized concentration versus downwind distance are presented in Appendix A for all cases. Only small variations of concentration are observed due to variations in particle mass distribution. For the particle phase, there is less than 1% variation in concentration compared to the base case at 100 meters from the source, with variation increasing gradually to a maximum of 18% at a distance of 50 kilometers. The particle-bound phase concentrations show even less variation, with a maximum 7% at 50 kilometers from the source. For both phases, skewing the mass distribution toward the larger particle size range produced lower concentrations than the base case and skewing the mass distribution toward the small particle size range produced higher concentrations than the base case.

5.6.4.3.2 DRY DEPOSITION

The results of the particle size resolution sensitivity analysis in terms of normalized dry deposition (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized dry deposition versus downwind distance are presented in Appendix A for all cases. Dry deposition experienced the greatest sensitivity to particle mass distribution. Skewing the mass distribution toward the larger particle range produced approximately 50% to 250% higher dry deposition rates than the base case for most downwind distances, depending on the phase. Skewing the mass distribution toward the smaller particle range produced approximately 50% lower dry deposition rates than the base case for most downwind distances (for both phases).

5.6.4.3.3 WET DEPOSITION

The results of the particle mass distribution sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case wet deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

Wet deposition is almost as sensitive to particle mass distribution than dry deposition. Particle mass distribution variations produced variations in wet deposition rates of up to 70% compared to the base case. For both particle and particle-bound phases skewing mass toward larger particles produced higher wet deposition rates than the base case from 100 meters to about 9 to 15 kilometers from the source, depending on the phase, and lower wet deposition rates beyond that. Skewing the mass toward the smaller particles had the opposite effect.

5.6.4.4 PARTICLE DENSITY ANALYSIS

5.6.4.4.1 CONCENTRATION

The results of the particle density sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized concentration versus downwind distance are presented in Appendix A for all cases.

Only small variations of concentration are observed due to variations in particle density. For the particle phase, there is less than 1% variation in concentration compared to the base case out to 700 meters from the source with variation increasing gradually to a maximum of 12% at a distance of 50 kilometers. The particle-bound phase concentrations show even less variation with a maximum of 3% at 50 kilometers from the source. For both phases the denser particles produced lower concentrations than the base case and the lighter particles produced higher concentrations than the base case.

5.6.4.4.2 DRY DEPOSITION

The results of the particle density sensitivity analysis in terms of normalized dry deposition (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

Dry deposition experienced the greatest sensitivity to particle density. The denser particles produced 40% to 50% higher dry deposition rates than the base case for most downwind distances, depending on the phase. The lighter particles produced 30% to 40% lower dry deposition rates than the base case for most downwind distances (for both phases).

5.6.4.4.3 WET DEPOSITION

The results of the particle density sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case wet deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

Wet deposition is not very sensitive to particle density. There is virtually no variation (less than

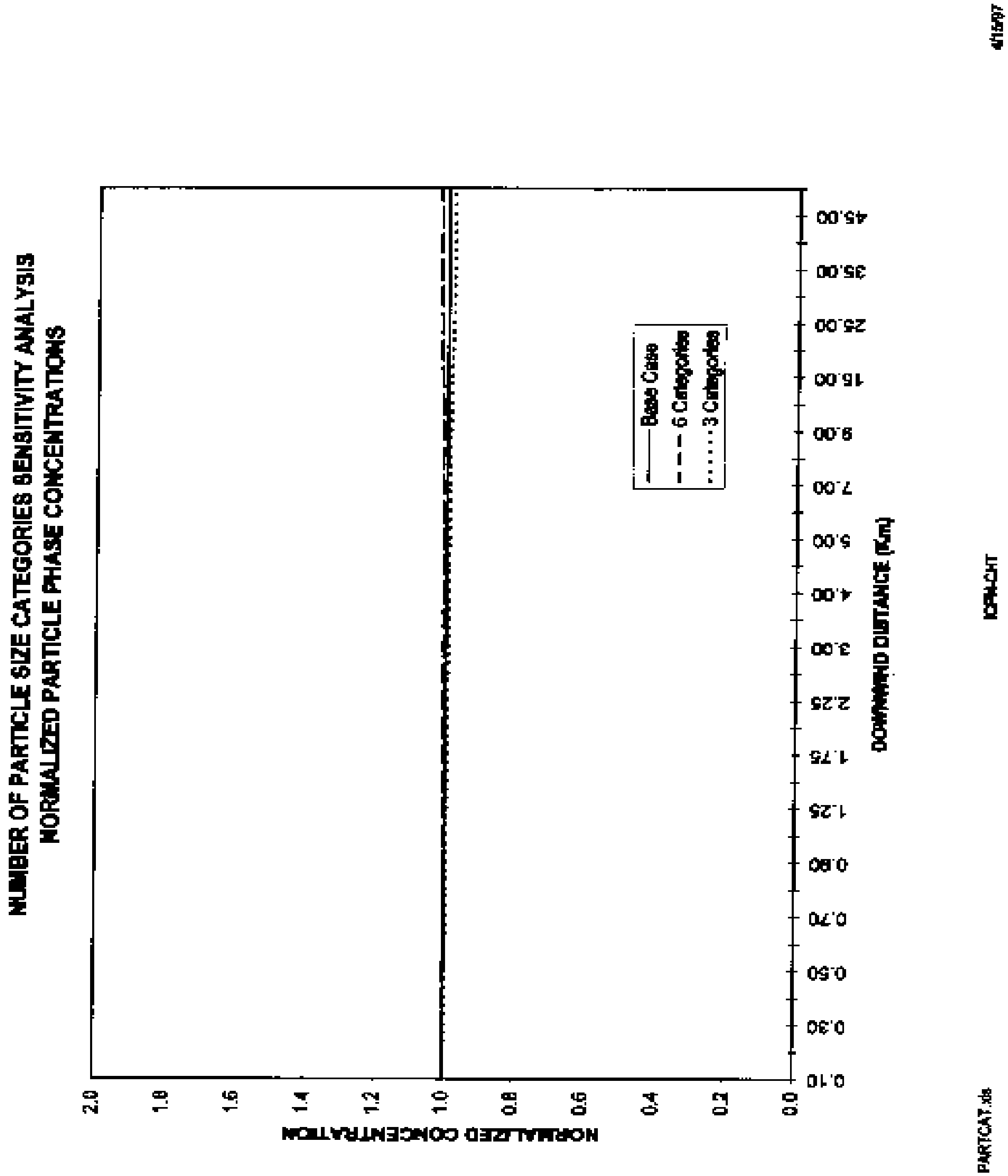
1%) within one kilometer of the source. The variation increases with distance, but only to a maximum of 7% at very remote distances. The denser particles produce lower wet deposition rates than the base case, and the lighter particles produce higher wet deposition rates than the base case.

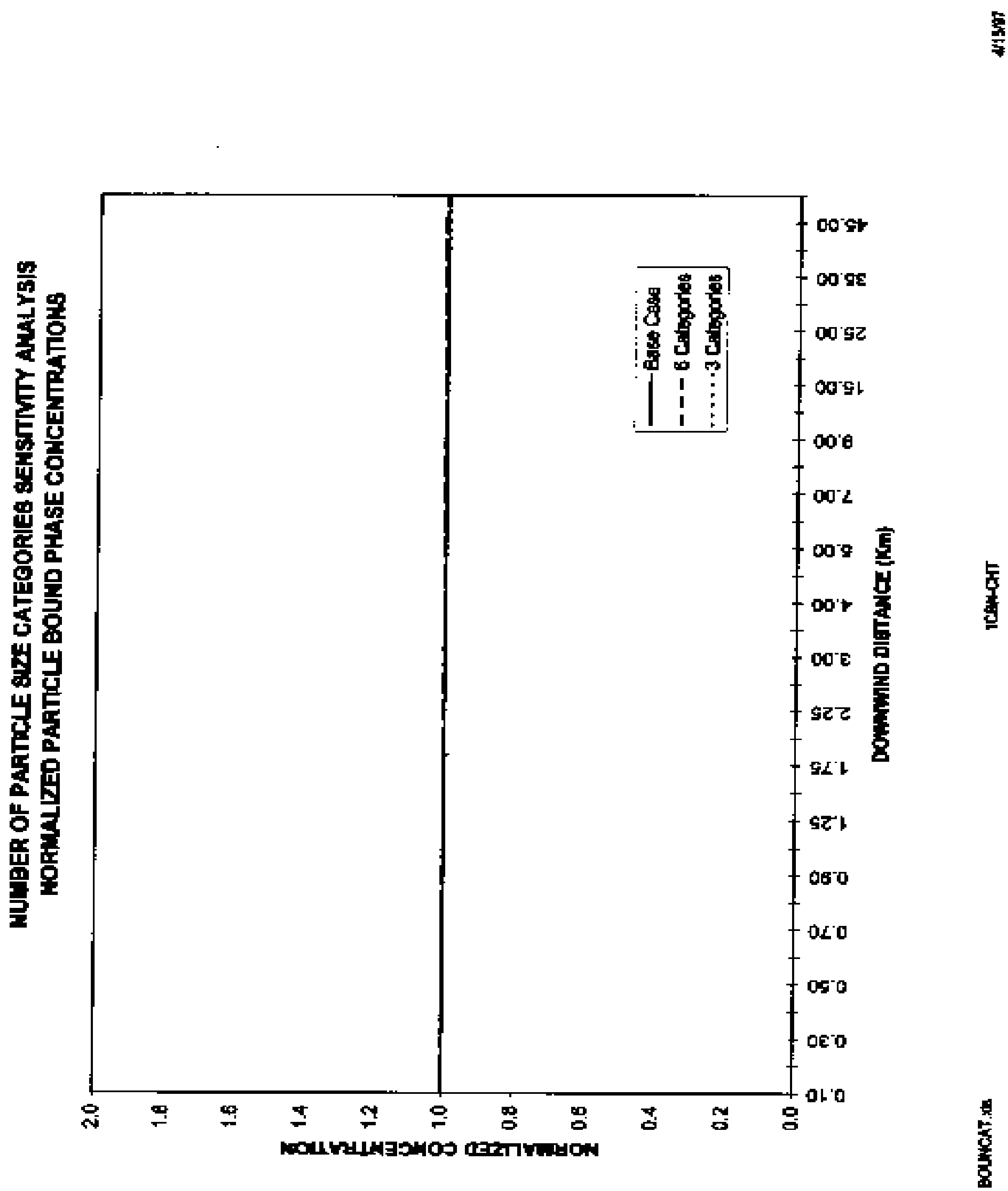
5.6.5 RECOMMENDATIONS

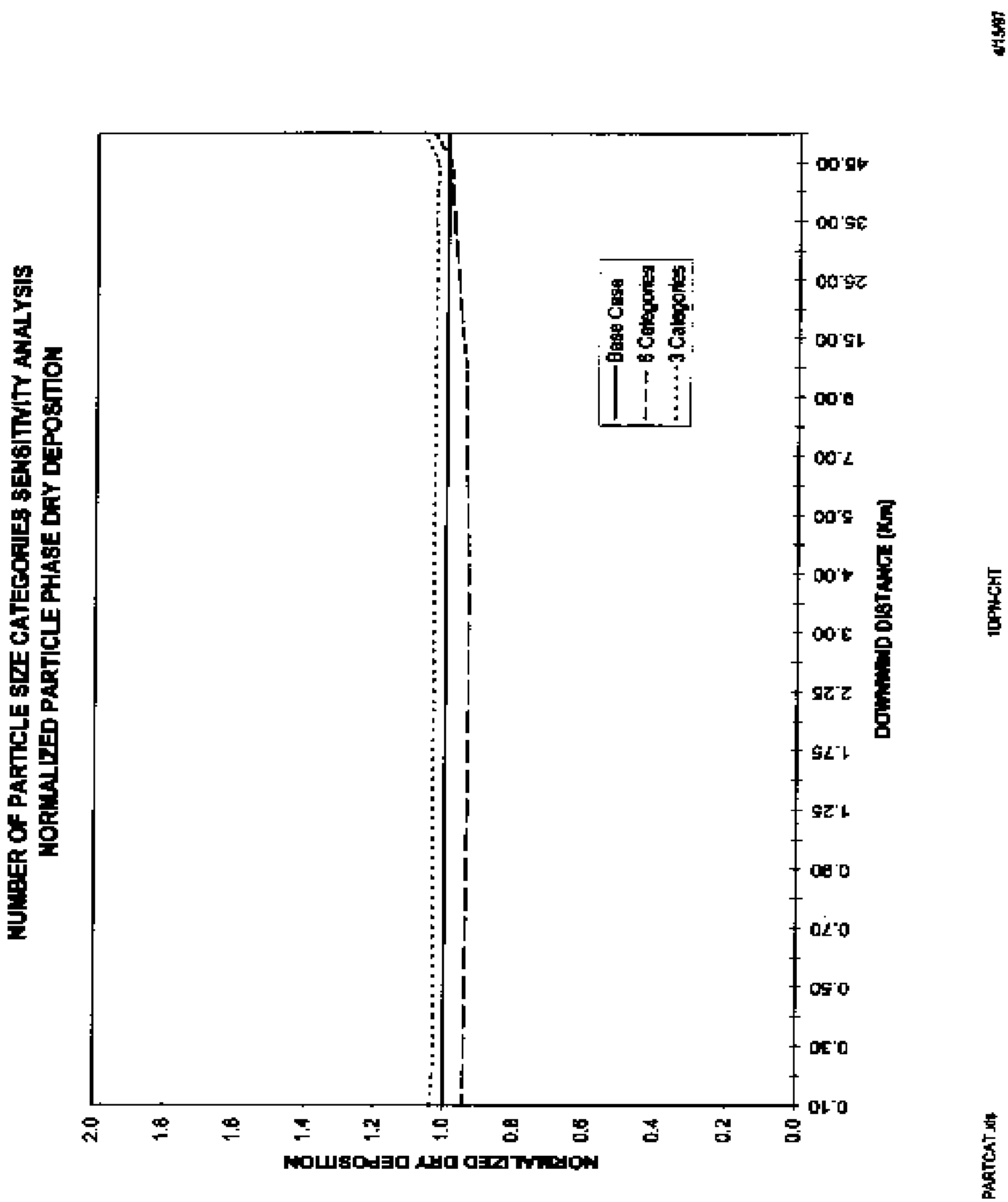
EPA could require as few as three size categories representative of the range of sizes for a facility and still achieve excellent modeling results. The number of particle size categories has little effect on the modeled results (less than 10%) for concentration, dry and wet deposition. However, the number of categories increases computer run time proportionately. Increasing the number of size categories to six or nine does not improve model results. EPA should consider specifying the size categories required for stack testing and model analyses. For a facility that provides nine size categories with high resolution in the smaller particle sizes, the modeled results will only slightly increase the concentration of suspended particles, but will significantly decrease deposition rates. Conversely, higher resolution in the larger particle sizes will increase deposition significantly and slightly reduce concentrations.

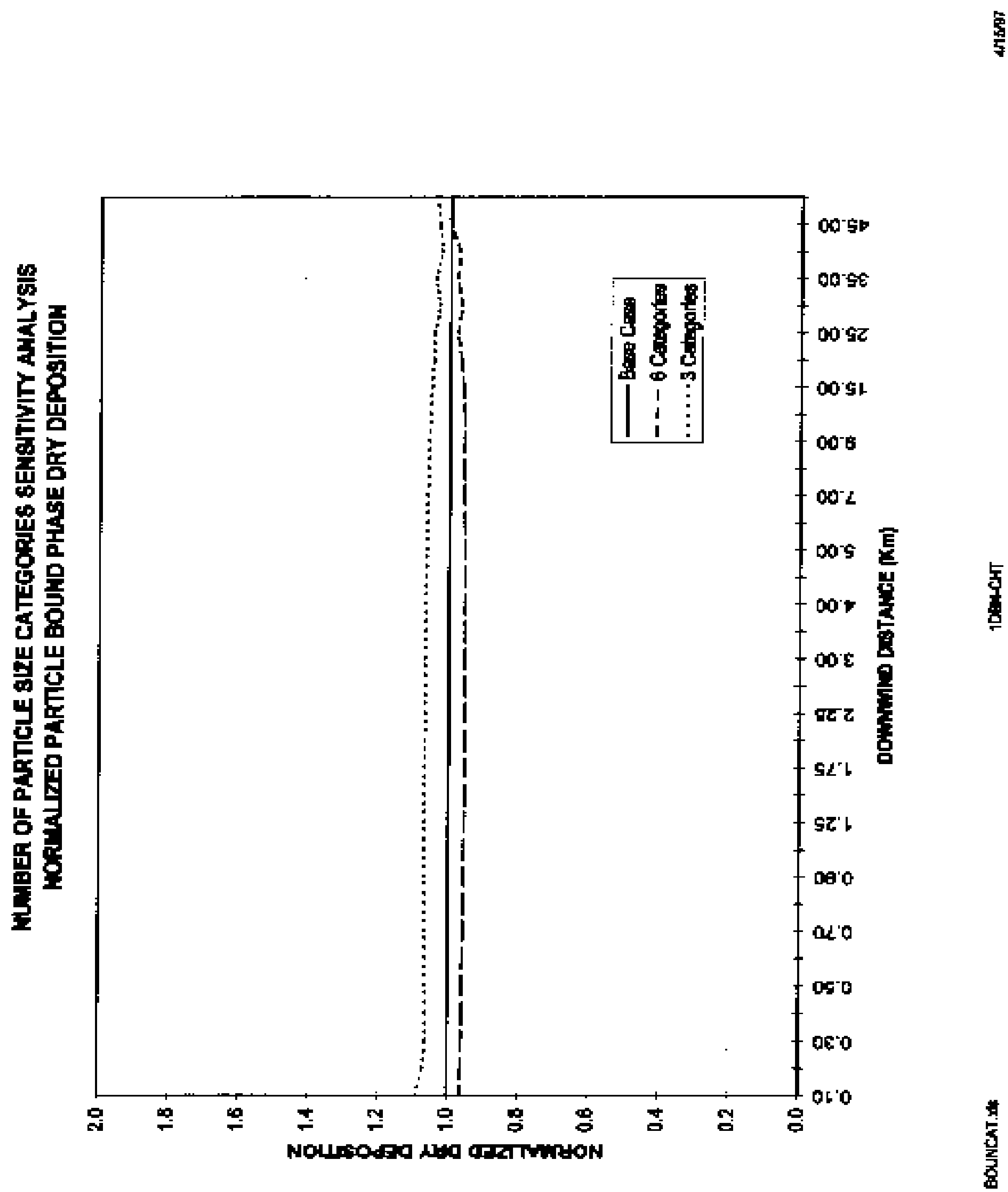
EPA should evaluate stack test data for consistency among similar processes and waste fuels. If test results are biased toward larger particles through test methods, quality assurance, or bum conditions, the facility deposition rates will be biased high resulting in higher deposited COPC near the source and reduced concentration and deposition away from the source. Conversely, small-biased data will decrease deposition near the facility and increase concentrations and deposition away from the source. For overall risk, facilities which report very small particles or mass biased in small size ranges should have the COPC characteristics or control technology which corresponds to stack test data to prevent significant under estimates of deposition near the source and potentially higher associated risks.

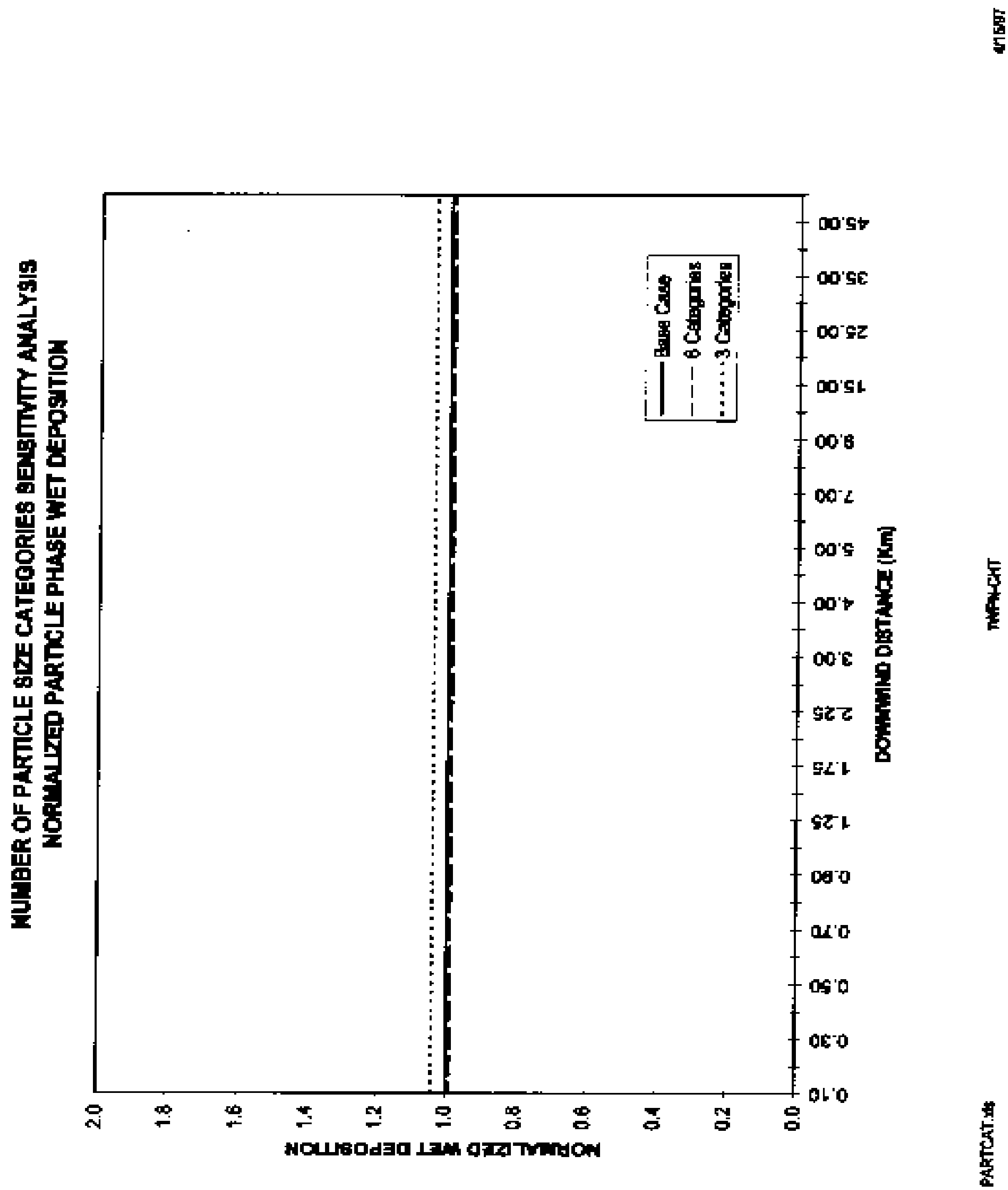
EPA should consider the value accepted for particle density and require stack test data. High density particles (greater than 1.0 g/cm^3) have correspondingly high deposition rates near the source. Low density (less than 1.0 g/cm^3) particles have reduced deposition rates near the source. Density has little affect on concentrations. The cement industry report very high densities (greater than 2.0 g/cm^3) which deposits COPCs immediately near the source. Combined with wet deposition occurring close to the source, high deposition rates on the facility and near the property should be expected for risk exposure.

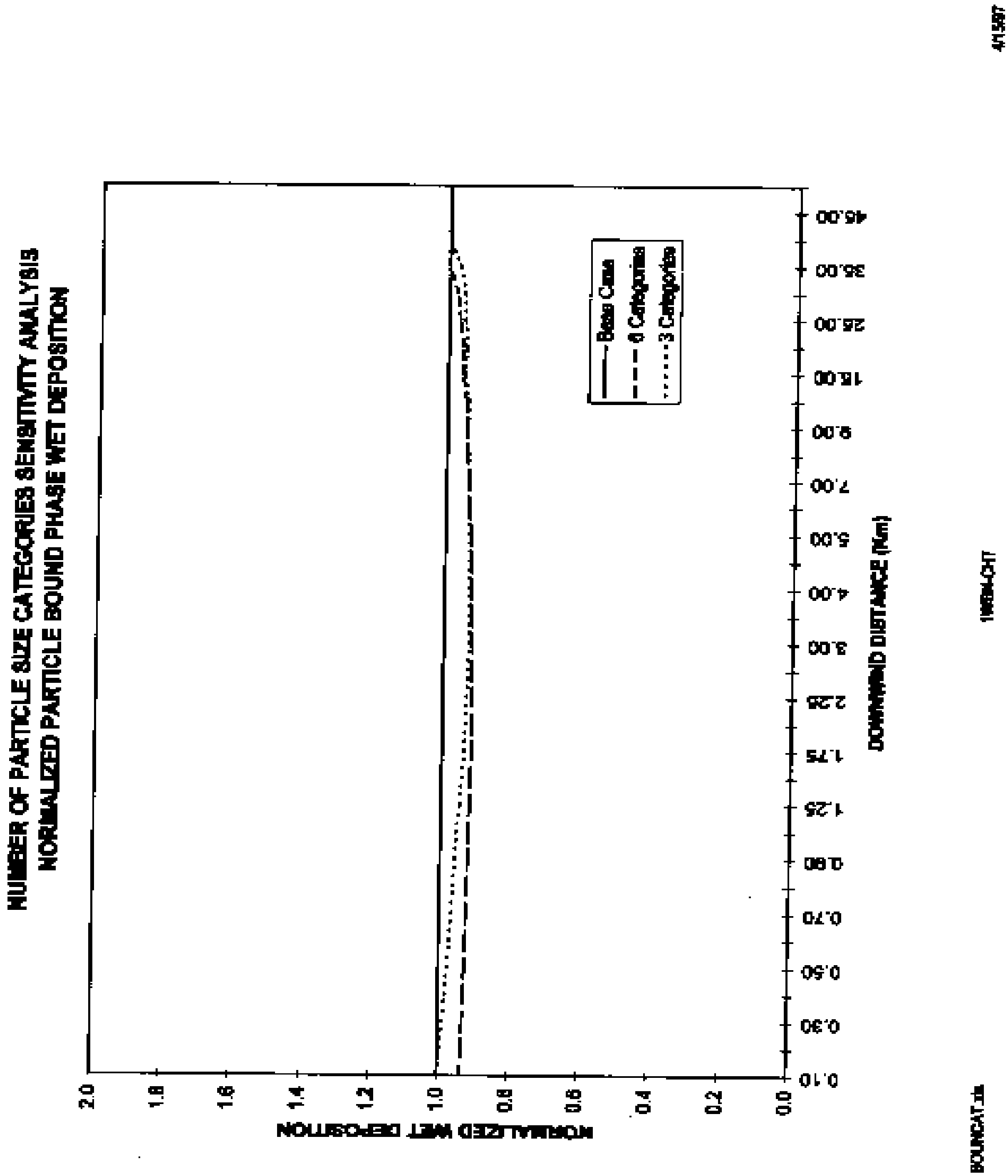

NUMBER OF PARTICLE SIZE CATEGORIES SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATIONS
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
Base Case
6 Categories
3 Categories
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
4/15/97
IOPM-CHT
PARTCAT.ds

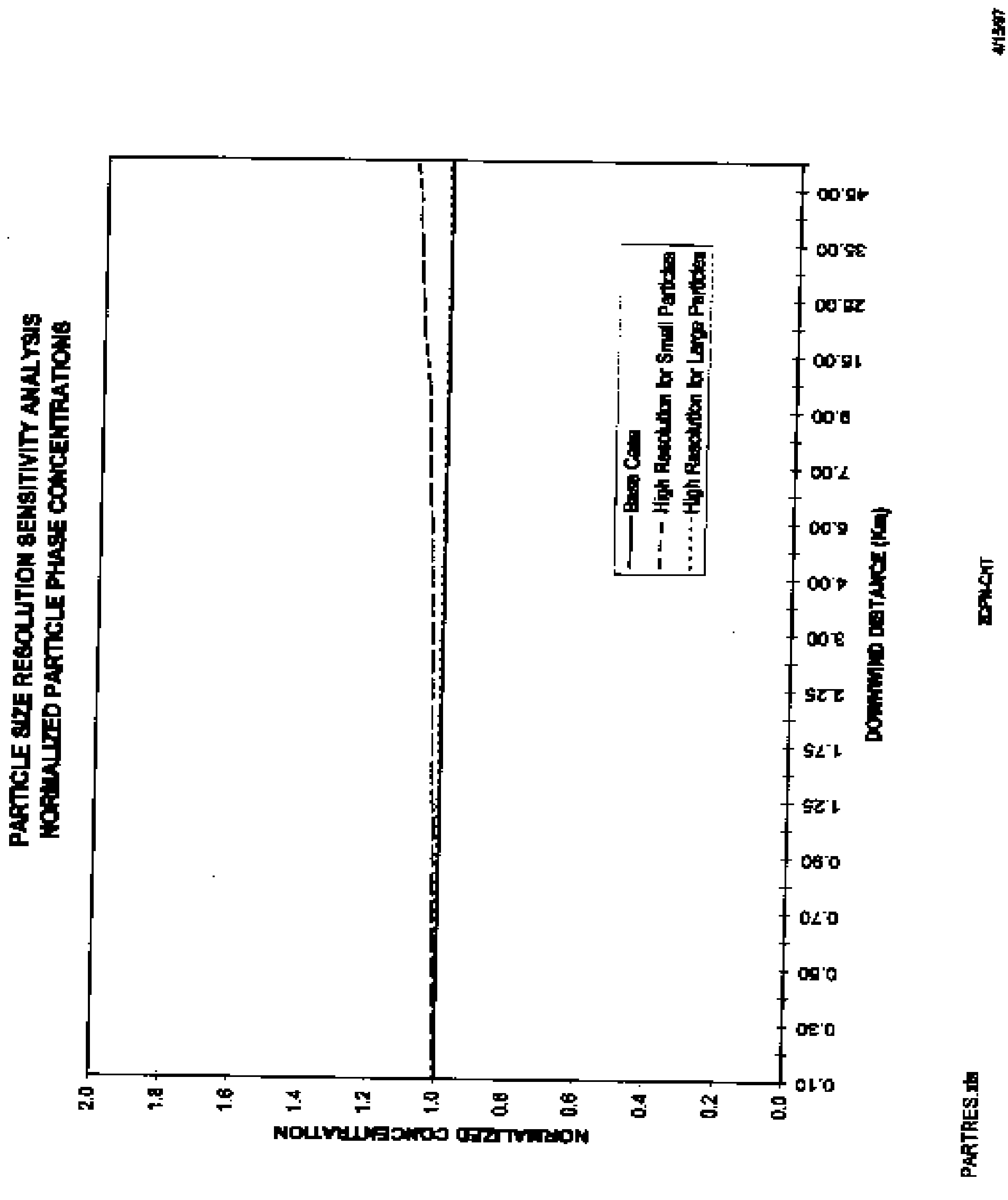

NUMBER OF PARTICLE SIZE CATEGORIES SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATIONS
NORMALIZED CONCENTRATION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
8.00
15.00
25.00
35.00
45.00
Base Case
6 Categories
3 Categories
BOUNCAT.xls
1CBN-CHT
4/15/97

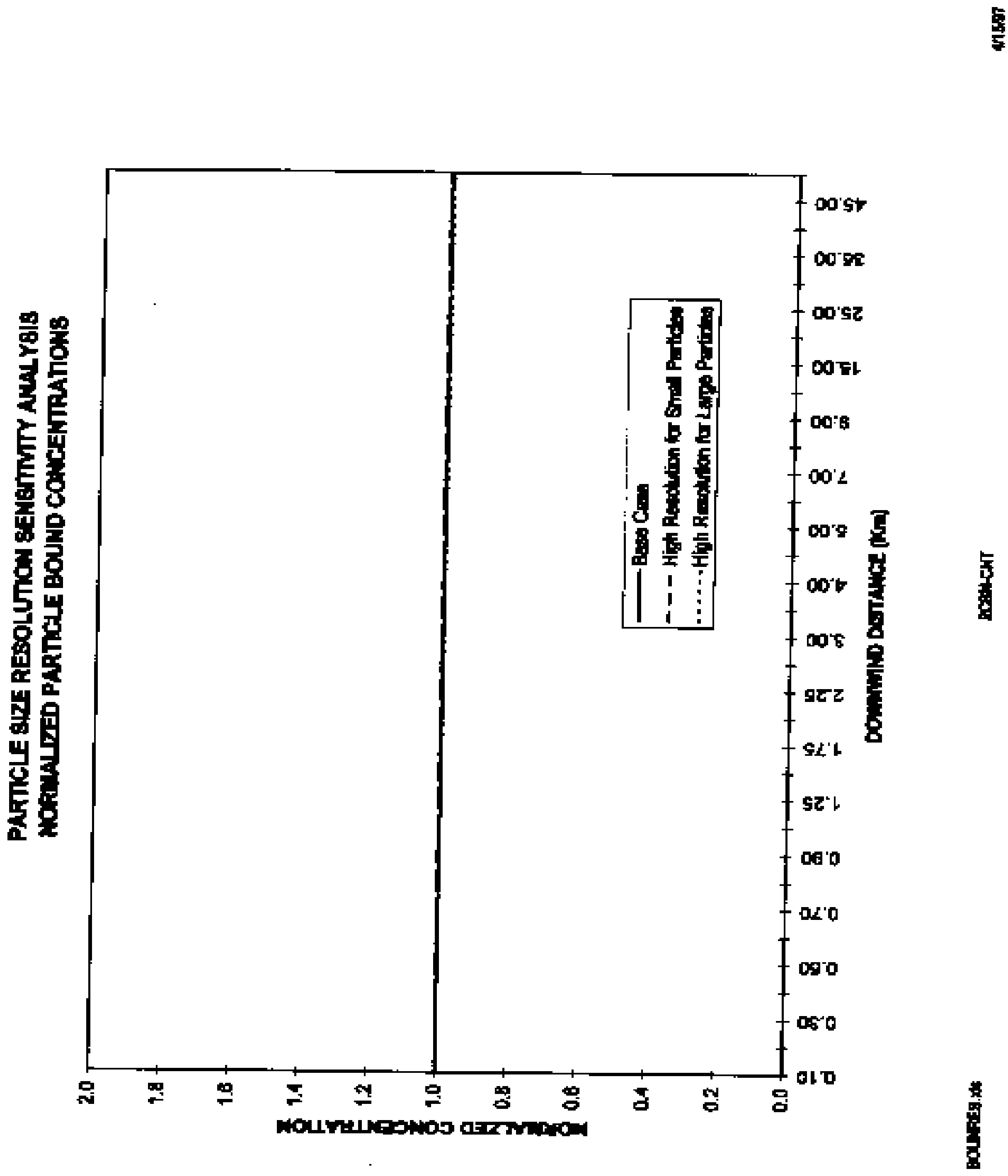

NUMBER OF PARTICLE SIZE CATEGORIES SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Base Case
6 Categories
3 Categories
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
PARTCAT.xls
1DPN-CHT
4/15/97

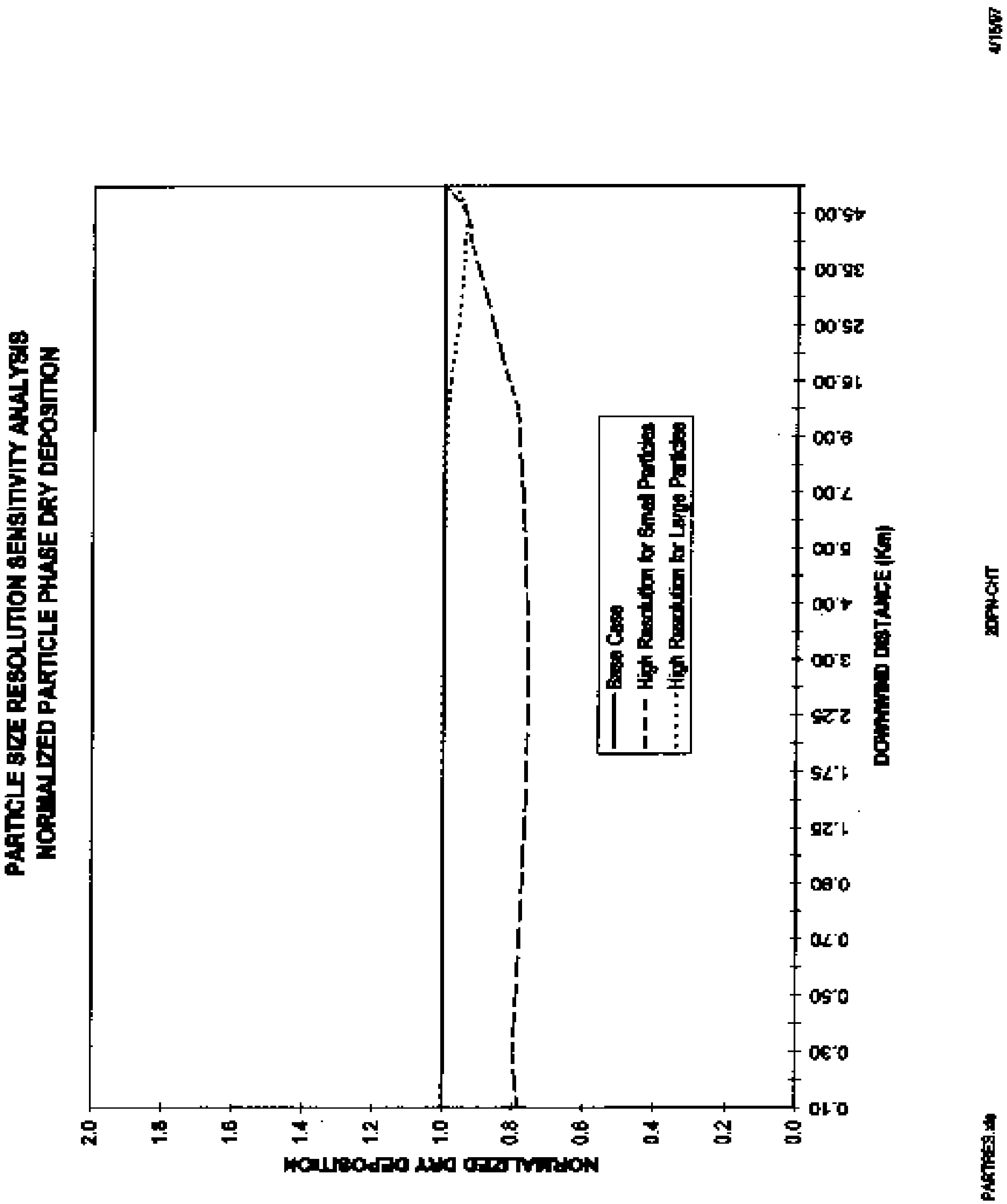

NUMBER OF PARTICLE SIZE CATEGORIES SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
Base Case
6 Categories
3 Categories
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00


NUMBER OF PARTICLE SIZE CATEGORIES SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Base Case
6 Categories
3 Categories
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
4/15/97
TWPN-CHT
PARTCAT.xls


NUMBER OF PARTICLE SIZE CATEGORIES SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Base Case
6 Categories
3 Categories
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
BOUNCAT.xls


PARTICLE SIZE RESOLUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATIONS
Base Case
High Resolution for Small Particles
High Resolution for Large Particles
DOWNWIND DISTANCE (Km)
NORMALIZED CONCENTRATION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
PARTRES.xls


PARTICLE SIZE RESOLUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND CONCENTRATIONS
Base Case
High Resolution for Small Particles
High Resolution for Large Particles
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)


PARTICLE SIZE RESOLUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Base Case
High Resolution for Small Particles
High Resolution for Large Particles
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
4/15/97
PARTRES.xls
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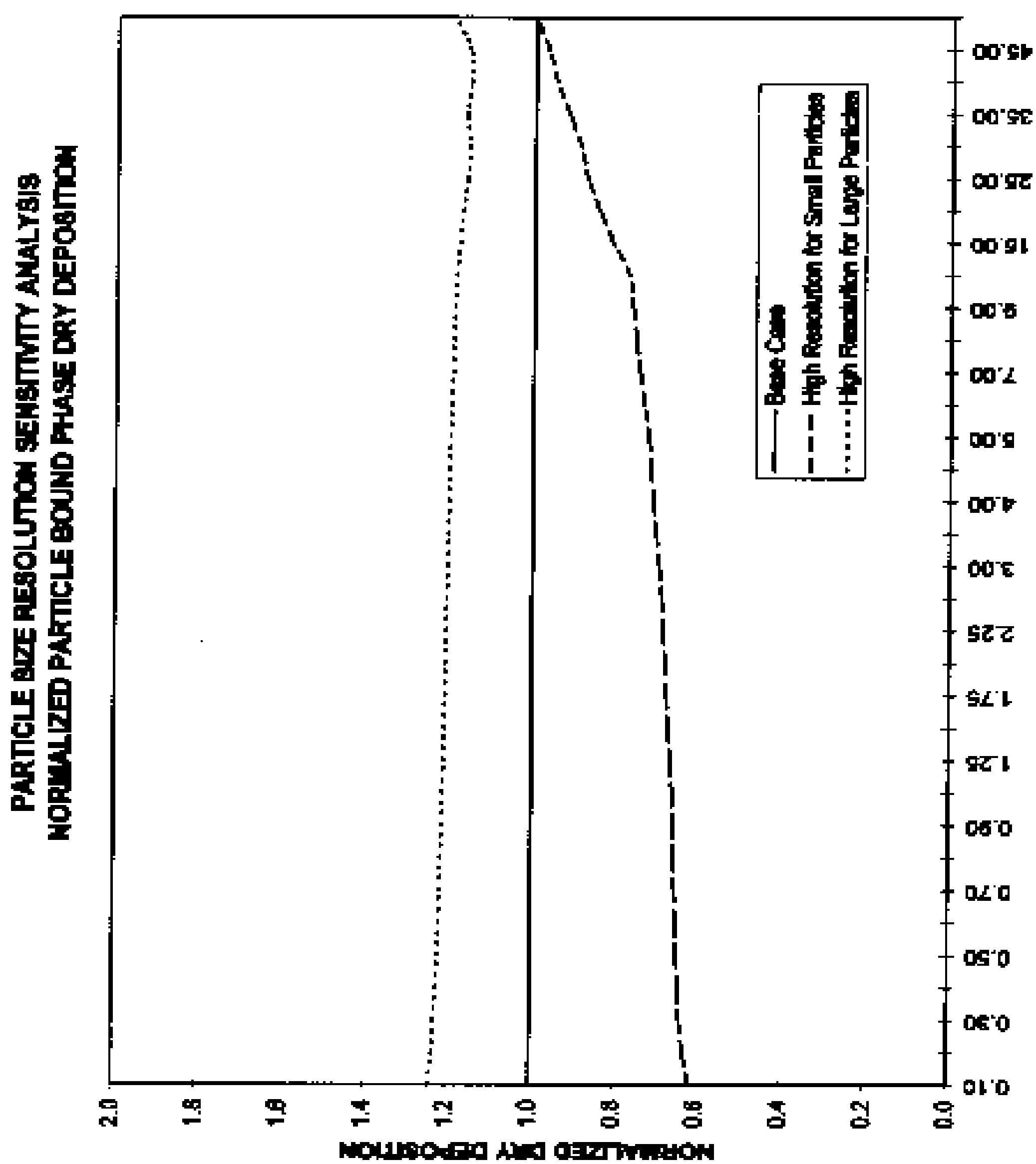
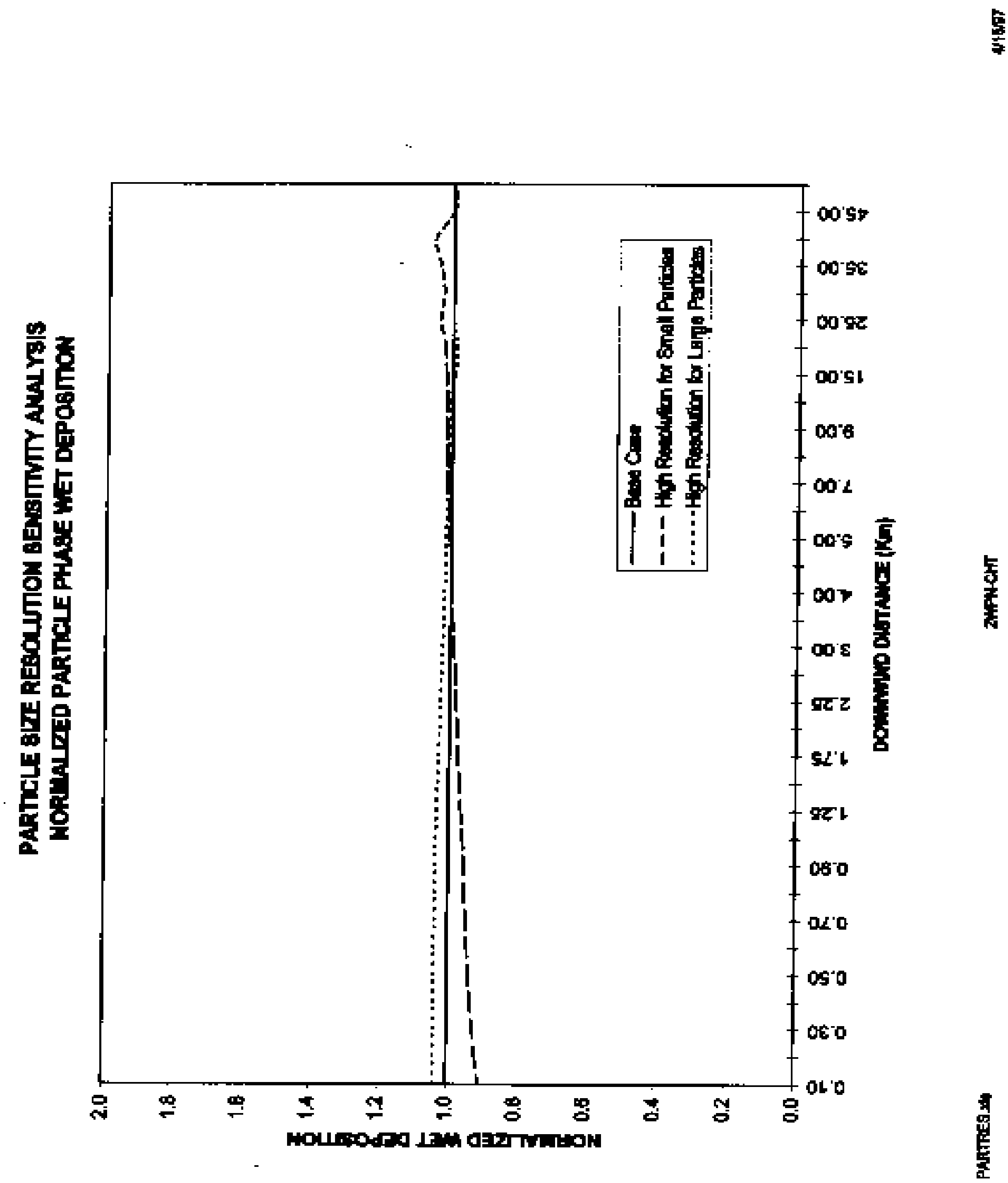

PARTICLE SIZE RESOLUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Base Case
High Resolution for Small Particles
High Resolution for Large Particles
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)


PARTICLE SIZE RESOLUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Base Case
High Resolution for Small Particles
High Resolution for Large Particles
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
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9.00
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35.00
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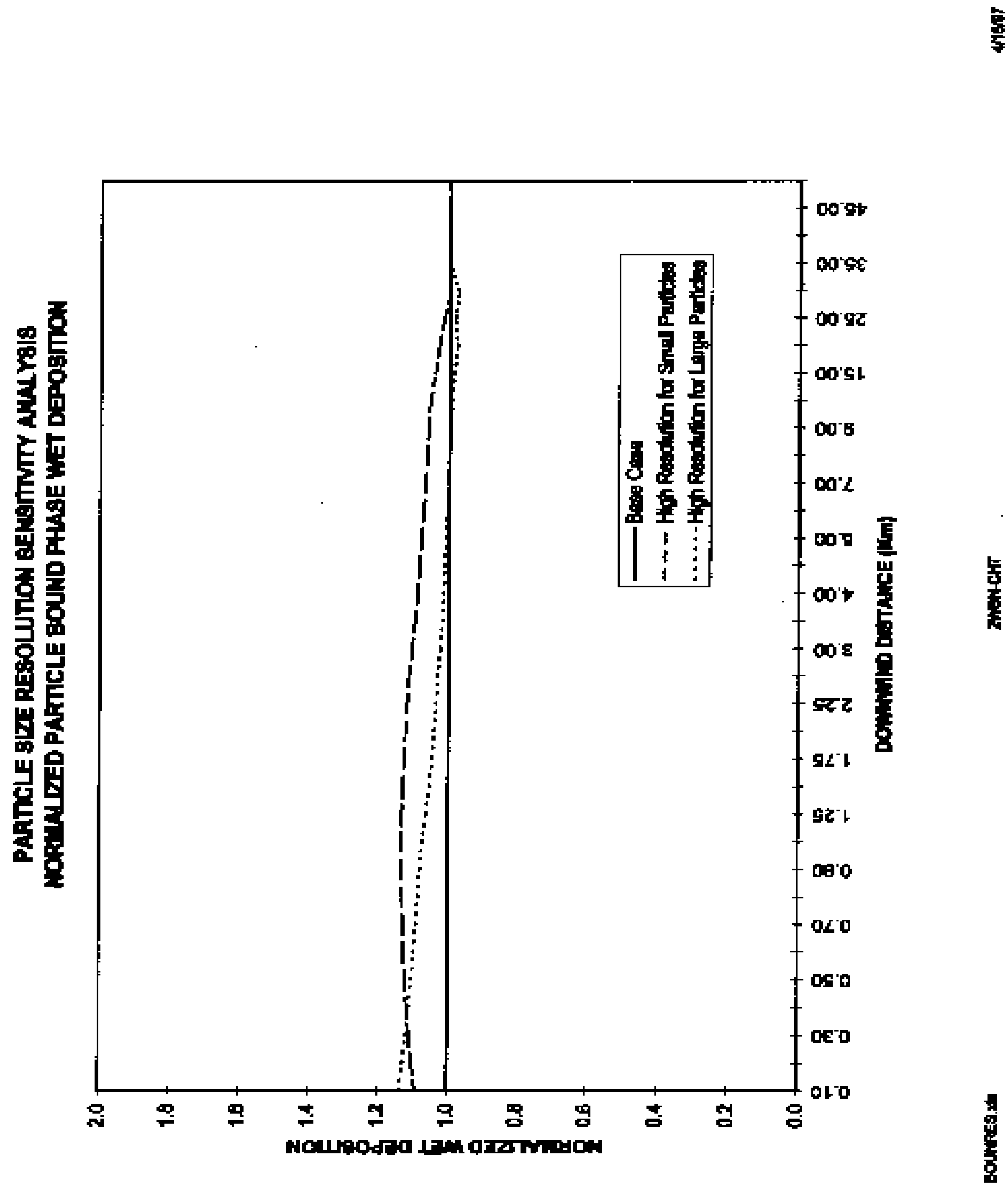
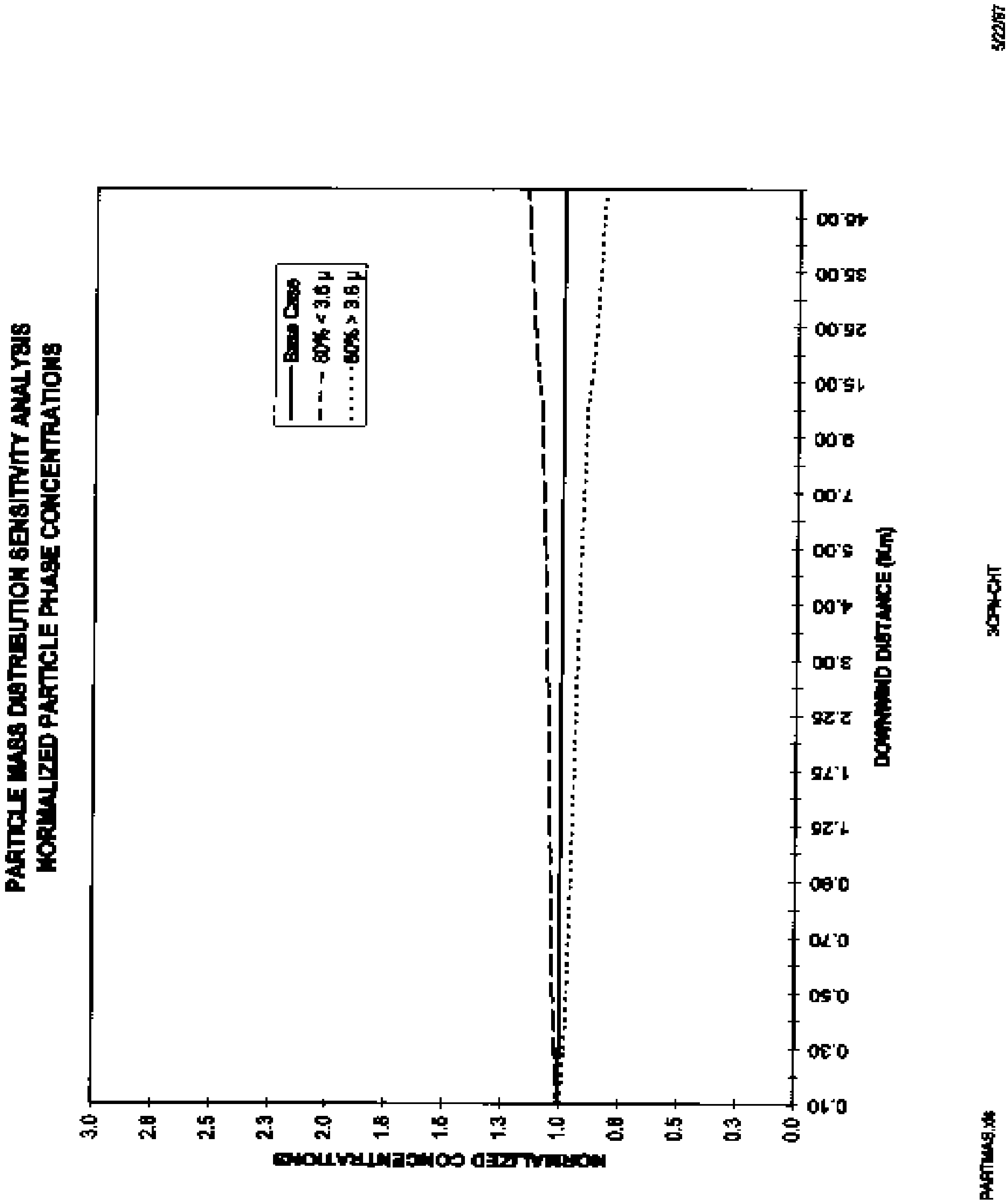

PARTICLE SIZE RESOLUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Base Case
High Resolution for Small Particles
High Resolution for Large Particles
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
0.10 0.30 0.50 0.70 0.80 1.25 1.75 2.25 3.00 4.00 5.00 7.00 9.00 15.00 25.00 35.00 45.00
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0



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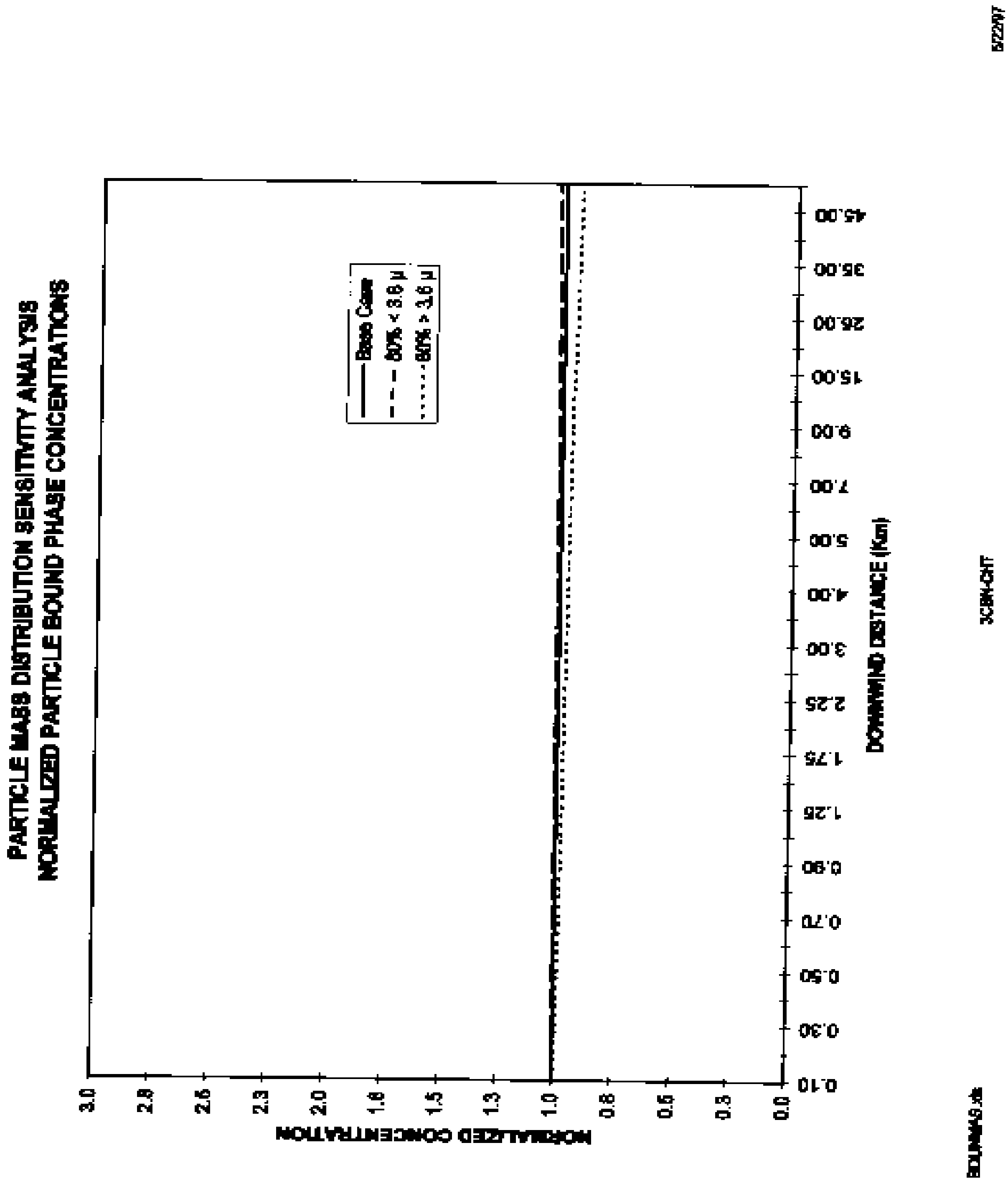
PARTICLE MASS DISTRIBUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATIONS
Base Case
80% < 3.6 µ
80% > 3.6 µ
NORMALIZED CONCENTRATIONS
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
3CPN-CHT
PARTMAS.lds


PARTICLE MASS DISTRIBUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATIONS
Base Case
80% < 3.6 μ
80% > 3.6 μ
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
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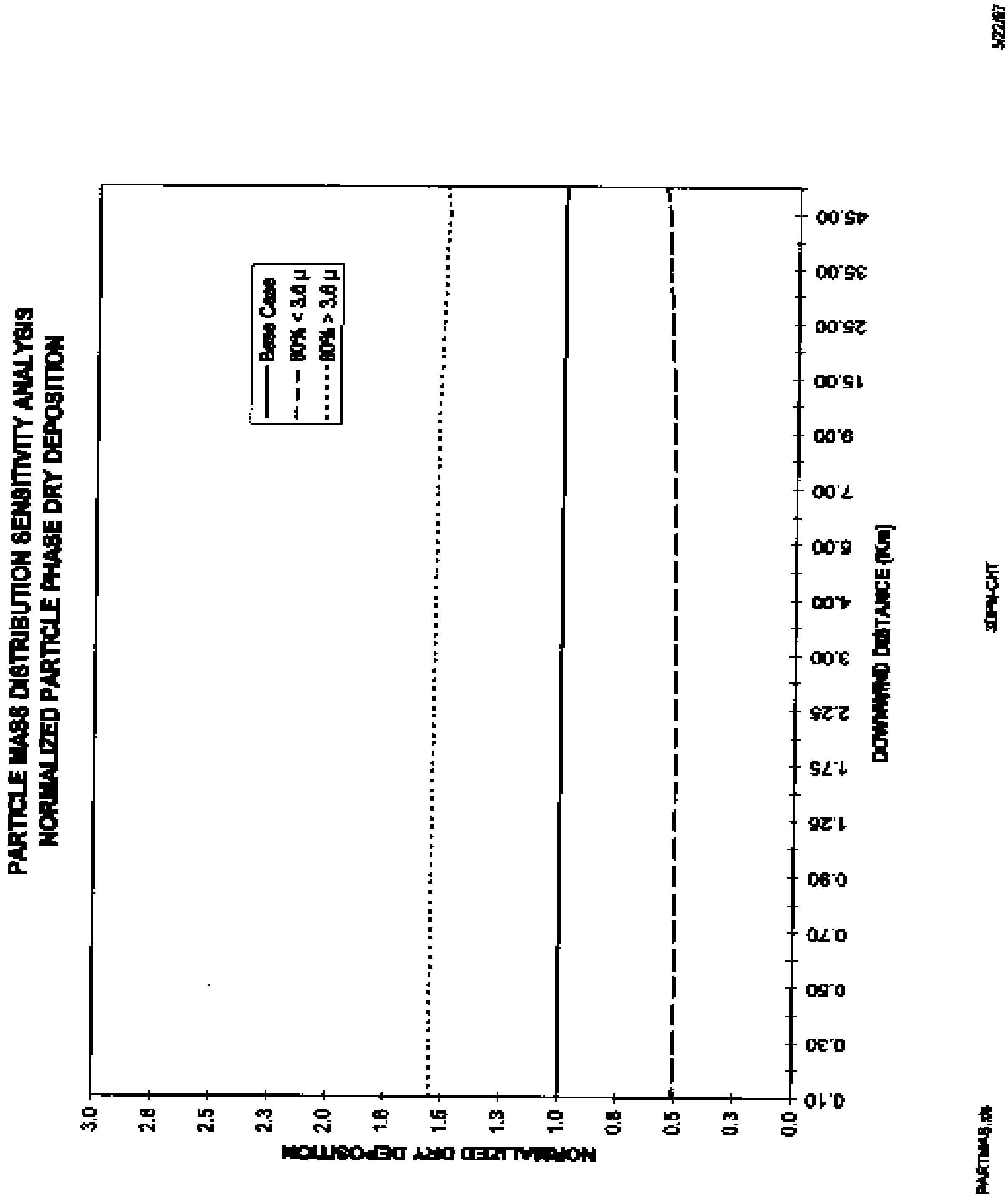
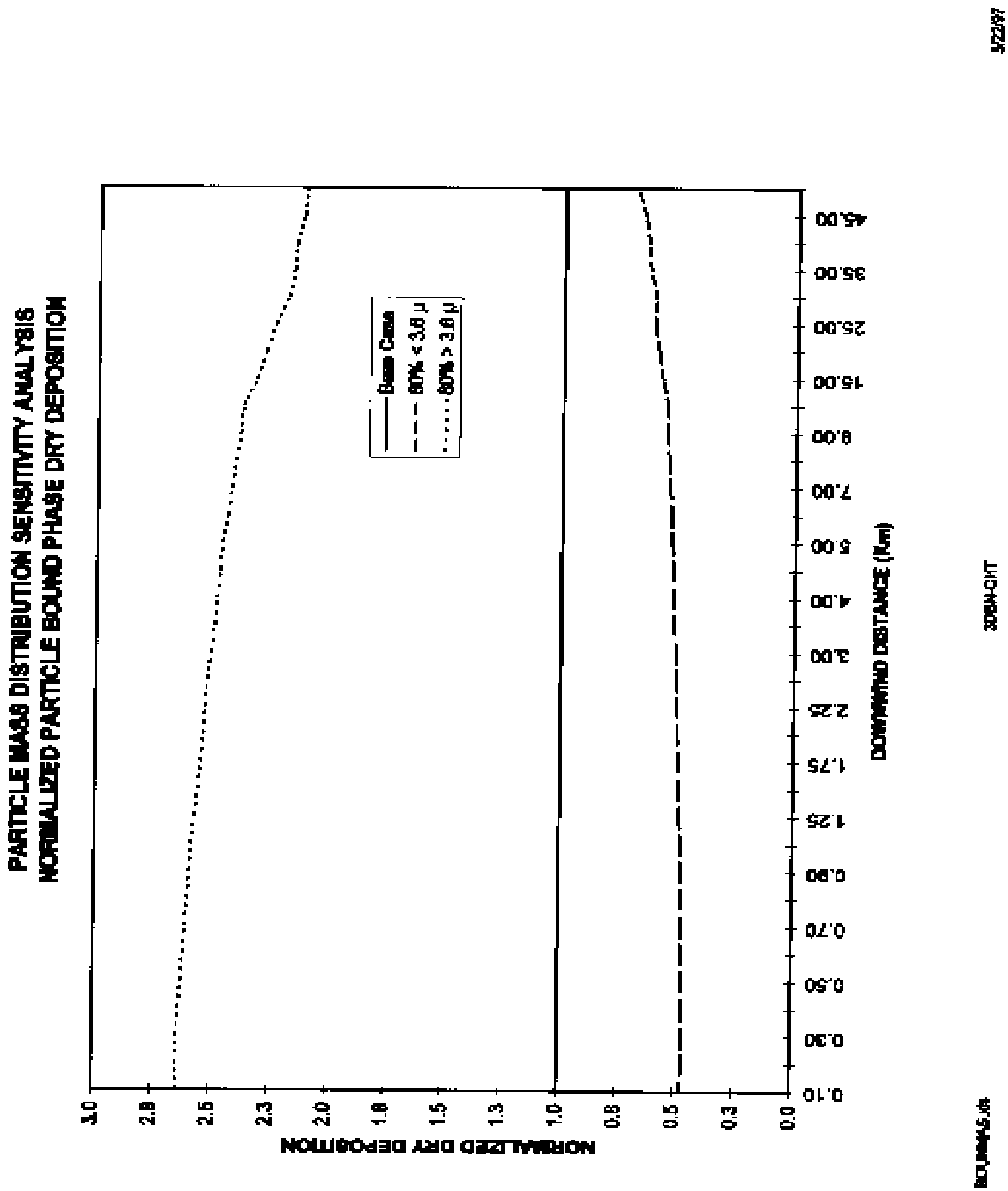
5/22/97
3CBN-CHT


PARTICLE MASS DISTRIBUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Base Case
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
NORMALIZED DRY DEPOSITION
0.0
0.3
0.5
0.8
1.0
1.3
1.5
1.8
2.0
2.3
2.5
2.8
3.0


PARTICLE MASS DISTRIBUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Base Case
80% < 3.6 µ
80% > 3.6 µ
NORMALIZED DRY DEPOSITION
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
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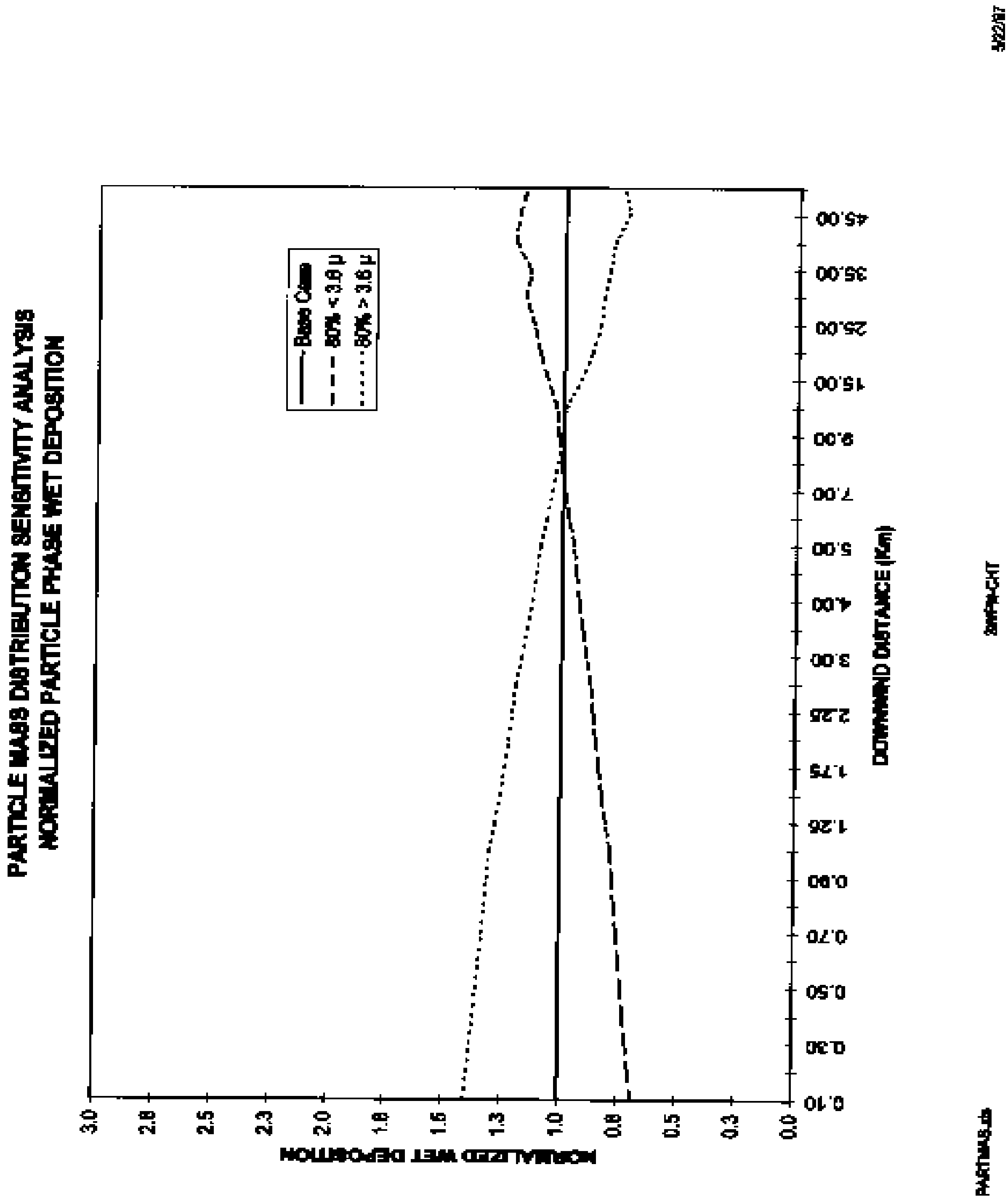
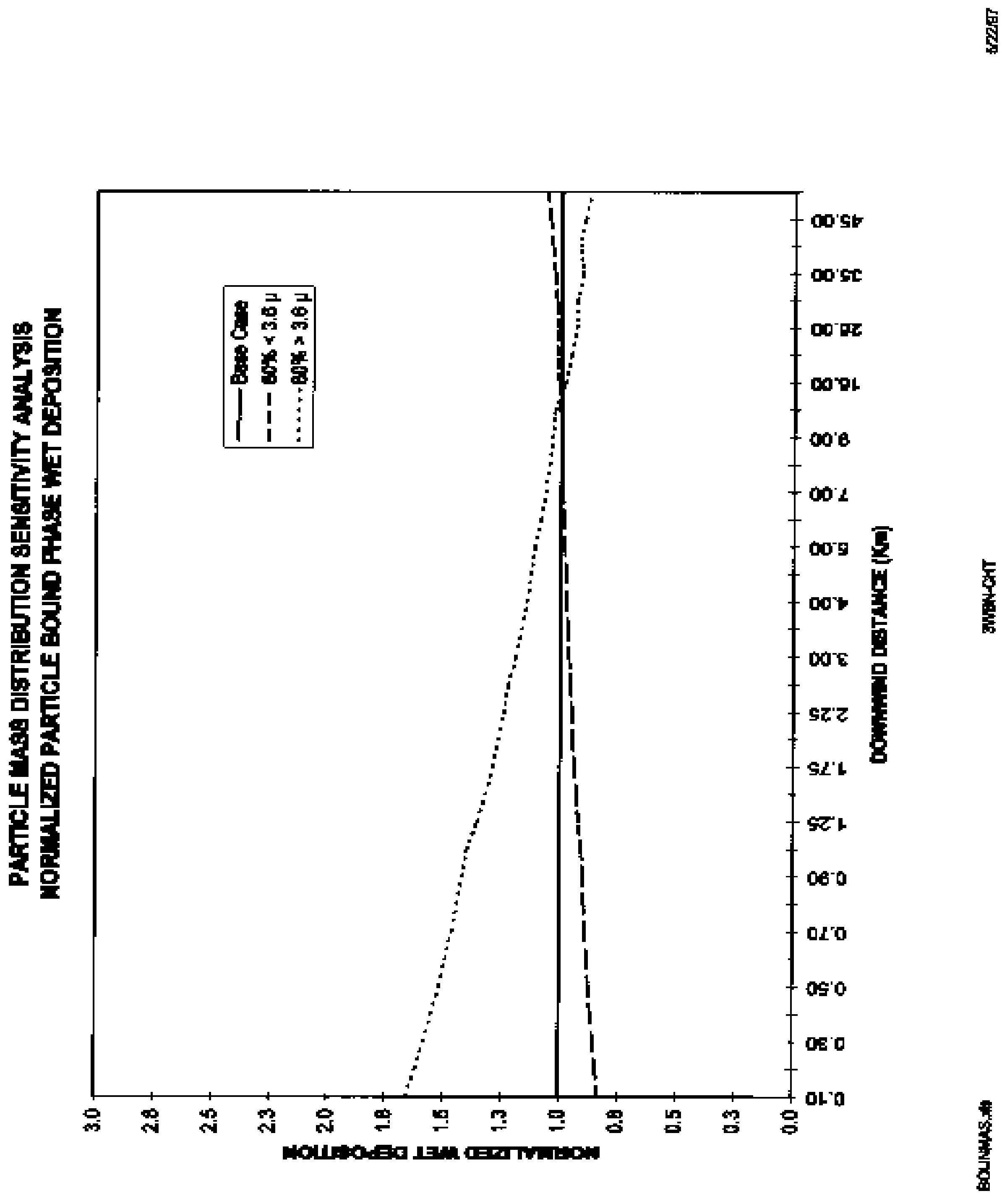
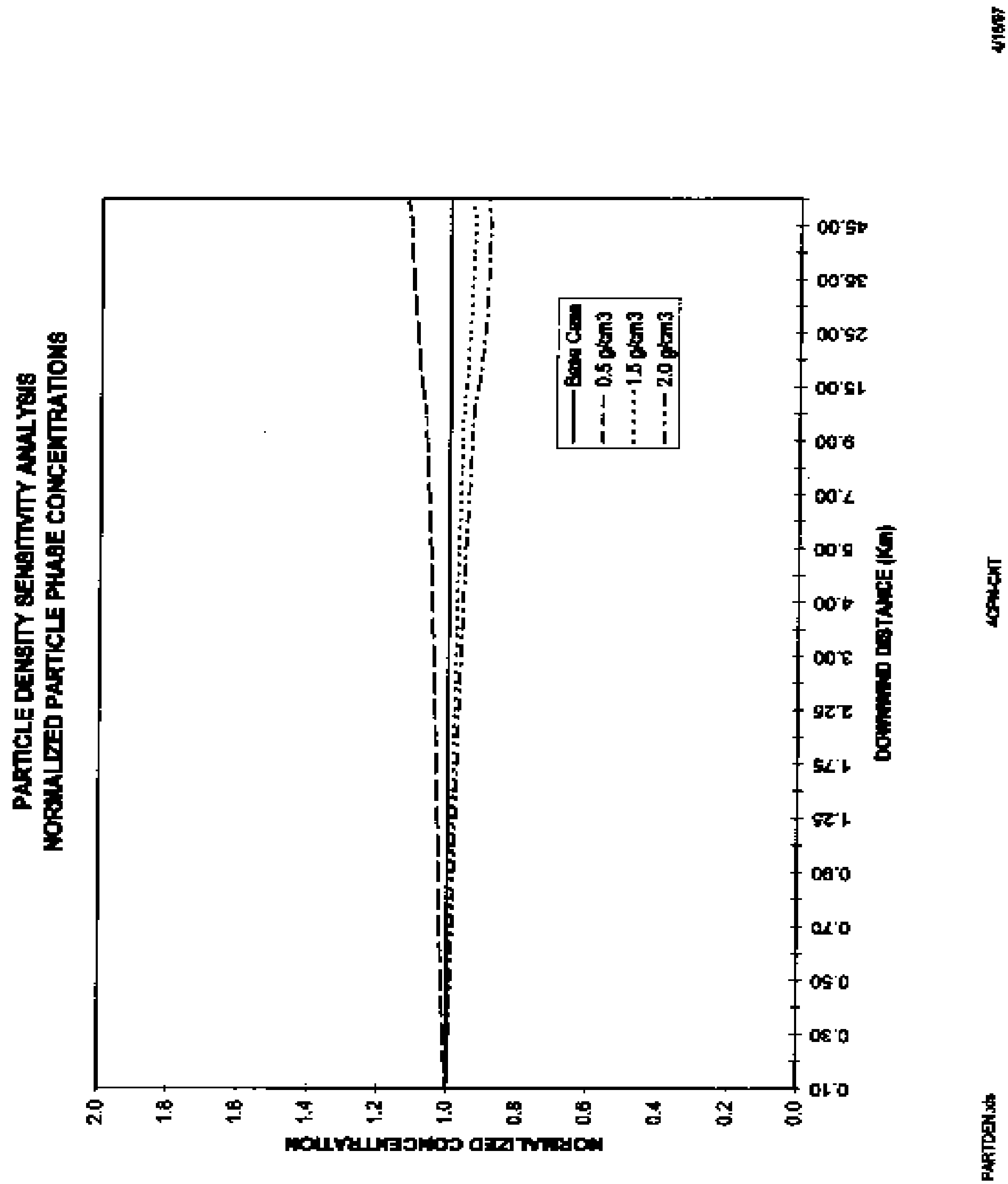
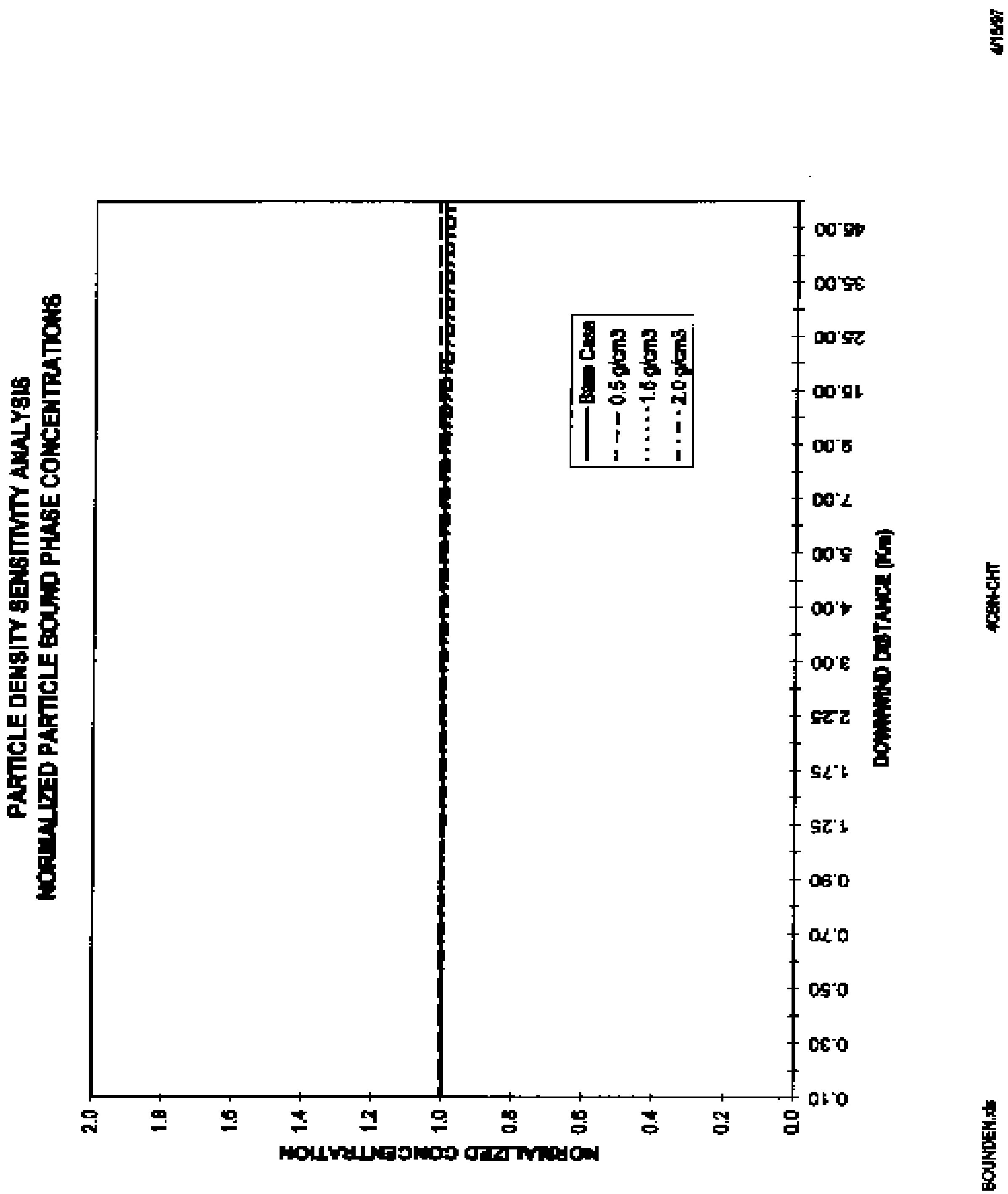
35.00
45.00
5/22/97
3DBN-CHT

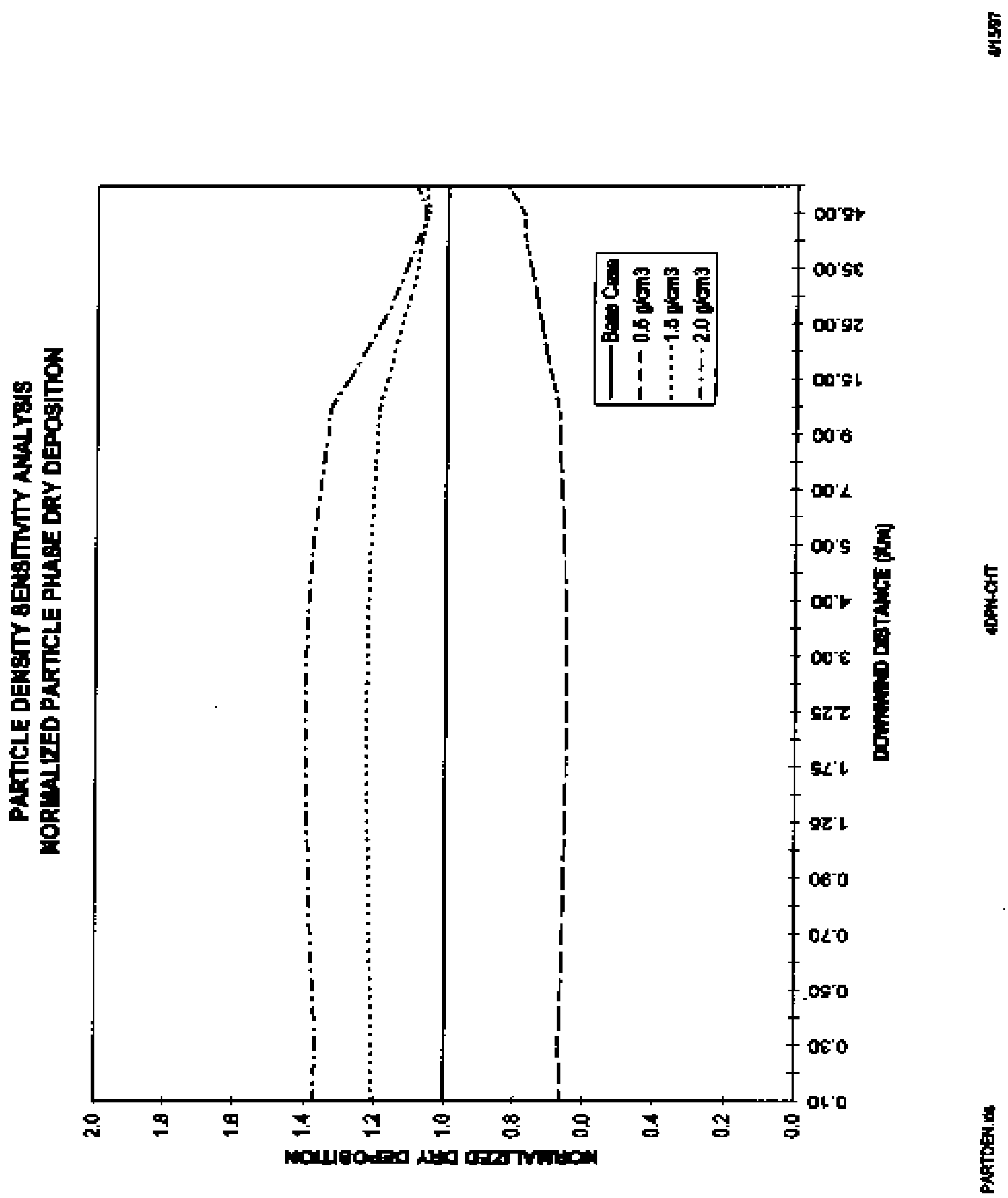

PARTICLE MASS DISTRIBUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Base Case
80% < 3.6 μ
80% > 3.6 μ
NORMALIZED WET DEPOSITION
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00

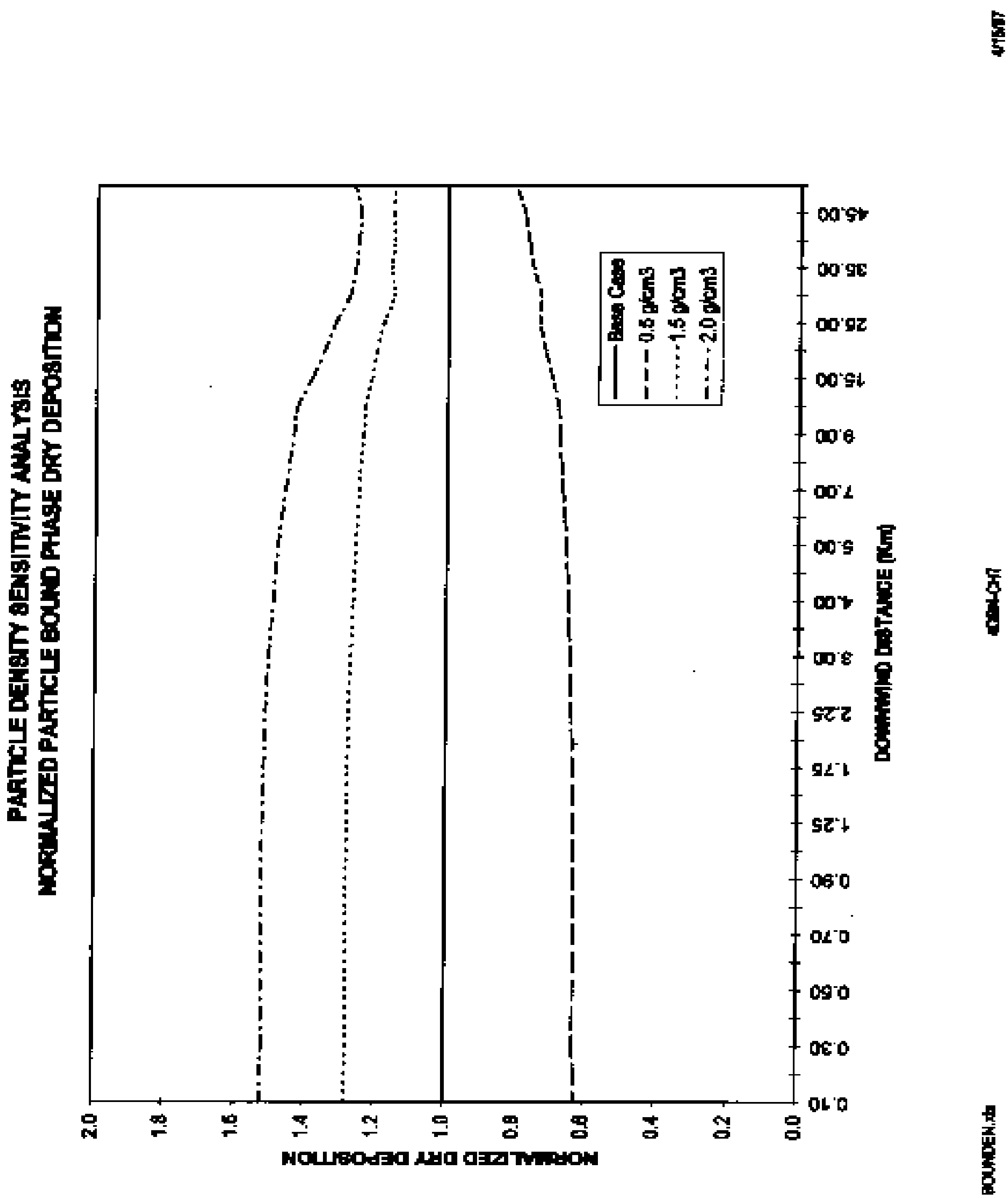

PARTICLE MASS DISTRIBUTION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Base Case
80% < 3.6 µ
80% > 3.6 µ
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
16.00
28.00
35.00
45.00
5/22/97
3WBN-CHT

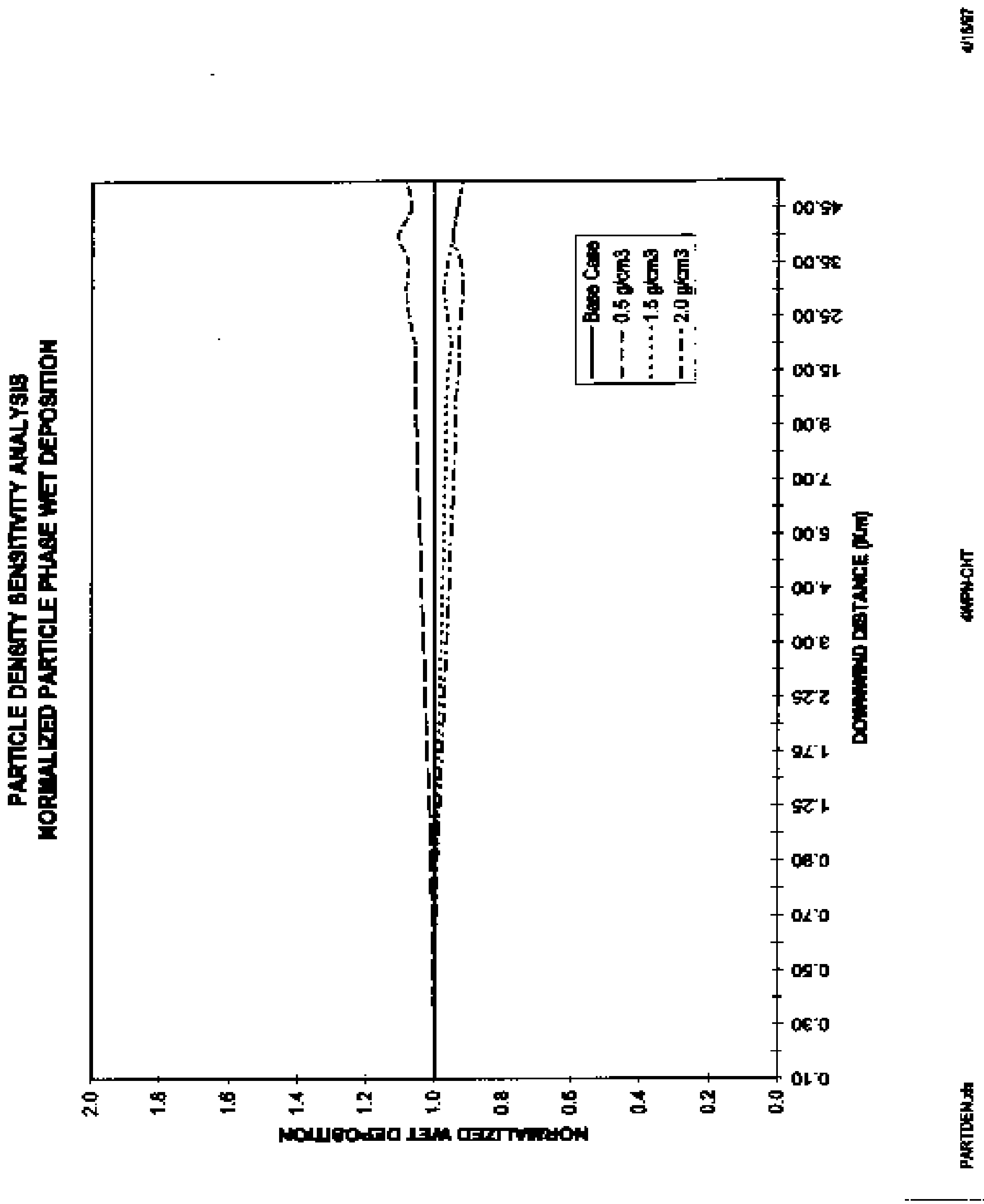

PARTICLE DENSITY SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATIONS
Base Case
0.5 g/cm3
1.5 g/cm3
2.0 g/cm3
NORMALIZED CONCENTRATION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
4/15/97
4CPN-CHT
PARTDEN.xls

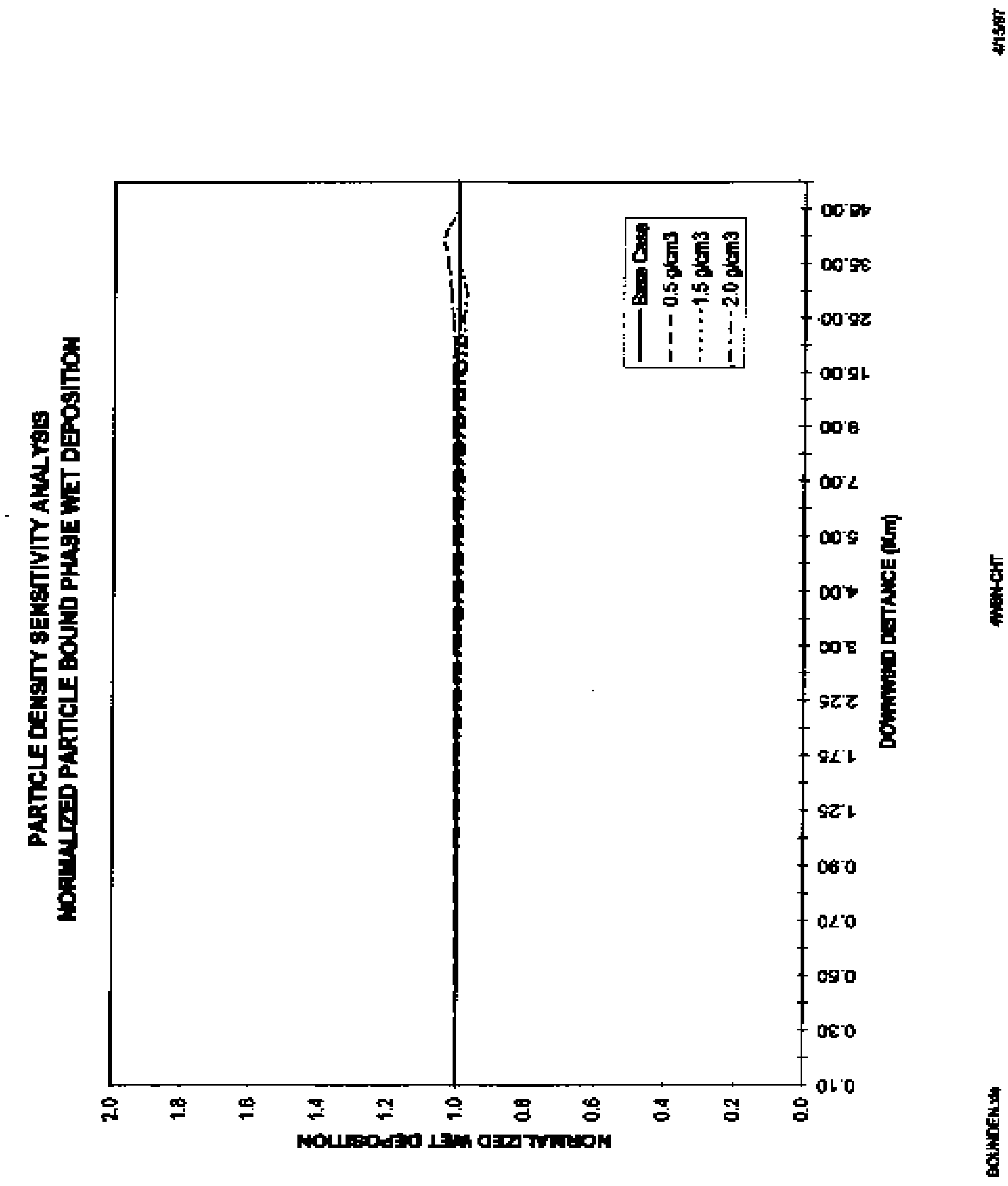


PARTICLE DENSITY SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATIONS
Base Case
0.5 g/cm3
1.5 g/cm3
2.0 g/cm3
NORMALIZED CONCENTRATION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
4/15/97
4CBN-CHT
BOUNDEN.xls


PARTICLE DENSITY SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
Base Case
0.5 g/cm3
1.5 g/cm3
2.0 g/cm3
4/15/97
4DPN-CHT
PARTDEN.xls


PARTICLE DENSITY SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
Base Case
0.5 g/cm3
1.5 g/cm3
2.0 g/cm3
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0


PARTICLE DENSITY SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
Base Case
0.5 g/cm3
1.5 g/cm3
2.0 g/cm3
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
4/15/97
4WPN-CHT
PARTDEN.cht


PARTICLE DENSITY SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
Base Case
0.5 g/cm3
1.5 g/cm3
2.0 g/cm3
BOUNDEN.xls

5.7 POLAR VERSUS CARTESIAN GRID

5.7.1 TECHNICAL OBJECTIVE

The technical objective of the polar versus Cartesian grid sensitivity analysis is to determine whether polar grid based on previous EPA risk assessment guidance documents produce similar modeled results as the Cartesian grid recommended in the Draft Protocol at all distances from the source (out to 50 kilometers).

5.7.2 THEORETICAL BASIS

The Protocol recommends the use of Cartesian grid nodes rather than polar grid nodes for risk assessment modeling. The benefit of Cartesian grid nodes is that the modeler can specify the spacing between all grid nodes. Additionally, Cartesian grid nodes correspond exactly to terrain grid files, which are required for sites located in elevated terrain. However, previous risk assessment guidance documents have recommended the use of polar rather than Cartesian grid nodes to reduce model set up and run times. The purpose of this analysis is to compare modeled results and model set up and run times using the Cartesian grid specified in the Protocol versus the polar grid that is recommended in previous guidance documents.

5.7.3 METHODOLOGY

5.7.3.1 BASE CASE - PROTOCOL RECOMMENDED CARTESIAN GRID

The base case for this analysis is identical to the base case described in Section 4 except for the use of the Protocol recommended Cartesian receptor grid instead of the linear grid. The Cartesian grid spacing is: 100 meter spacing out to 1 kilometer from the source, 250 meter spacing from 1 to 2.5 kilometers, 500 meter spacing from 2.5 to 5 kilometers, and 1000 meter spacing from 5 to 10 kilometers. The figures at the end of this section illustrate the Cartesian grid for the base case.

5.7.3.2 TEST CASE I - POLAR GRID BASED ON PREVIOUS EPA GUIDANCE

Test Case 1 is identical to the base case except that a polar grid with spacing that follows the criteria specified in previous EPA risk assessment guidance documents is modeled in lieu of the Cartesian grid. The polar grid spacing between radials is every 22.5 degrees. Polar grid spacing along each radial is as follows: 50 meter spacing out to 200 meters from the source, 100 meter spacing from 200 to 500 meters, 200 meter spacing from 500 to 700 meters, 300 meter spacing from 700 to 1 kilometer, 500 meter spacing from 1 to 2 kilometers, 1 kilometer spacing from 2 to 5 kilometers, 2 kilometer spacing from 5 to 7 kilometers, and 3 kilometer spacing from 7 to 10 kilometers. The figure at the end of this section illustrates the polar grid utilized for Test Case I superimposed on the Cartesian grid used as the base case.

5.7.4 RESULTS

As illustrated in the figures at the end of this section which present isopleths of constant concentration for both grids, the polar and Cartesian grids produce similar resolution of results. The Cartesian grid, however, performs slightly better than the polar grid, as indicated by the fact that the Cartesian isopleths are less smooth than the polar isopleths and some of the maximum impacts are slightly higher for the Cartesian grid than polar grid.

Dry deposition and wet deposition results, although not plotted, give similar results as concentration. Variation of impacts from polar and Cartesian grids are small.

The polar and Cartesian grids took approximately the same time to set up. However, no terrain data is extracted for the grids in this study. Terrain extraction in a polar coordinate requires special processing programs and caution to confirm the correct terrain elevations are matched with the locations of the polar grids in an absolute (UTM) coordinate system. Model run times for the Cartesian grid are 10 times longer than for the polar grid. This time is due to the 1764 grid nodes modeled in the Cartesian grid and only 240 grid nodes modeled in the polar grid.

COMPARISON OF PARTICLE PHASE MAXIMUM IMPACTS

	Polar Grid	Cartesian Grid
Concentration (ug/m^3/g/s)	1.013	1.027
Dry Deposition (g/m^3/g/s)	2.378	2.394
Wet Deposition (g/m^3/g/s)	3.611	3.611

COMPARISON OF PARTICLE -BOUND PHASE MAXIMUM IMPACTS

	Polar Grid	Cartesian Grid
Concentration (ug/m^3/g/s)	1.051	1.074
Dry Deposition (g/m^2/g/s)	0.411	0.414
Wet Deposition (g/m^2/g/s)	1.440	1.440

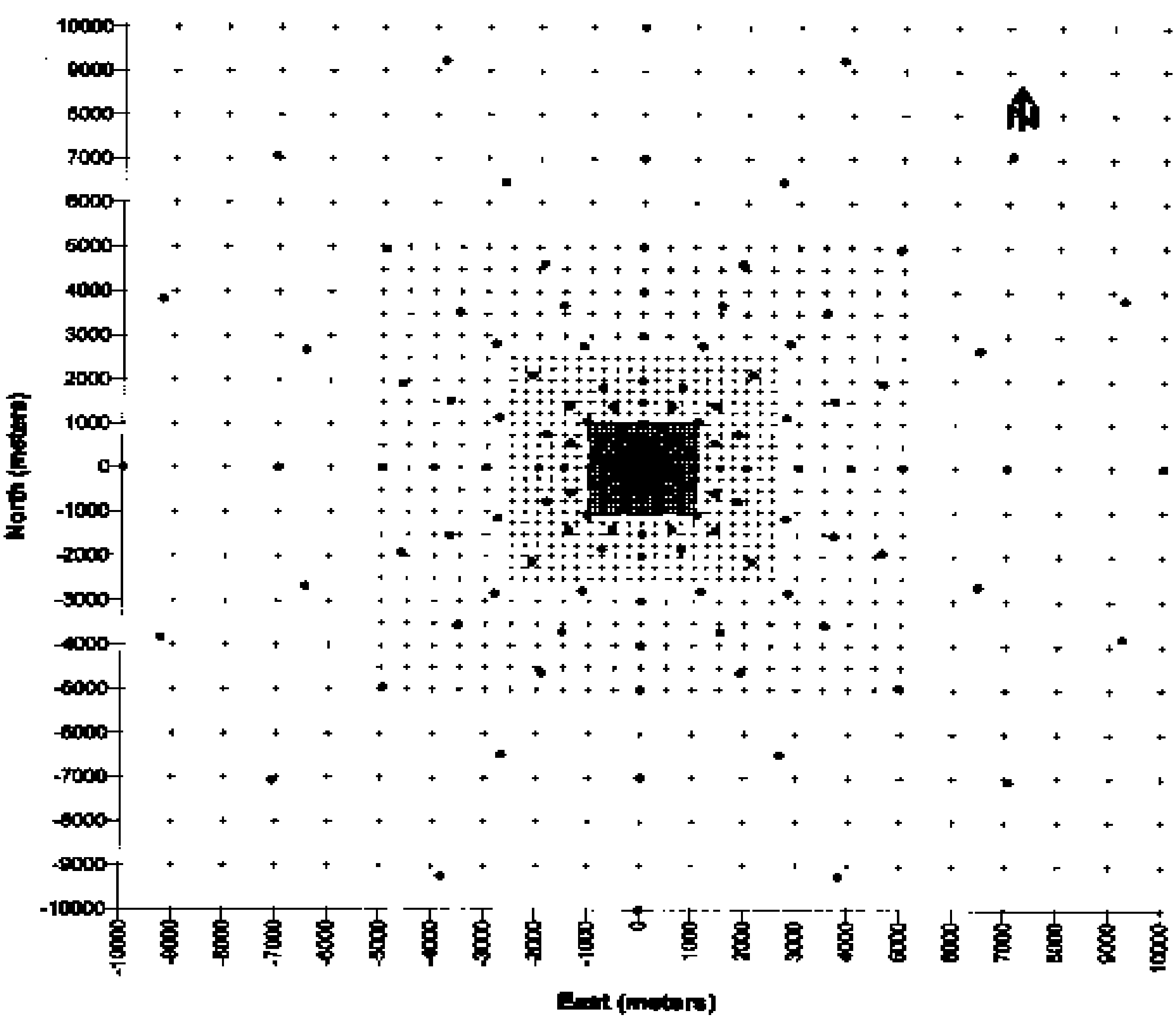
COMPARISON OF VAPOR PHASE MAXIMUM IMPACTS

	Polar Grid	Cartesian Grid
Concentration (u/m^3/g/s)	1.060	1.083
Wet Deposition (g/m^2/g/s)	2.158	2.158

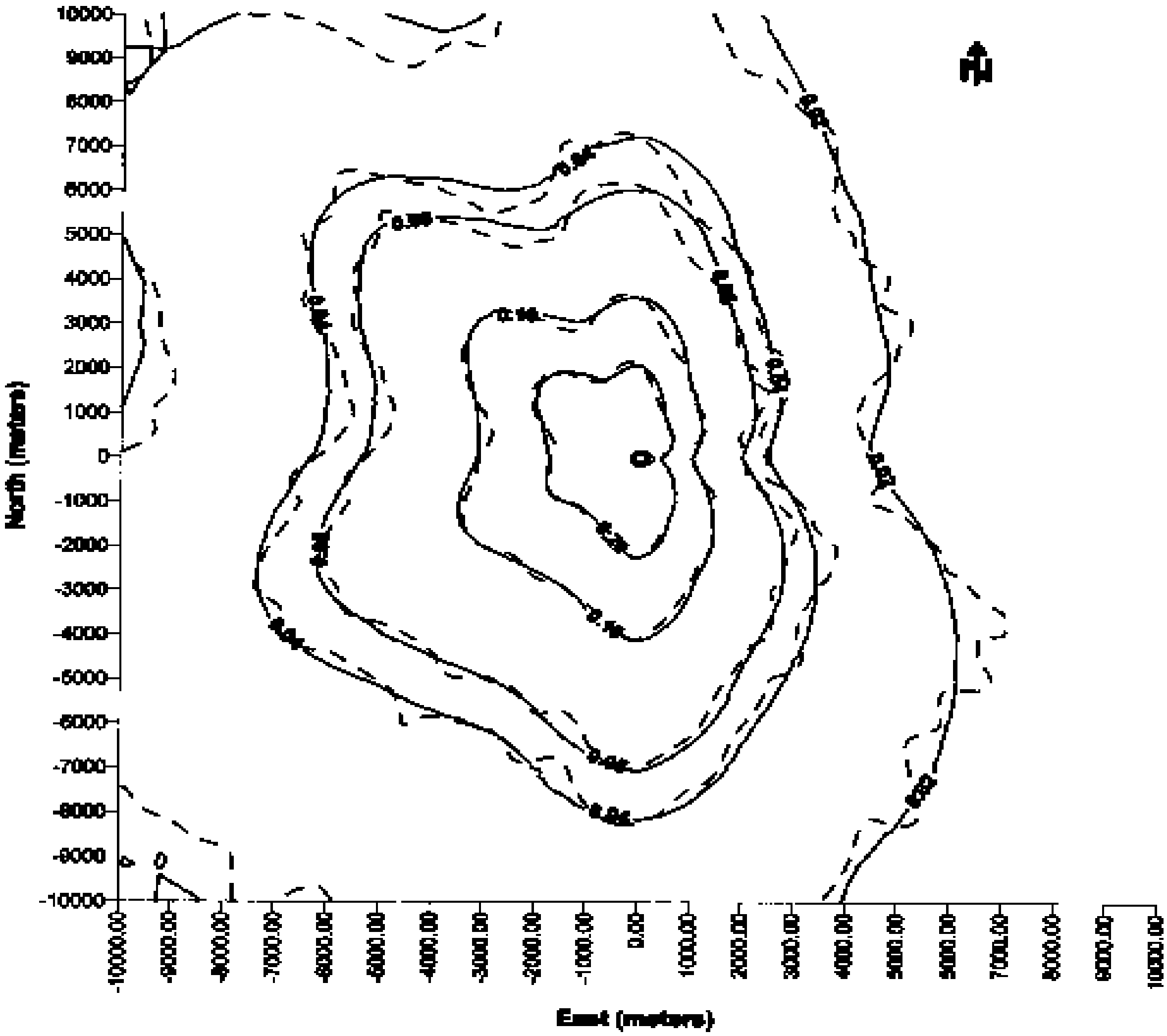
5.7.5 RECOMMENDATIONS

U.S. EPA should consider allowing the use of either Cartesian or polar grids for risk assessment modeling analyses since variations in impacts based on either grid are relatively small. The polar grid model run times are significantly less than for the Cartesian grid. However, if EPA requires all modeling to include terrain elevations, the modeler must address two important issues in their proposed modeling approach: 1) it is difficult to correlate polar grid nodes with USGS digitized terrain elevation data required for sites located in elevated terrain; and, 2) it is cumbersome to determine impacts at discrete locations of sensitive receptors because the polar grid is not in either latitude-longitude or UTM coordinates for ease in locating on a USGS map.

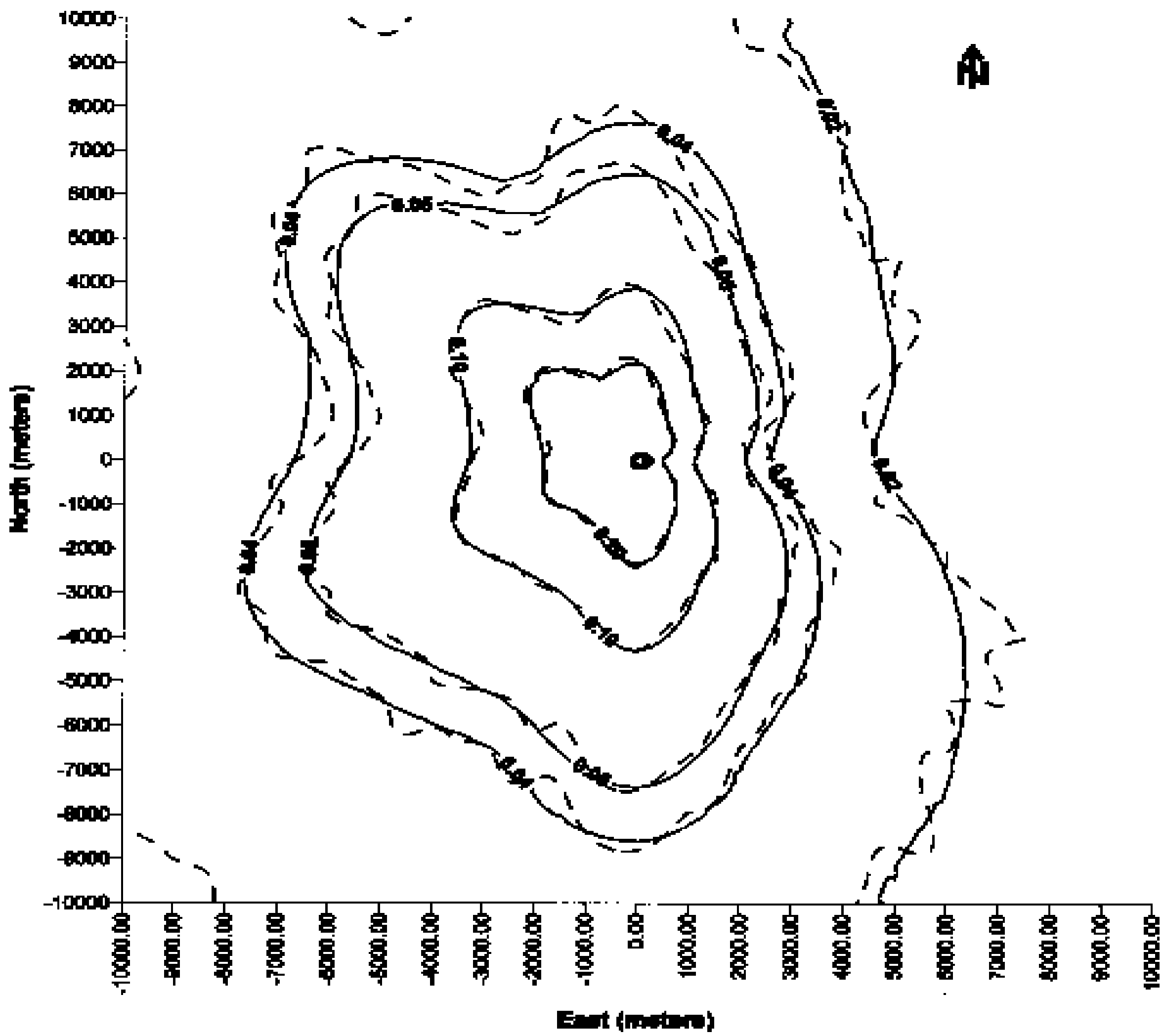
POLAR VS. CARTESIAN SENSITIVITY ANALYSIS
CARTESIAN GRID NODES OUT TO 10 KM (+)
POLAR GRID NODES OUT TO 10 KM (•)



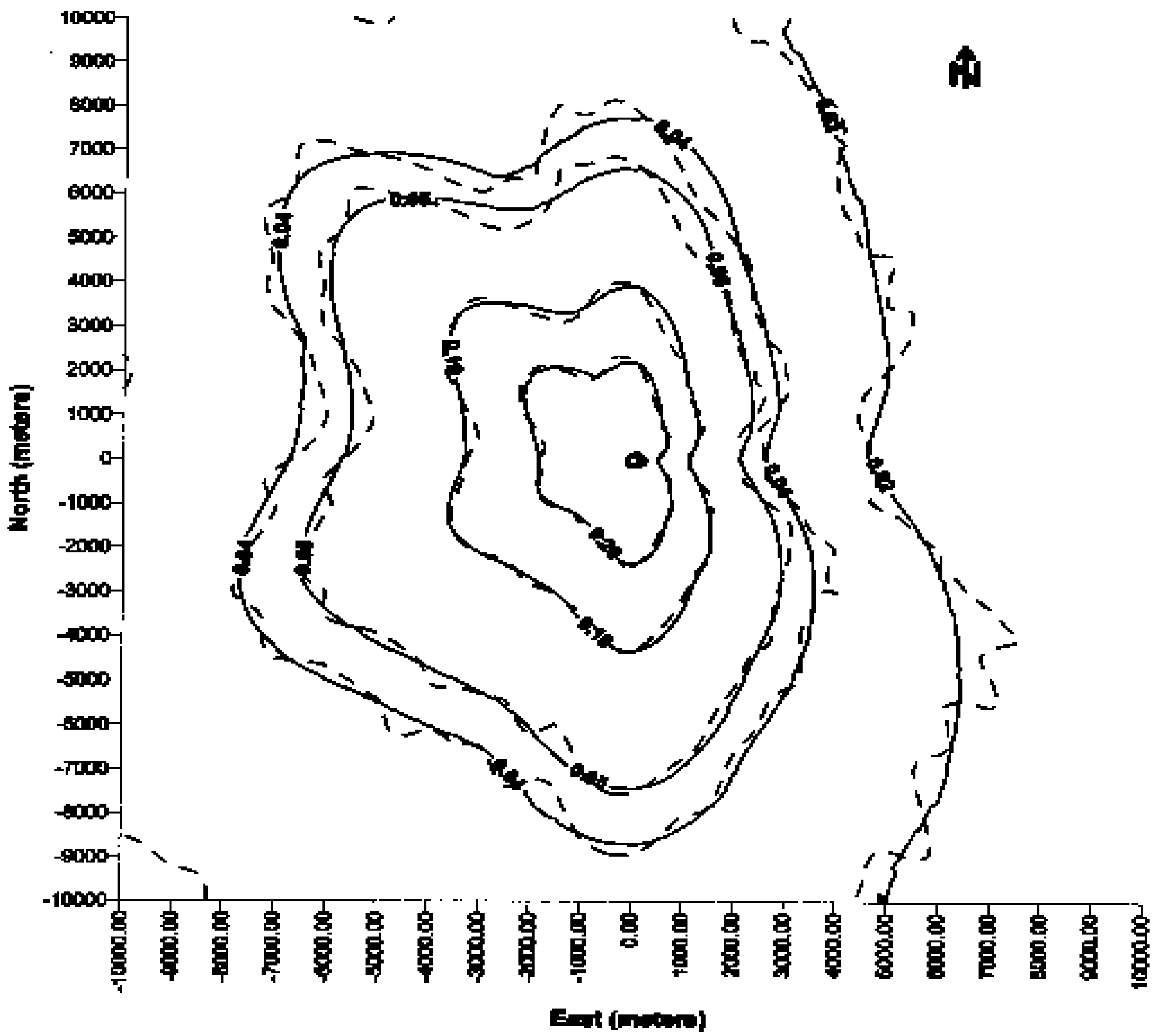
POLAR VS. CARTESIAN SENSITIVITY ANALYSIS
PARTICLE PHASE CONCENTRATIONS
(Cartesian Grid Isopleths -- Dashed Lines)
(Polar Grid Isopleths -- Solid Lines)
ug/m3/g/s



POLAR VS. CARTESIAN SENSITIVITY ANALYSIS
PARTICLE-BOUND PHASE CONCENTRATIONS
(Cartesian Grid Isopleths -- Dashed Lines)
(Polar Grid Isopleths -- Solid Lines)
ug/m3/g/s



POLAR VS. CARTESIAN SENSITIVITY ANALYSIS
VAPOR PHASE CONCENTRATIONS
(Cartesian Grid Isopleths-- (Dased Lines)
(Polar Grid Isopleths -- Solid Lines)
ug/m3/g/s



5.8 TERRAIN GRID

5.8.1 TECHNICAL OBJECTIVE

The technical objective of the terrain grid sensitivity analysis is to determine whether the effort is justified to set up terrain grid files to invoke the terrain grid algorithms in ISCST3 for sites located in elevated terrain. If variations of results with and without the use of terrain grids are insignificant, then it would streamline the modeling analysis to run the model without terrain grid files.

5.8.2 THEORETICAL BASIS

The terrain grid file is an option in ISCST3 identified as refining plume depletion due to dry deposition. The ISCST3 User Guide identifies the use of a terrain grid file only in complex terrain with terrain elevations above stack top. If a terrain grid file is not provided, ISCST3 assumes a linear relationship between stack base elevation and grid node elevation. This assumption should have negligible impact on modeled results in areas of rolling terrain. In areas of harsh terrain, the impact may be significant.

5.8.3 METHODOLOGY

An arbitrarily-shaped, gently rolling terrain profile is generated for use in this analysis. A plot of the terrain profile is provided at the end of this section. The slope of the terrain profile ranges from 0.5% (a 0.5-foot terrain rise over a distance of 100 feet) to 5%, with an average slope of approximately 2%. Three terrain grid files are prepared: 1) 500 meter spaced grid nodes; 2) 250 meter spaced grid nodes; and, 3) 100 meter spaced grid nodes. The terrain elevation from the terrain profile corresponding to each grid node is entered into the terrain grid files.

5.8.3.1 BASE CASE - 500 METER SPACED GRID NODES, NO TERRAIN GRID

The base case consists of running a linear receptor grid (oriented due north of the source) with 500 meter spacing, elevated terrain heights at each grid node, and no terrain grid file. 500 meter receptor spacing was chosen as a worst-case spacing most likely to be affected by whether or not a terrain grid file is used in the modeling analysis. For tighter spacing, the effect of neglecting to use terrain grid files should be less. All other inputs to the base case model runs are based on Protocol recommended methods and values, as specified in the description of base case model runs in Section 4.

5.8.3.2 TEST CASE I - 500 M. SPACED GRID NODES, 500 M. SPACED TERRAIN GRID

Test Case 1 is identical to the base case, except for the 500 meter spaced terrain grid file.

5.8.3.3 TEST CASE 2 - 500 M. SPACED GRID NODES, 250 M. SPACED TERRAIN GRID

Test Case 2 is identical to the base case, except for the 250 meter spaced terrain grid file.

5.8.3.4 TEST CASE 3 - 500 M. SPACED GRID NODES, 250 M. SPACED TERRAIN GRID

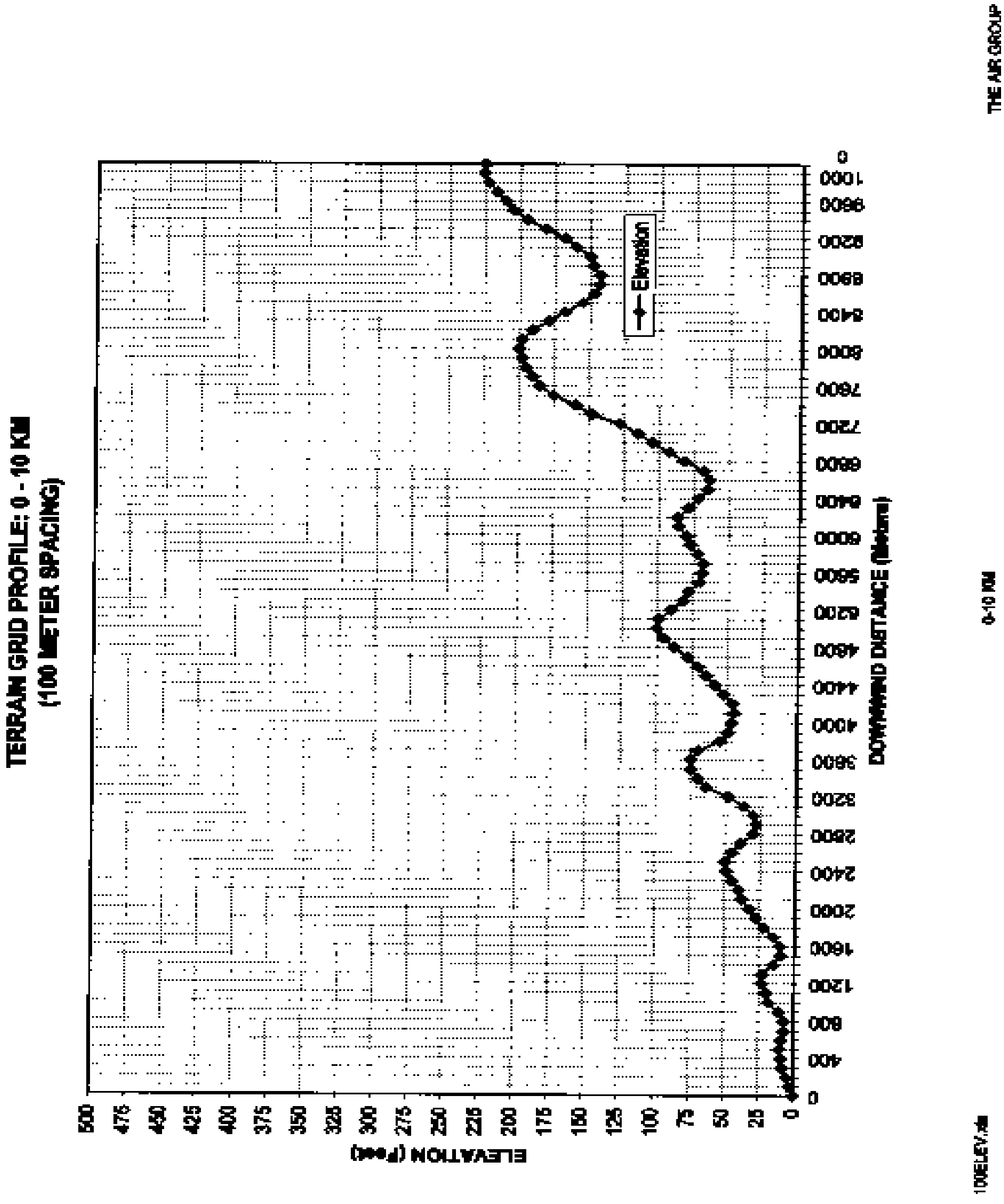
Test Case 3 is identical to the base case, except for the 100 meter spaced terrain grid file.

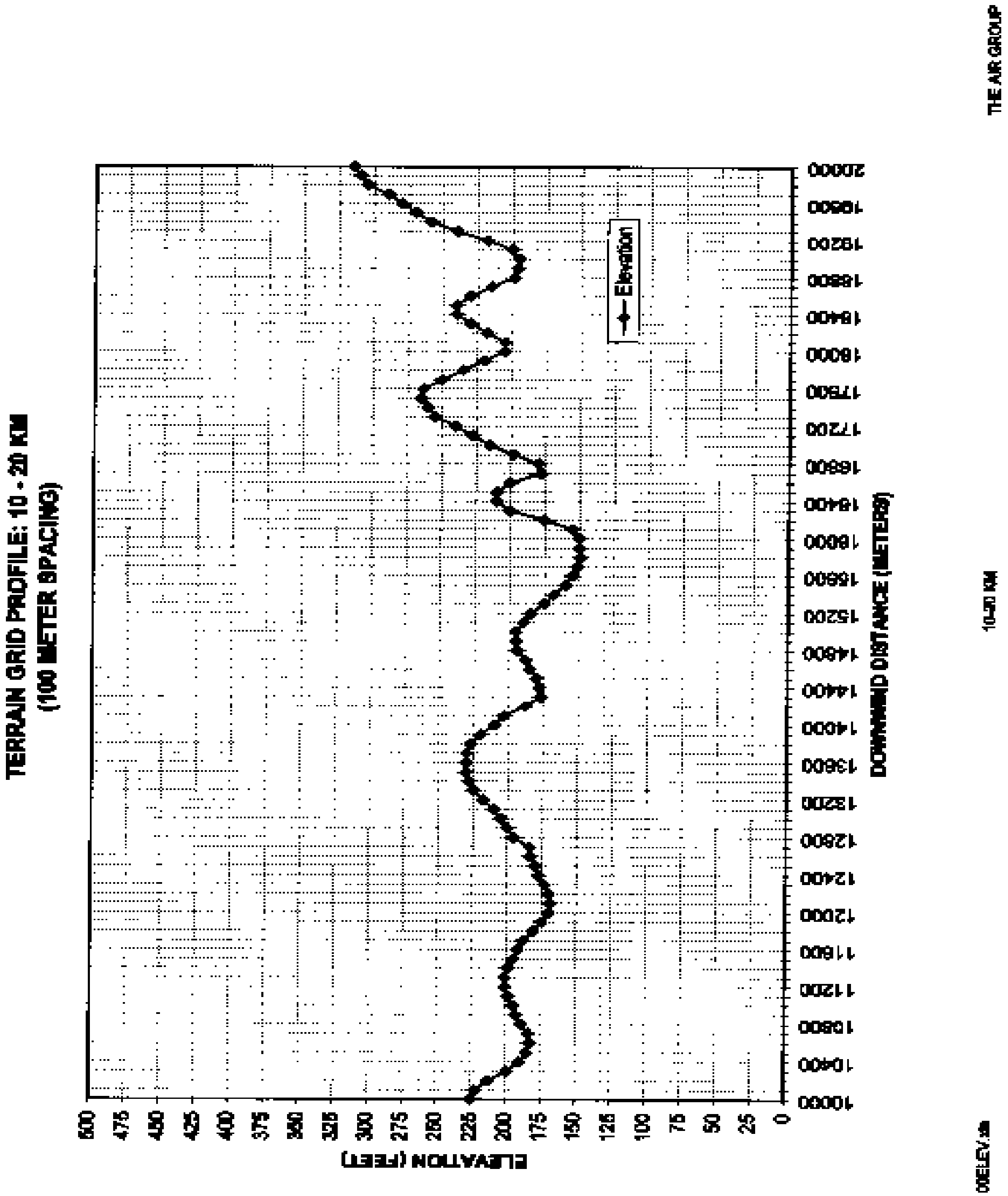
5.8.4 RESULTS

Concentration, dry and wet deposition rates are virtually unaffected by any of the terrain grid scenarios modeled. The maximum variation of any test cases compared to the base case for any of the phases is approximately 2%.

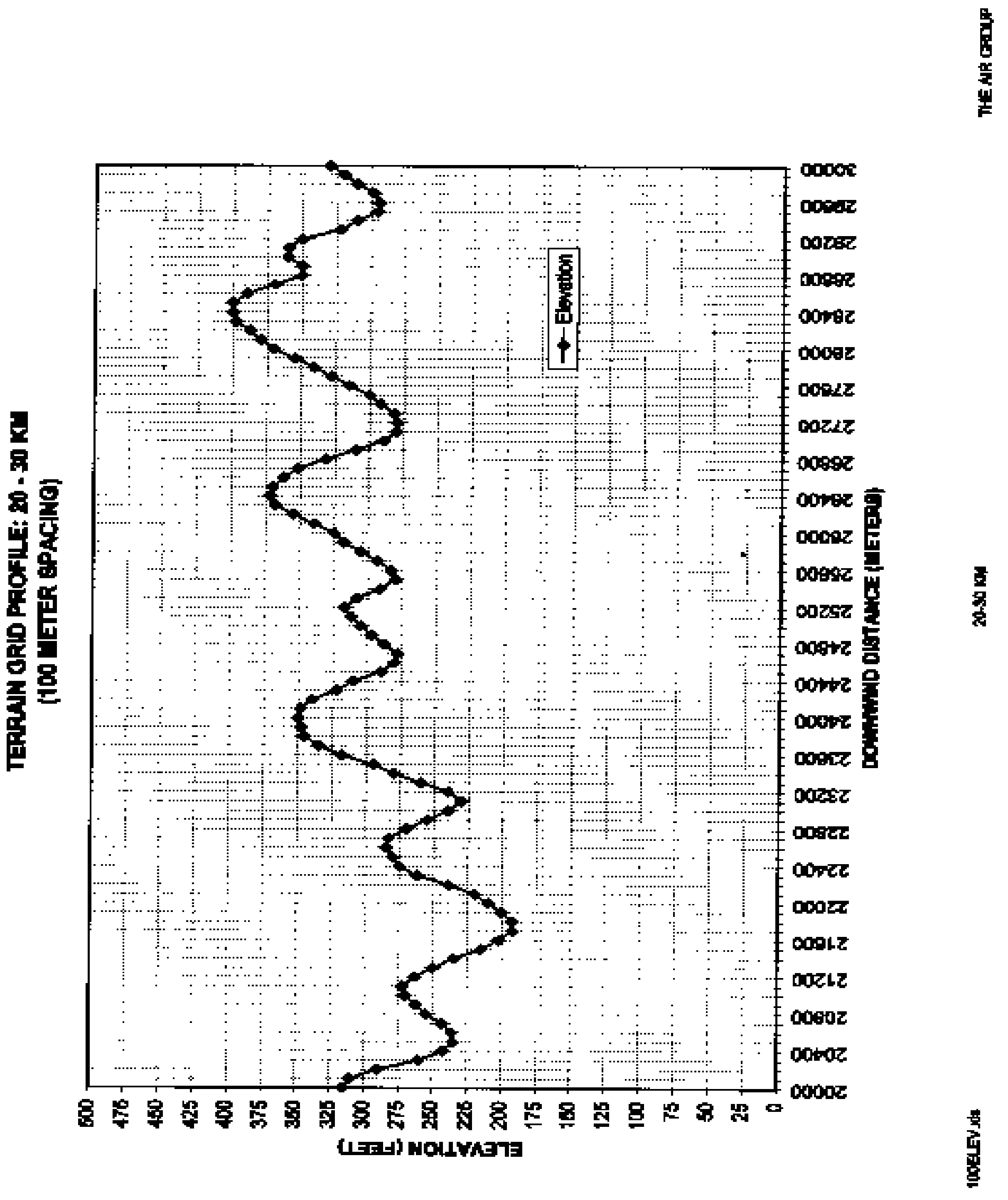
5.8.5 RECOMMENDATIONS

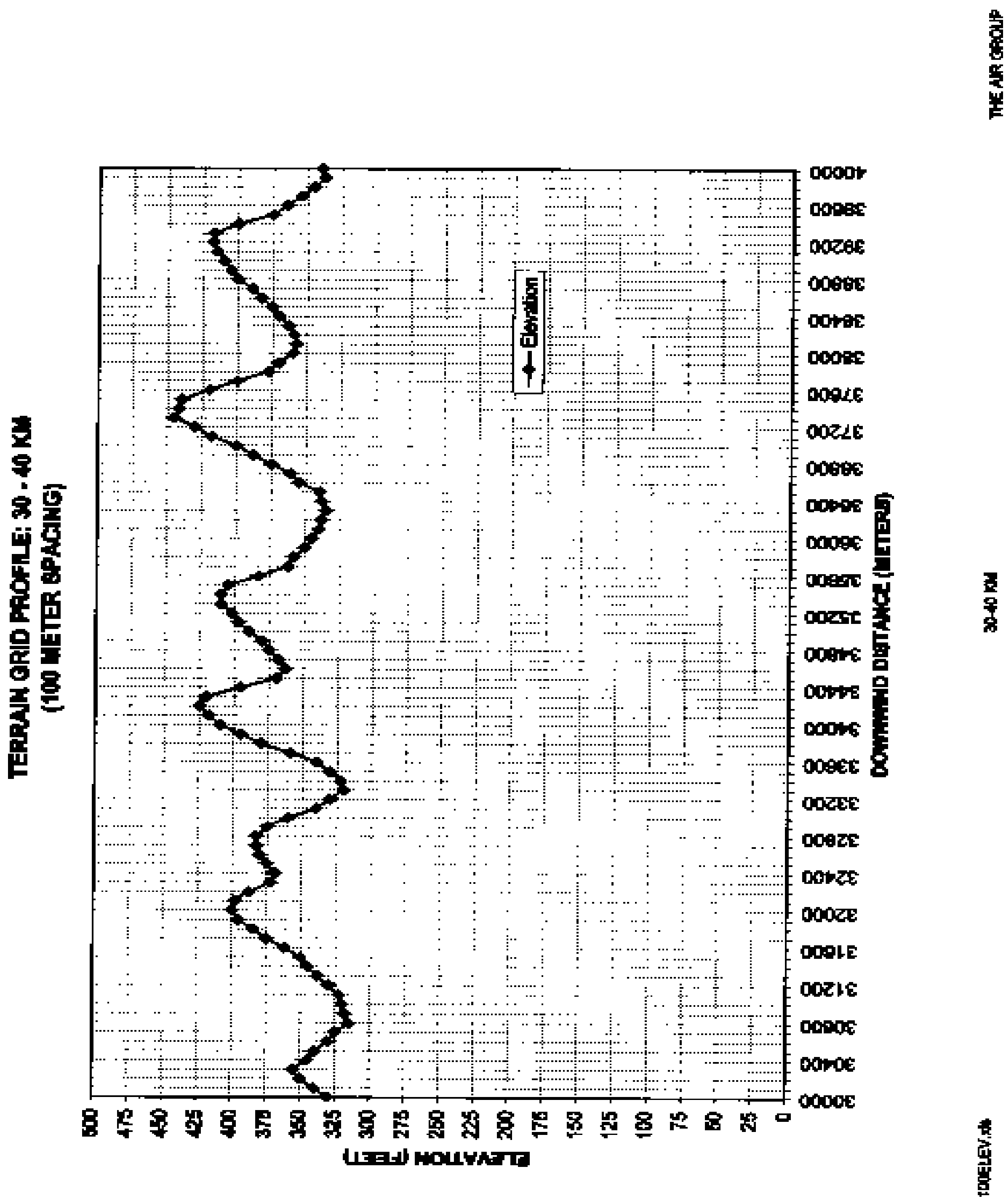
EPA should not require the use of terrain grid files unless additional information is provided that identifies the benefit in approved estimates of risk to offset the effort to create the terrain grid files and additional run times. It appears that modeled impacts will be relatively unaffected by not using a terrain grid file in the modeling analysis if the site is located in an area of gradually rising terrain. Therefore, EPA should consider not requiring the use of terrain grids for sites located in gently rolling terrain. However, this study did not include an analysis of the effect of terrain grid files on impacts in mountainous areas. Therefore, it is recommended that terrain grids be required for mountainous or very hilly areas and neglected for gently rolling terrain.

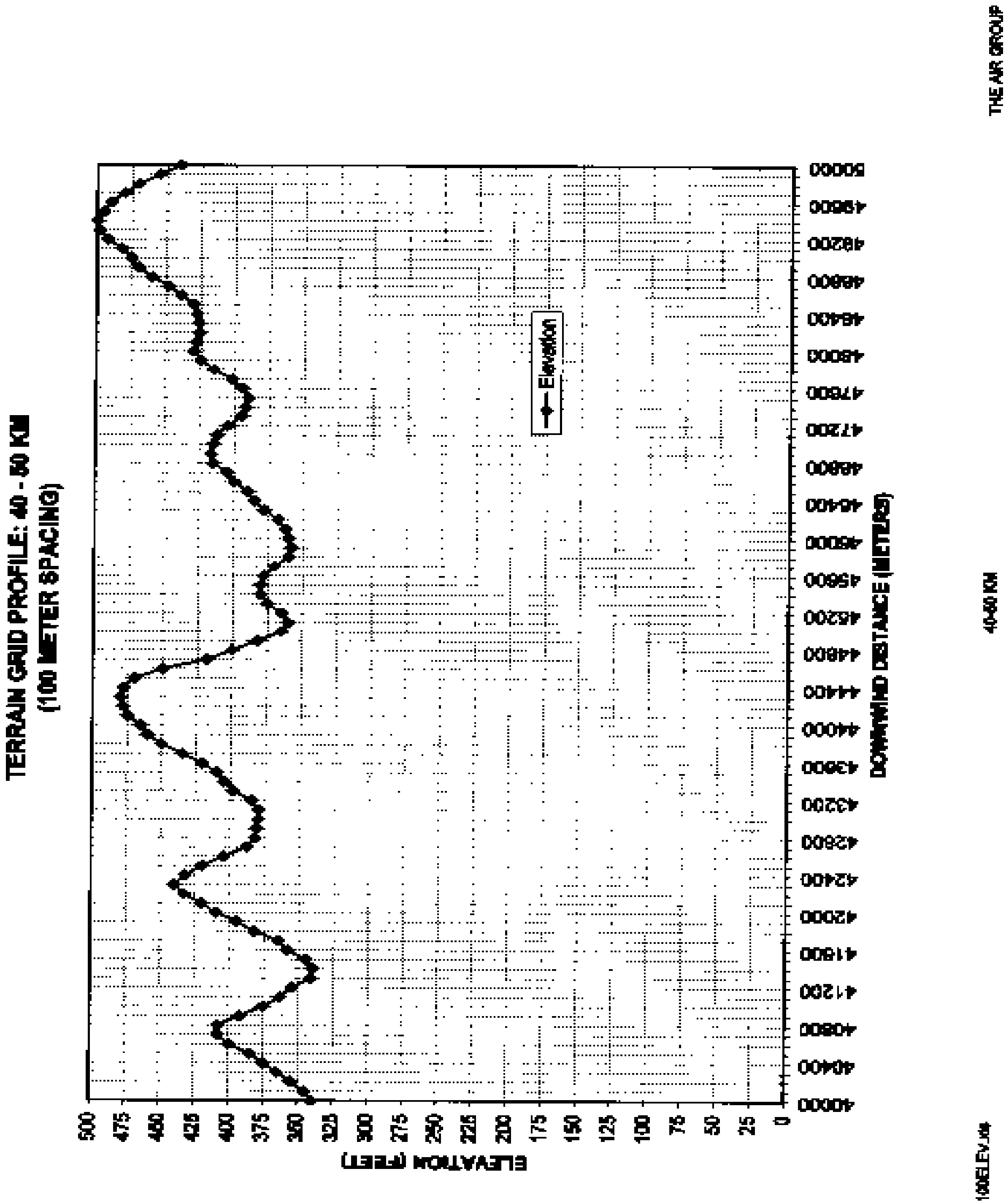

TERRAIN GRID PROFILE; 0 - 10 KM
(100 METER SPACING)
THE AIR GROUP
Elevation
ELEVATION (Feet)
DOWNWIND DISTANCE (Meters)
0-10 KM
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000 4400 4800 5200 5600 6000 6400 6800 7200 7600 8000 8400 8800 9200 9600 10000

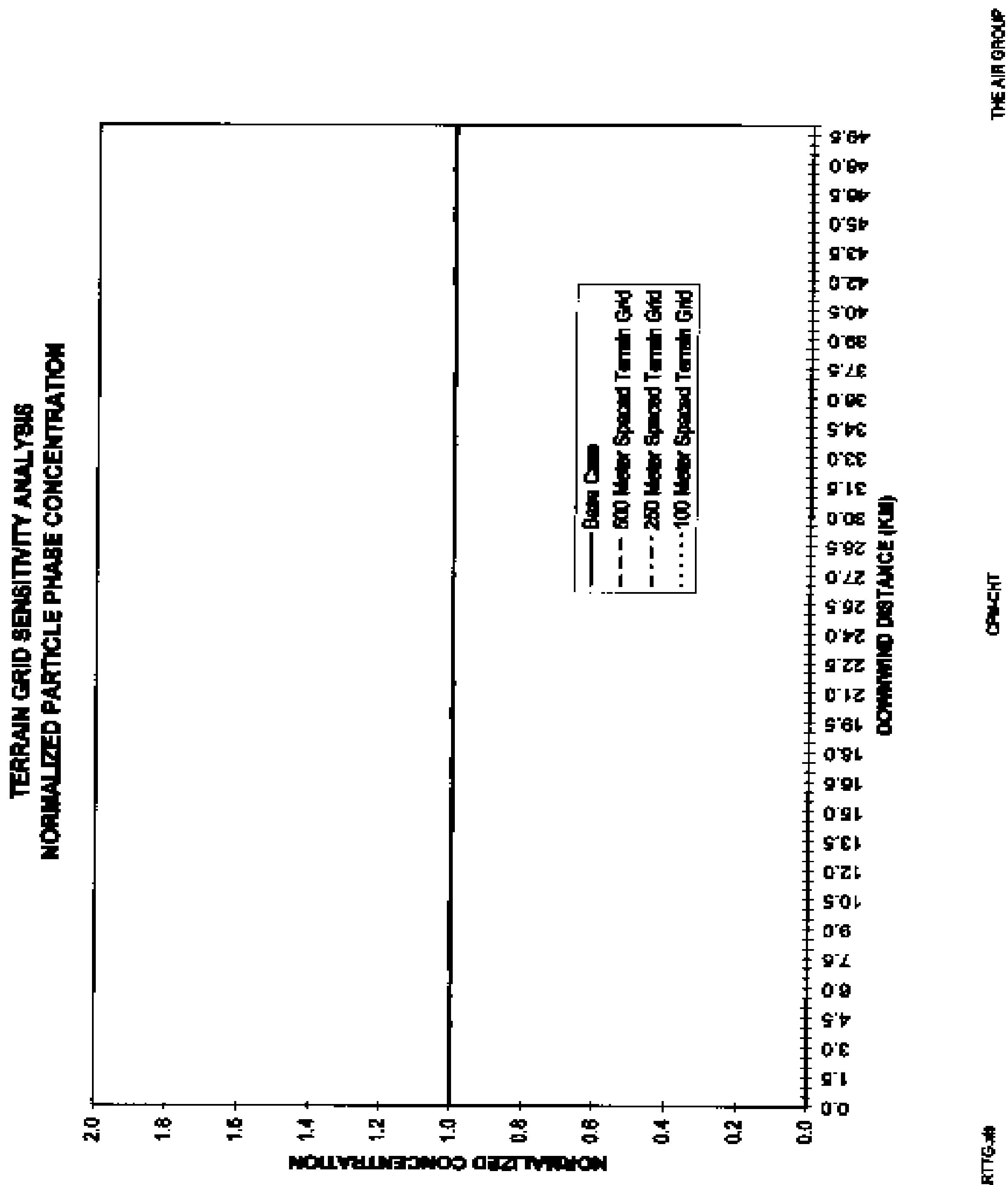


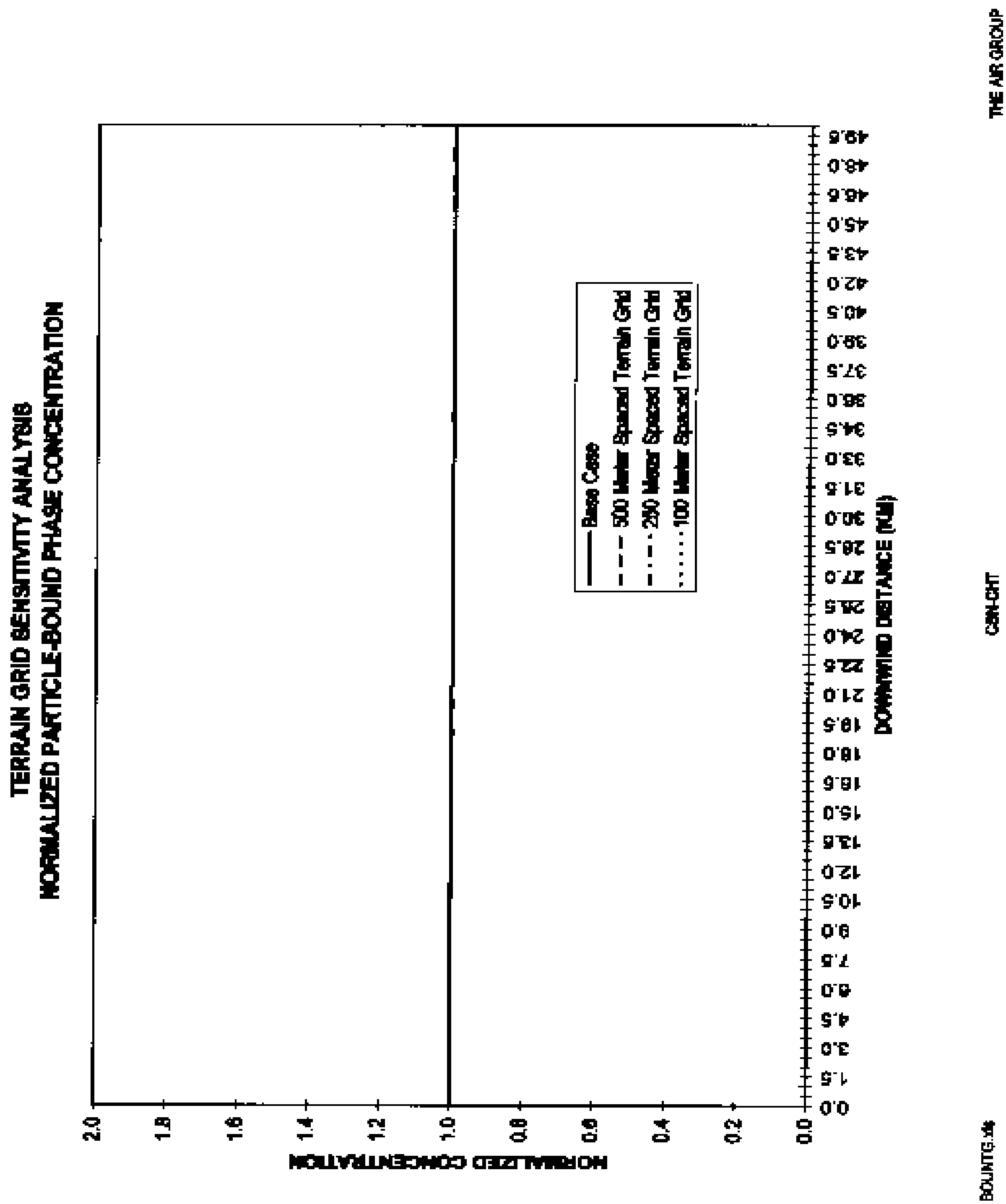
THE AIR GROUP
TERRAIN GRID PROFILE: 10 - 20 KM
(100 METER SPACING)
Elevation
DOWNWIND DISTANCE (METERS)
ELEVATION (FEET)
10-20 KM
100ELEV.xls

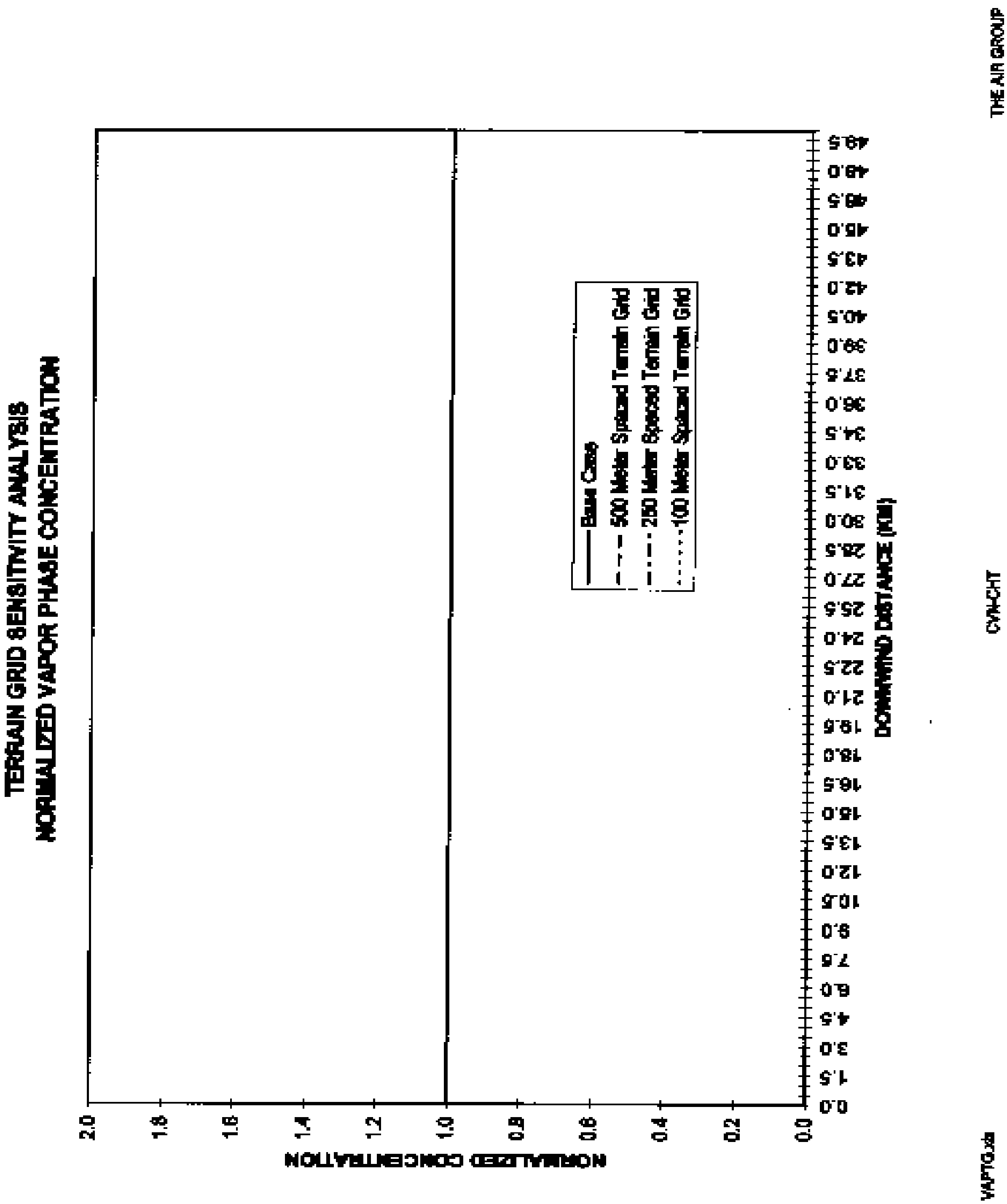

THE AIR GROUP
TERRAIN GRID PROFILE: 20 - 30 KM
(100 METER SPACING)
Elevation
ELEVATION (FEET)
DOWNWIND DISTANCE (METERS)
20-30 KM
100ELEV.xls

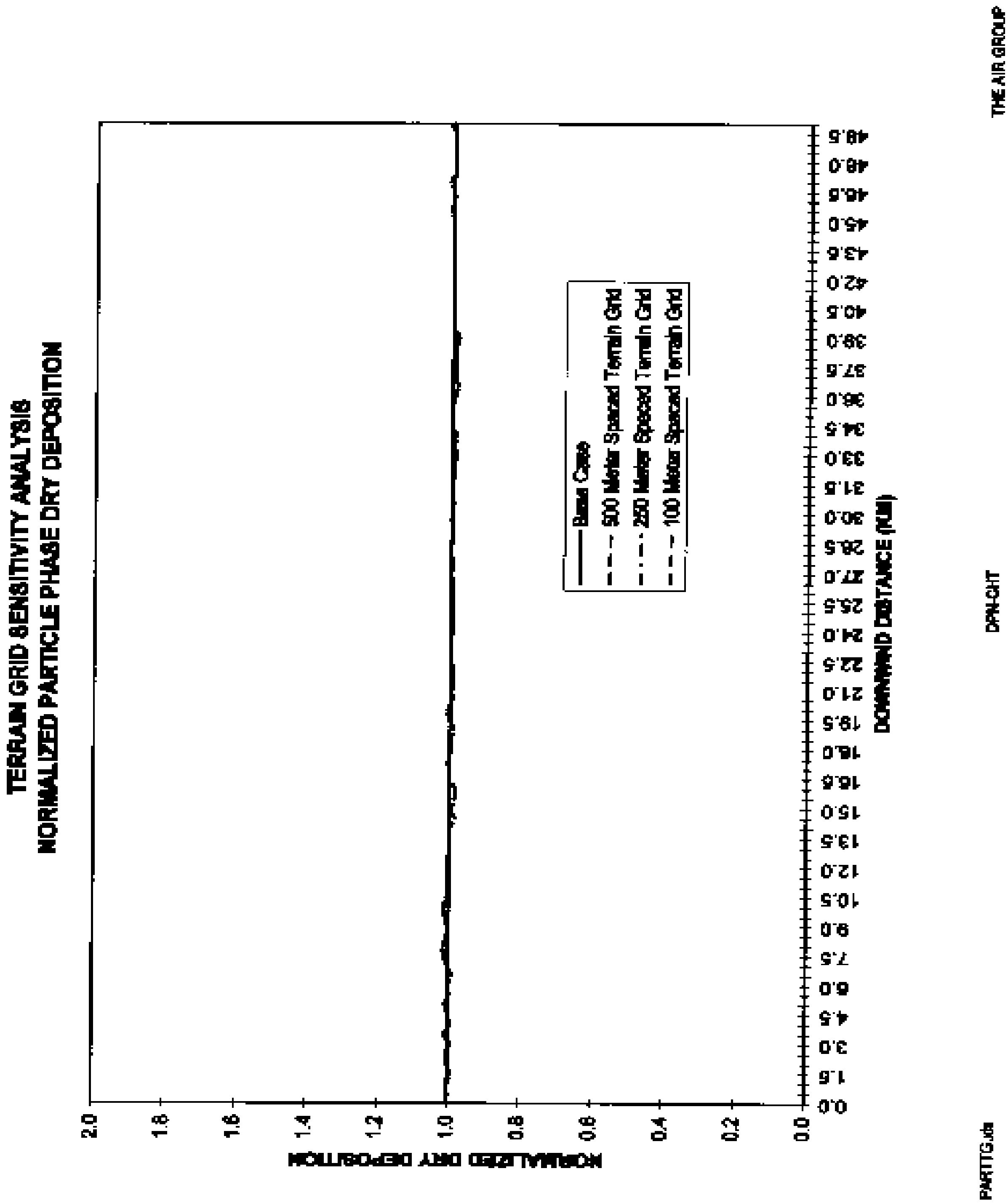

TERRAIN GRID PROFILE: 30 - 40 KM
(100 METER SPACING)
Elevation
ELEVATION (FEET)
DOWNWIND DISTANCE (METERS)
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
30000
30400
30800
31200
31600
32000
32400
32800
33200
33600
34000
34400
34800
35200
35600
36000
36400
36800
37200
37600
38000
38400
38800
39200
39600
40000
THE AIR GROUP
30-40 KM
100ELEV.xls

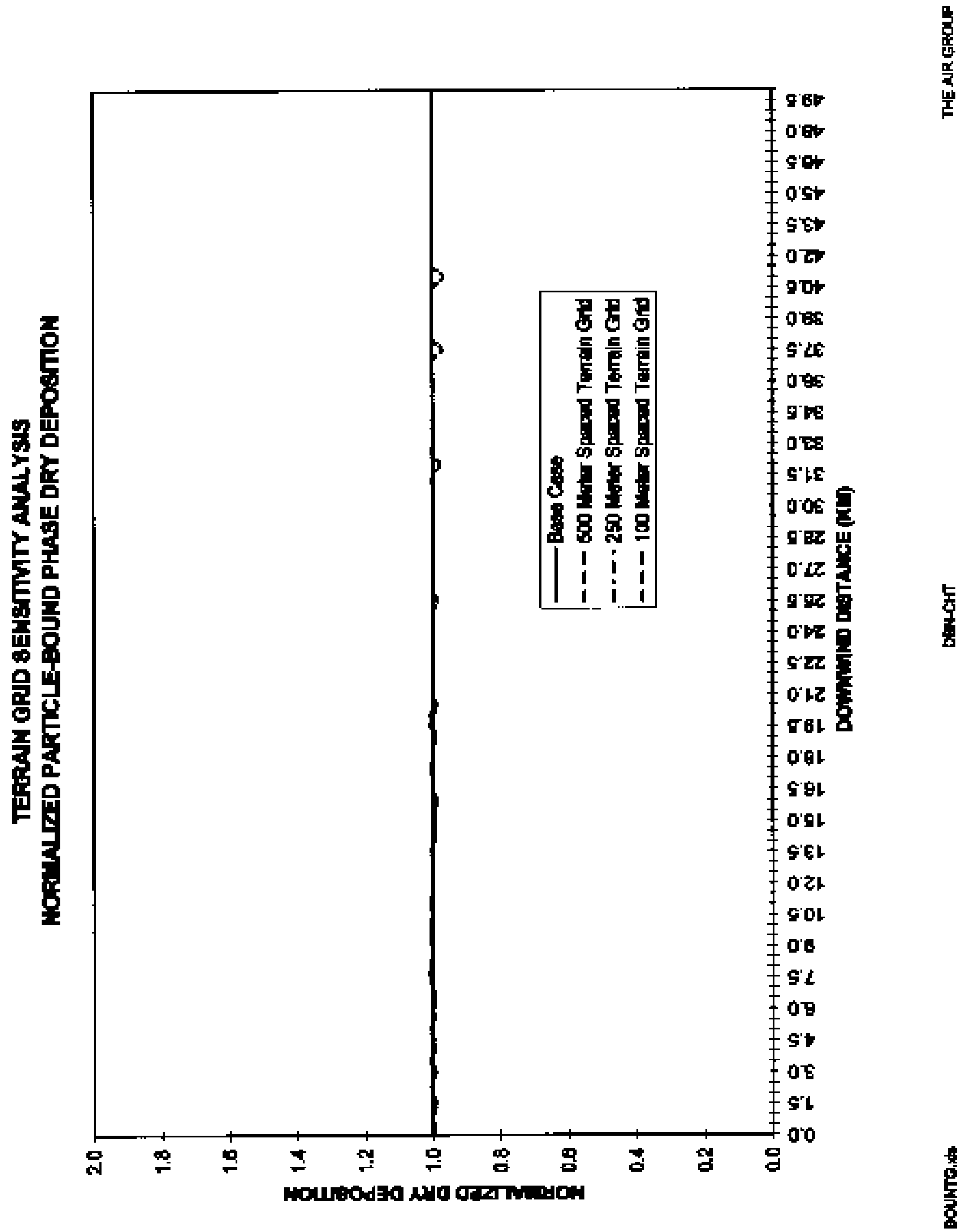

TERRAIN GRID PROFILE: 40 - 50 KM
(100 METER SPACING)
Elevation
DOWNWIND DISTANCE (METERS)
ELEVATION (FEET)
THE AIR GROUP
40-50 KM


TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
DOWNWIND DISTANCE (KM)
NORMALIZED CONCENTRATION
THE AIR GROUP


TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED PARTICLE-BOUND PHASE CONCENTRATION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (KM)
THE AIR GROUP
CBN-CHT
BOUNTG.xls


TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
NORMALIZED CONCENTRATION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (KM)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
18.0
19.5
21.0
22.5
24.0
25.5
27.0
28.5
30.0
31.5
33.0
34.5
36.0
37.5
39.0
40.5
42.0
43.5
45.0
46.5
48.0
49.5
THE AIR GROUP
CVN-CHT
VAPTG.xls


TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (KM)
THE AIR GROUP
DPN-CHT
PARTTG.xls


TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED PARTICLE-BOUND PHASE DRY DEPOSITION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (KM)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
18.0
19.5
21.0
22.5
24.0
25.5
27.0
28.5
30.0
31.5
33.0
34.5
36.0
37.5
39.0
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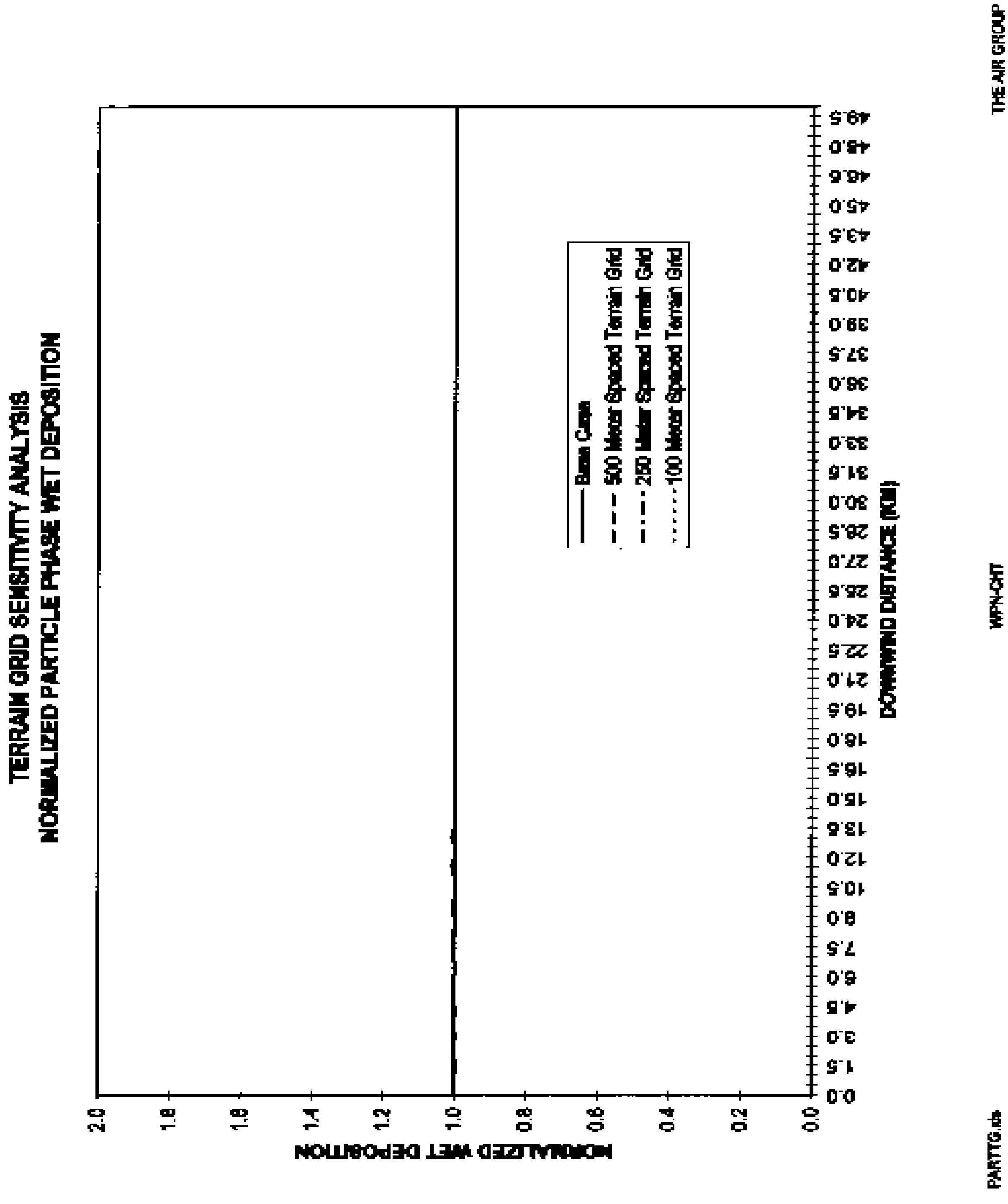
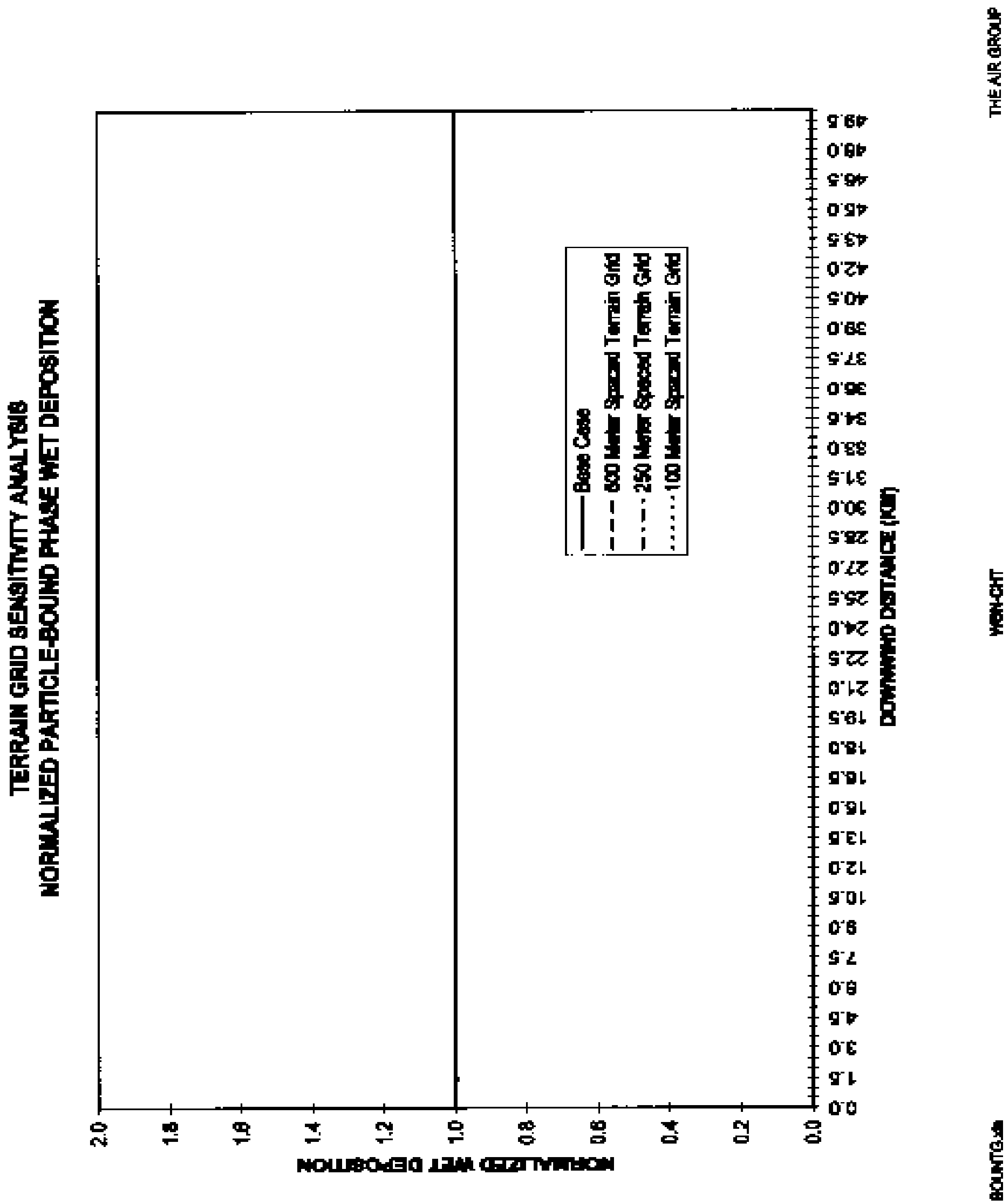
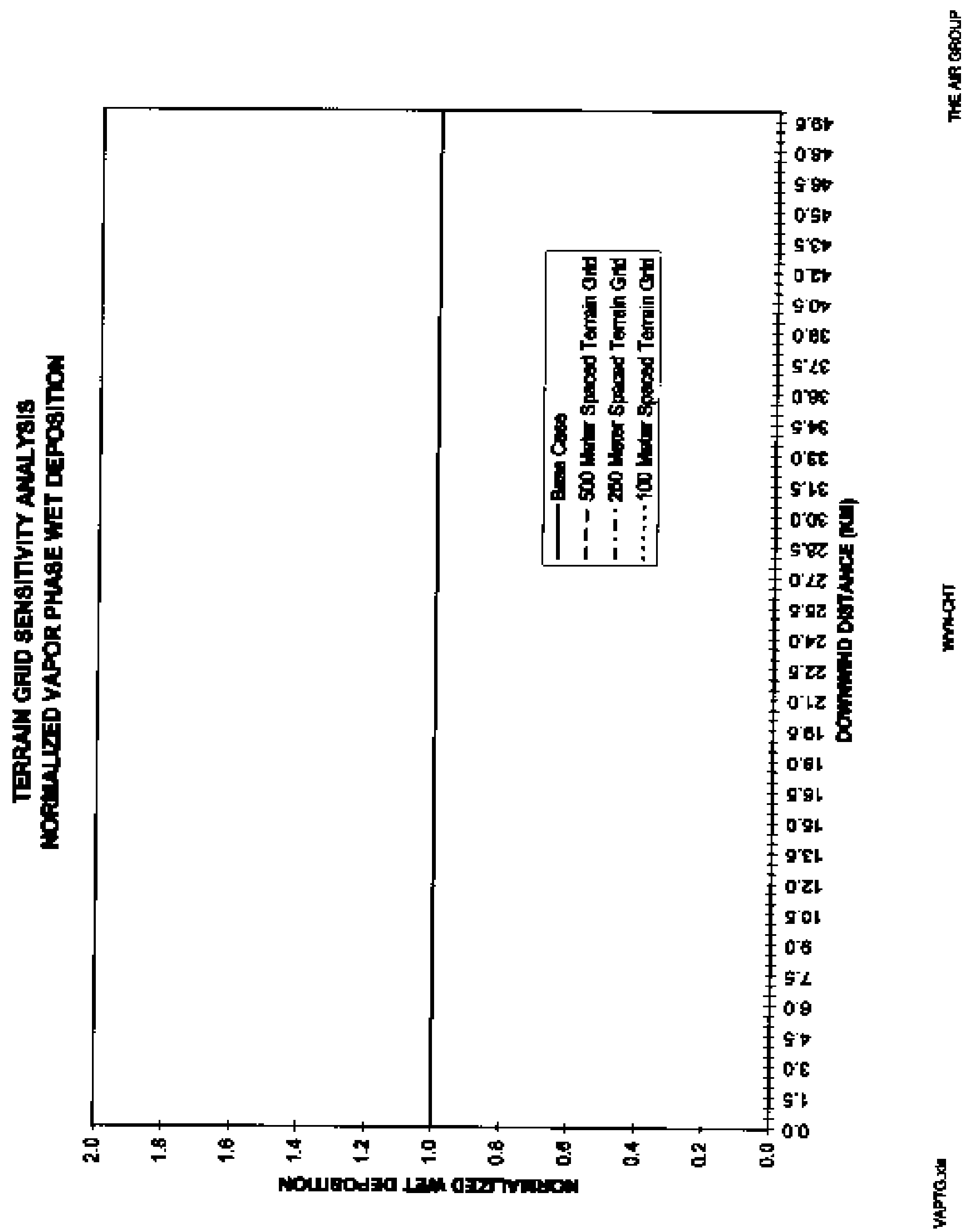
42.0
43.5
45.0
46.5
48.0
49.5
THE AIR GROUP
DBN-CHT
BOUNTG.xls


TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (KM)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
0.0 1.5 3.0 4.5 6.0 7.5 9.0 10.5 12.0 13.5 15.0 16.5 18.0 19.5 21.0 22.5 24.0 25.5 27.0 28.5 30.0 31.5 33.0 34.5 36.0 37.5 39.0 40.5 42.0 43.5 45.0 46.5 48.0 49.5
THE AIR GROUP
WPN-CHT
PARTTG.xls


TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED PARTICLE-BOUND PHASE WET DEPOSITION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (KM)
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
16.5
18.0
19.5
21.0
22.5
24.0
25.5
27.0
28.5
30.0
31.5
33.0
34.5
36.0
37.5
39.0
40.5
42.0
43.5
45.0
46.5
48.0
49.5
THE AIR GROUP



TERRAIN GRID SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Base Case
500 Meter Spaced Terrain Grid
250 Meter Spaced Terrain Grid
100 Meter Spaced Terrain Grid
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (KM)
THE AIR GROUP
WW-CHT
VAPTG.xls

6. SECONDARY ELEMENTS STUDIES

6.1 MINIMUM MONIN-OBUKHOV LENGTH

6.1.1 TECHNICAL OBJECTIVE

The technical objective of the minimum Monin-Obukhov length (L) sensitivity analysis is to determine the sensitivity of modeled results to variations of the minimum L specified in processing the meteorological data. The full range of potential minimum L values specified in Section 3.6. 1.1 of the Draft Protocol is investigated in the study.

6.1.2 THEORETICAL BASIS

The Monin-Obukhov length (L) is a measure of atmospheric stability. It is calculated from other meteorological preprocessor input parameters, such as noon-time albedo and Bowen ratio. Specification of a minimum L is necessary for urban areas to force the meteorological preprocessor to account for the effect of building-induced instability during stable atmospheric conditions. The purpose of the minimum Monin-Obukhov length sensitivity analysis is to determine the effect on modeled results at urban sites of using various values of minimum L. Test cases using the lowest (2 meters) and highest (150 meters) potential values for minimum L are compared with modeled results using a more typical minimum L value (50 meters).

6.1.3 METHODOLOGY

Since minimum Monin-Obukhov length only applies to urban conditions, urban values are chosen for all applicable input parameters in both the meteorological data and ISCST3.

6.1.3.1 BASE CASE - TYPICAL MINIMUM MONIN-OBUKHOV LENGTH

The base case utilizes Protocol recommended methods and values, urban meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact, and the flat terrain option. A minimum L of 50 meters typical for urban conditions is used in the base case.

6.1.3.2 TEST CASE I - UPPER LIMIT FOR MINIMUM MONIN-OBUKHOV LENGTH

Test Case 1 is identical to the base case, except a minimum L of 150 meters representing the upper limit of minimum L values is used to process the meteorological data.

6.1.3.3 TEST CASE 2 - LOWER LIMIT FOR MINIMUM MONIN-OBUKHOV LENGTH

Test Case 1 is identical to the base case, except a minimum L of 2 meters representing the lower limit of potential minimum L values is used to process the meteorological data.

6.1.4 RESULTS

6.1.4.1 CONCENTRATION

The results of the minimum Monin-Obukhov length sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute concentration and normalized concentration versus downwind distance are presented in Appendix A for all cases. Concentrations are virtually unaffected by minimum L, with a maximum variation of 3% relative to the base case.

6.1.4.2 DRY DEPOSITION

The results of the minimum Monin-Obukhov length sensitivity analysis in terms of normalized dry deposition (test case concentration divided by base case concentration) versus downwind distance are presented in Figures at the end of this section. Tables of absolute dry deposition rates and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

The effect of minimum L on dry deposition is small, with a maximum variation of 8% relative to the base case. The upper limit minimum L value results in higher dry deposition rates than the base case at all distances. The lower limit minimum L value results in lower dry deposition rates than the base case at all distances

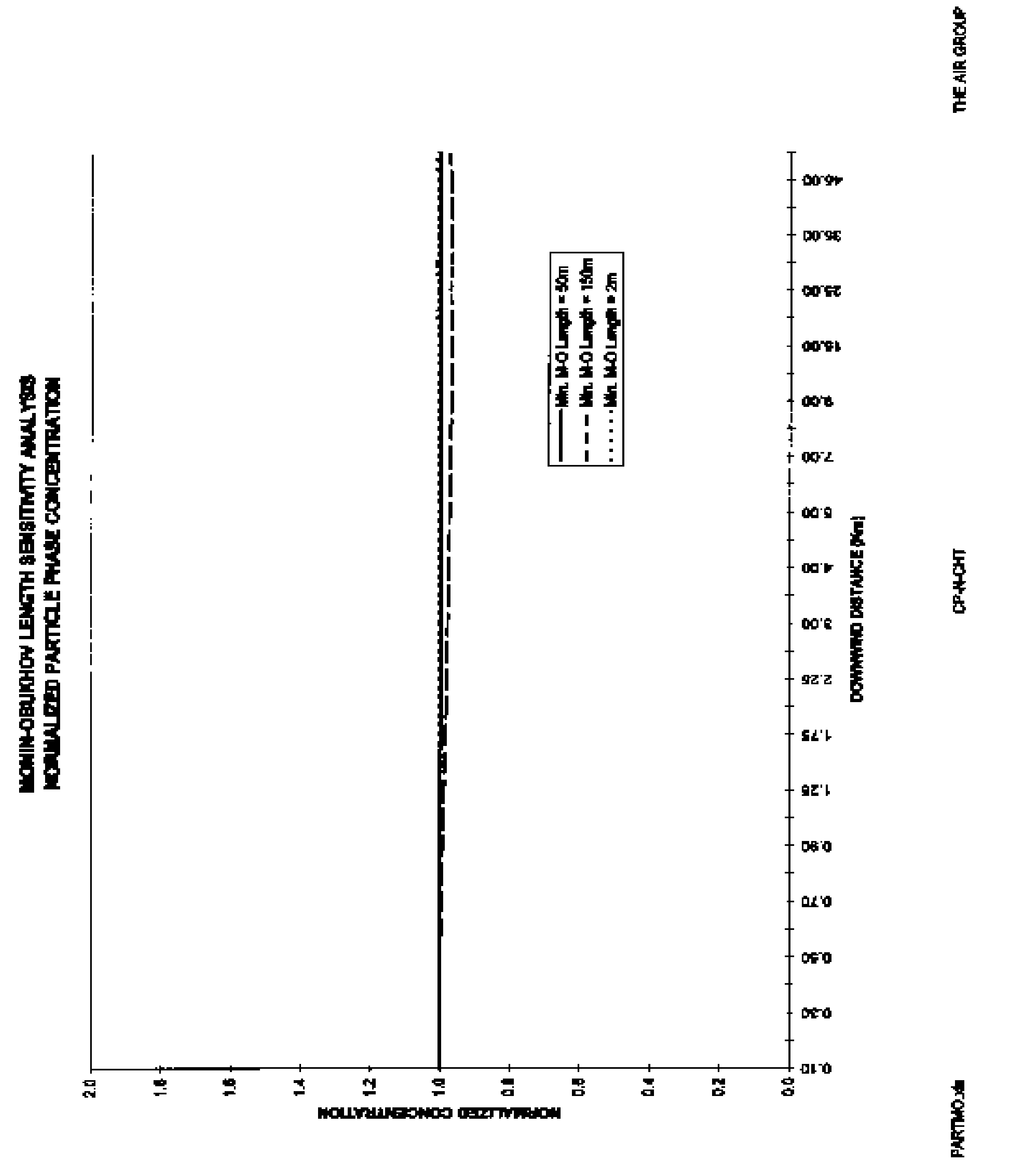
6.1.4.3 WET DEPOSITION

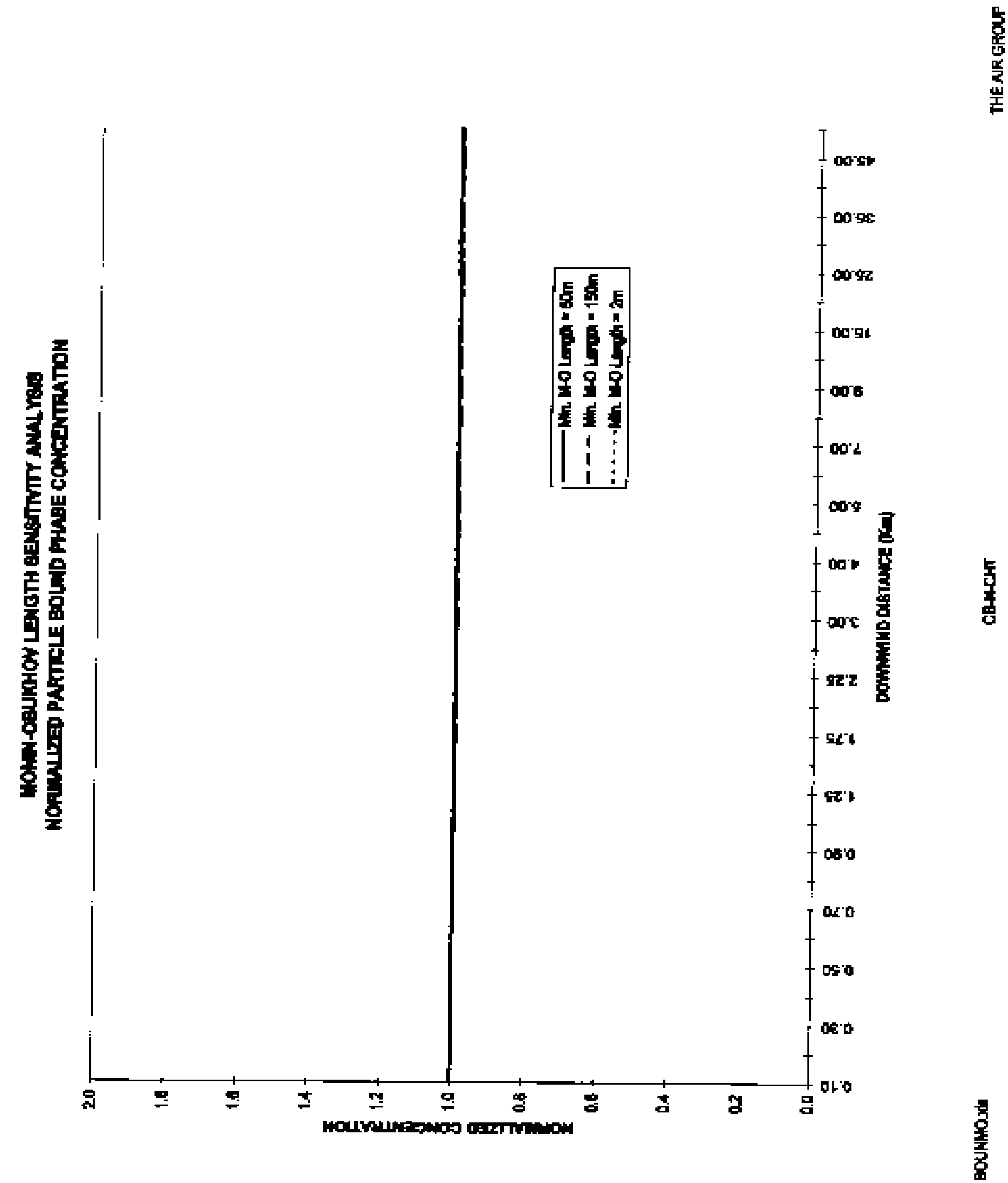
The results of the minimum Monin-Obukhov length sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case concentration) versus downwind distance are presented in Figures at the end of this section. Tables of absolute wet deposition and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

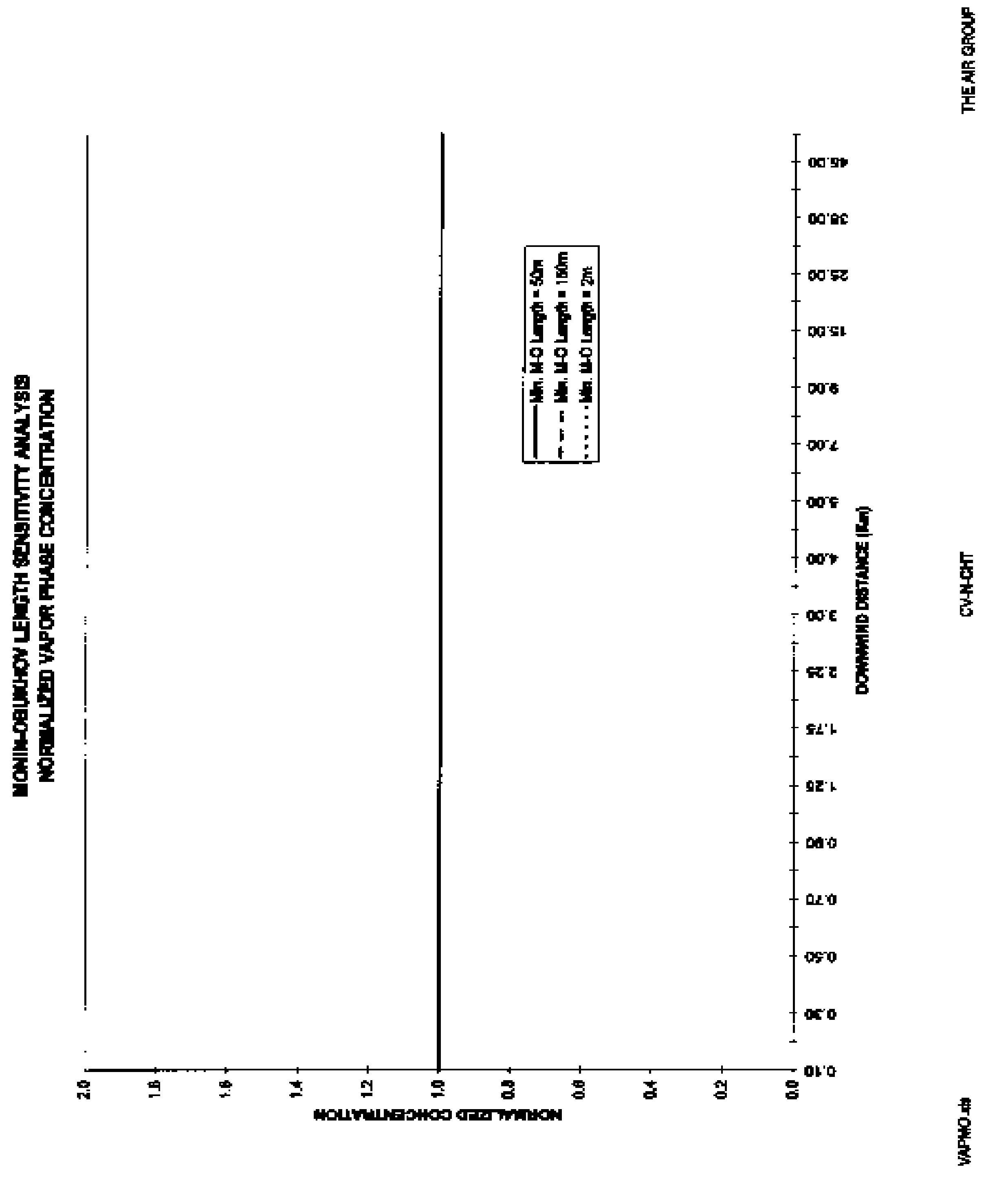
Wet deposition rates are virtually unaffected by minimum L, with a maximum variation of 2% relative to the base case.

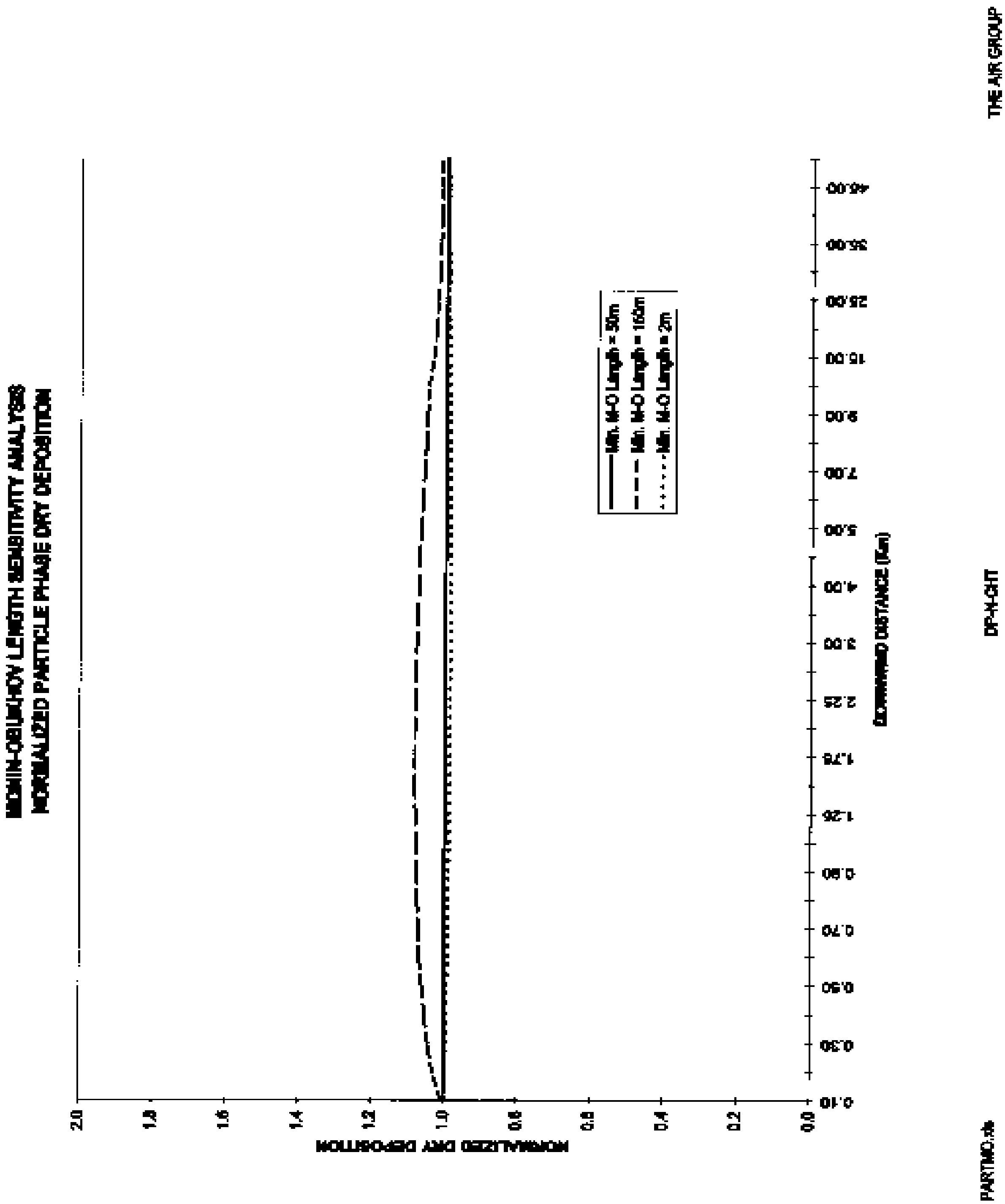
6.1.5 RECOMMENDATIONS

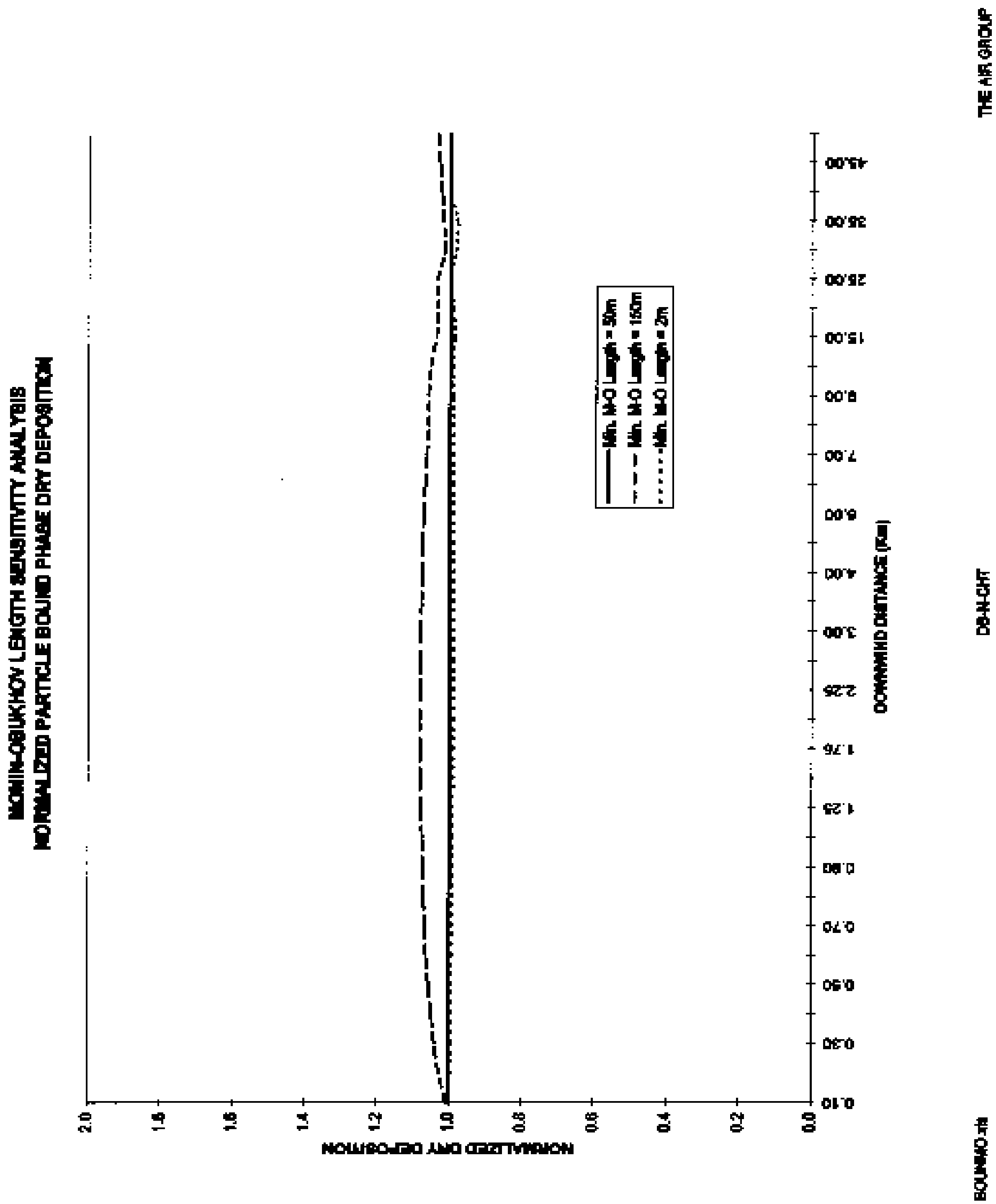
EPA should specify in the Protocol to use a value of 50 meters for minimum Monin-Obukhov length in urban sites. For processing meteorological data using PCRAMMET, the minimum Monin-Obukhov length should be set to 2 meters to prevent PCRAMMET from crashing on a read error. The value is not used when processing meteorological data for rural sites. Refinement of minimum Monin-Obukhov length can be given low priority, since this parameter has little effect on modeled impacts.

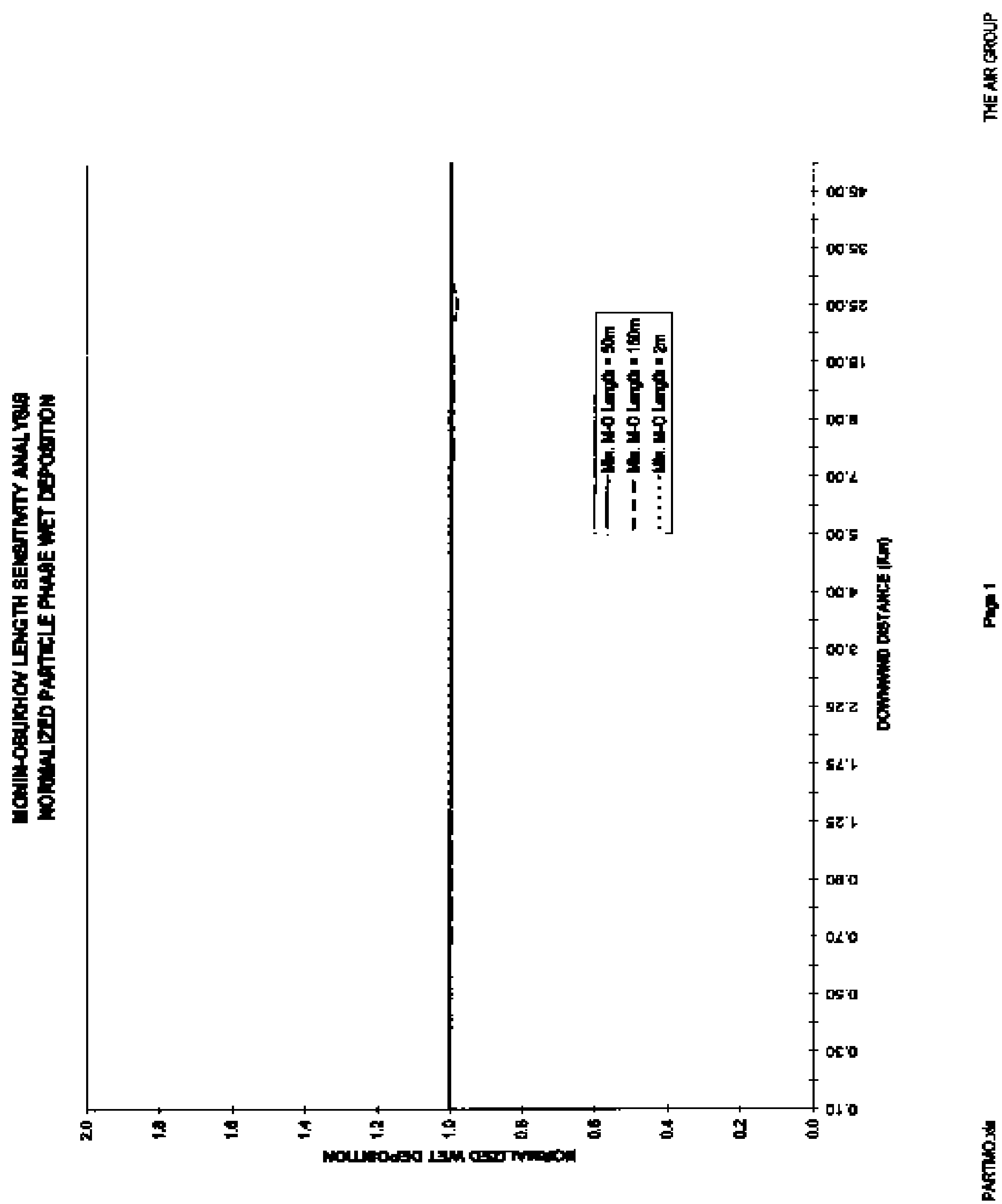

MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE [Km]
THE AIR GROUP

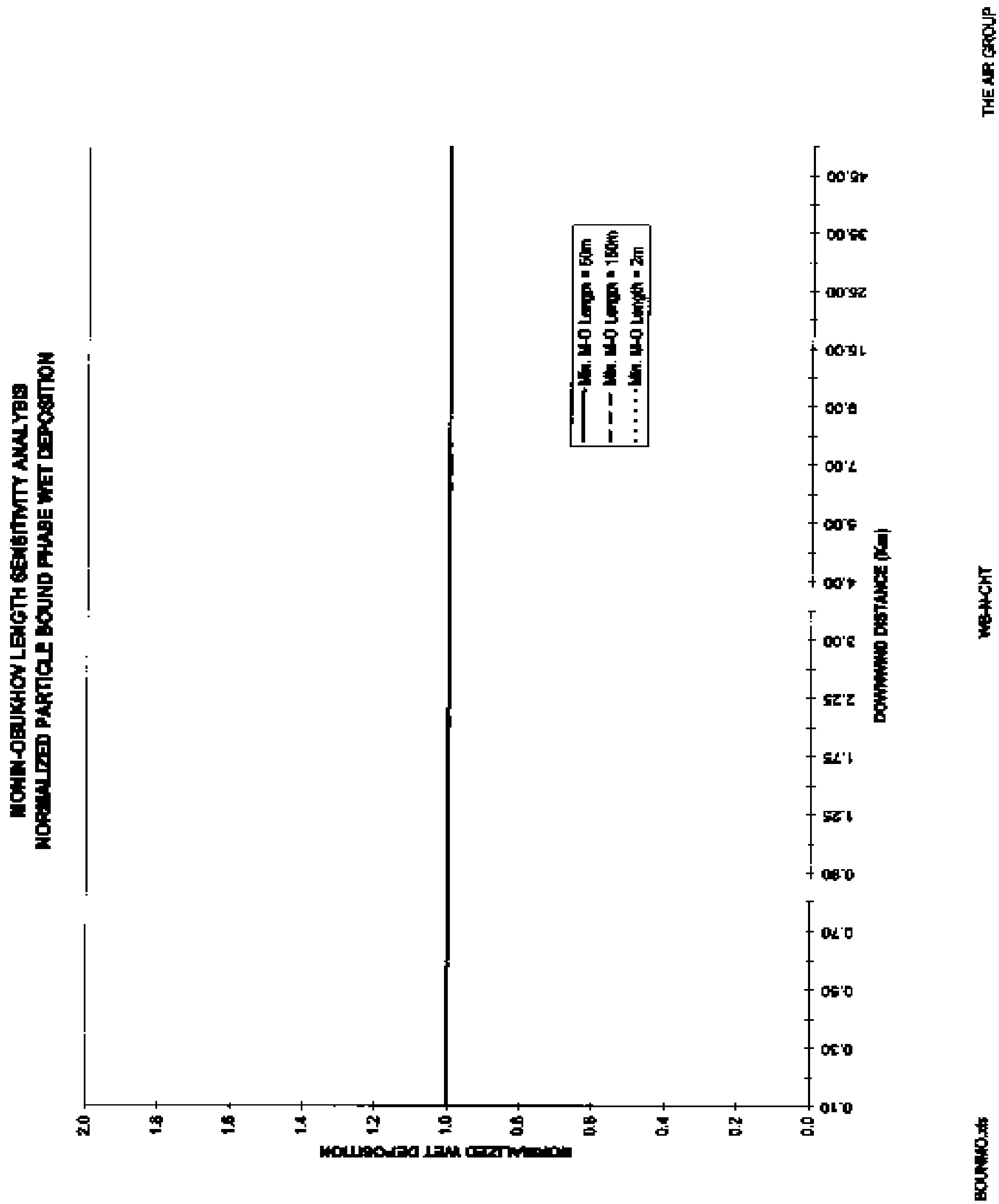

MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
2.0
1.0
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00

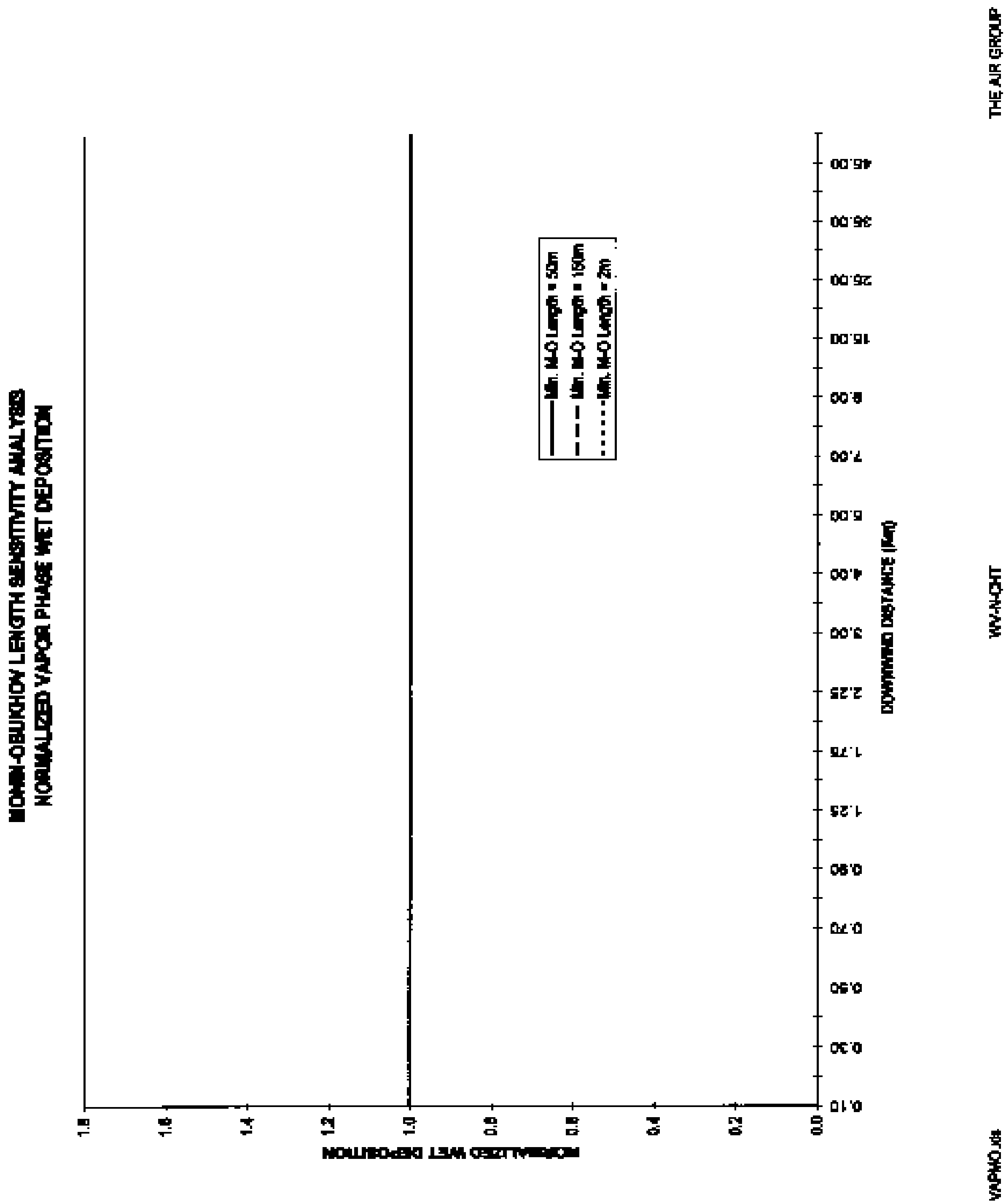

MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
CV-N-CHT
VAPMO.#


MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
DP-K-CHT
PARTMO.xls


MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


THE AIR GROUP
MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
Page 1
PARTMO.xls


MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WB-M-CHT
BOUNMO.xls


MONIN-OBUKHOV LENGTH SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Min. M-O Length = 50m
Min. M-O Length = 150m
Min. M-O Length = 2m
NORMALIZED WET DEPOSITION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WV-N-CHT
VAPMO.xls

6.2 SURFACE ROUGHNESS AT MEASUREMENT SITE

6.2.1 TECHNICAL OBJECTIVE

The technical objective of the surface roughness at measurement site sensitivity analysis is to determine the sensitivity of modeled results to the surface roughness specified for the measurement site in processing of the meteorological data. If modeled results are relatively unaffected by surface roughness at the measurement site, then a site-specific analysis of surface roughness at each individual weather station would not be necessary and a default value based on strict siting criteria in NWS guidance for primary weather stations could be used in all studies.

6.2.2 THEORETICAL BASIS

Surface roughness is a measure of the height of obstacles to wind flow and is an input to the meteorological preprocessor. Similar to the application site, surface roughness adjusts the behavior of the atmosphere for stability, Monin-Obukhov length, and friction velocity.

6.2.3 METHODOLOGY

6.2.3.1 BASE CASE - PROTOCOL RECOMMENDED SURFACE ROUGHNESS AT MEASUREMENT SITE

The base case model runs described in Section 4 are used as the base case for this analysis. The base case includes Protocol recommended methods and values, rural meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact, and the flat terrain option. The surface roughness at measurement site used in the base case is 0. I meters, which best represents the siting criteria for primary NWS weather stations.

6.2.3.2 TEST CASE 1 - MAXIMUM SURFACE ROUGHNESS HEIGHT

Test Case 1 is identical to the base case model runs, except that a surface roughness height at measurement site of 1.3 meters was used to develop the meteorological data. This roughness height is the maximum over the range of roughness heights and is representative of forests during the summer.

6.2.3.3 TEST CASE 2 - MINIMUM SURFACE ROUGHNESS HEIGHT

Test Case 2 is identical to the base case model runs, except that a surface roughness height at application site of 0.001 meters was used to develop the meteorological data. This roughness height is within the lower range of potential values and is representative of grassland in the winter or a water surface.

6.2.4 RESULTS

6.2.4.1 CONCENTRATION

The results of the surface roughness at measurement site sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in Figures at the end of this section. Tables of absolute concentration and normalized concentration versus downwind distance are presented in Appendix A for all cases.

For both the particle phase and particle-bound phase, test case concentrations are within 16% of the base case for all distances modeled. Particle phase concentrations using the maximum surface roughness (Test Case 1) are 3% to 5% lower than base case concentrations within 300 meters of the source. Normalized concentrations for this case gradually decrease with distance to a minimum of 16% lower than the base case at distances of 10 to 50 kilometers from the source. Particle phase concentrations using minimum surface roughness height (Test Case 2) are approximately 2% to 3% higher than base case concentrations within 500 meters of the source. Normalized concentrations gradually increase with distance from the source to a maximum of 1% higher than base case at 35 kilometers.

For the particle-bound phase, relative differences between the base case and the test cases are even smaller than for the particle phase, with concentrations for both test cases staying within 4% of the base case for all distances modeled. Particle-bound phase concentrations using the maximum surface roughness (Test Case 1) are less than 2% lower than base case concentrations within one kilometer of the source. Normalized concentrations for this case gradually decrease with distance to a minimum of 4% lower than the base case at 50 kilometers from the source. Particle-bound phase concentrations using minimum surface roughness height (Test Case 2) are less than 1% higher than base case concentrations within 2.5 kilometers of the source. Normalized concentrations gradually increase with distance from the source to a maximum of 2% higher than base case at 35 kilometers.

For the vapor phase, concentrations are unaffected by the variation in surface roughness.

6.2.4.2 DRY DEPOSITION

The results of the surface roughness at measurement site sensitivity analysis in terms of normalized dry deposition rates (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in Figures at the end of this section. Tables of absolute dry deposition and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

For both the particle and particle-bound phases, the normalized curves follow a similar progression. For the maximum surface roughness case (Test Case 1), the dry deposition rates are approximately 200% of the base case at 100 meters, gradually dropping relative to the base case to a minimum of 113% to 140% of the base case at a distance of 50 kilometers from the source. For the minimum surface roughness case (Test Case 2), the dry deposition rates are 50% to 60% of the base case at 100 meters, gradually rising relative to the base case to a maximum of 85% to 88% of the base case at a distance of 50 kilometers from the source.

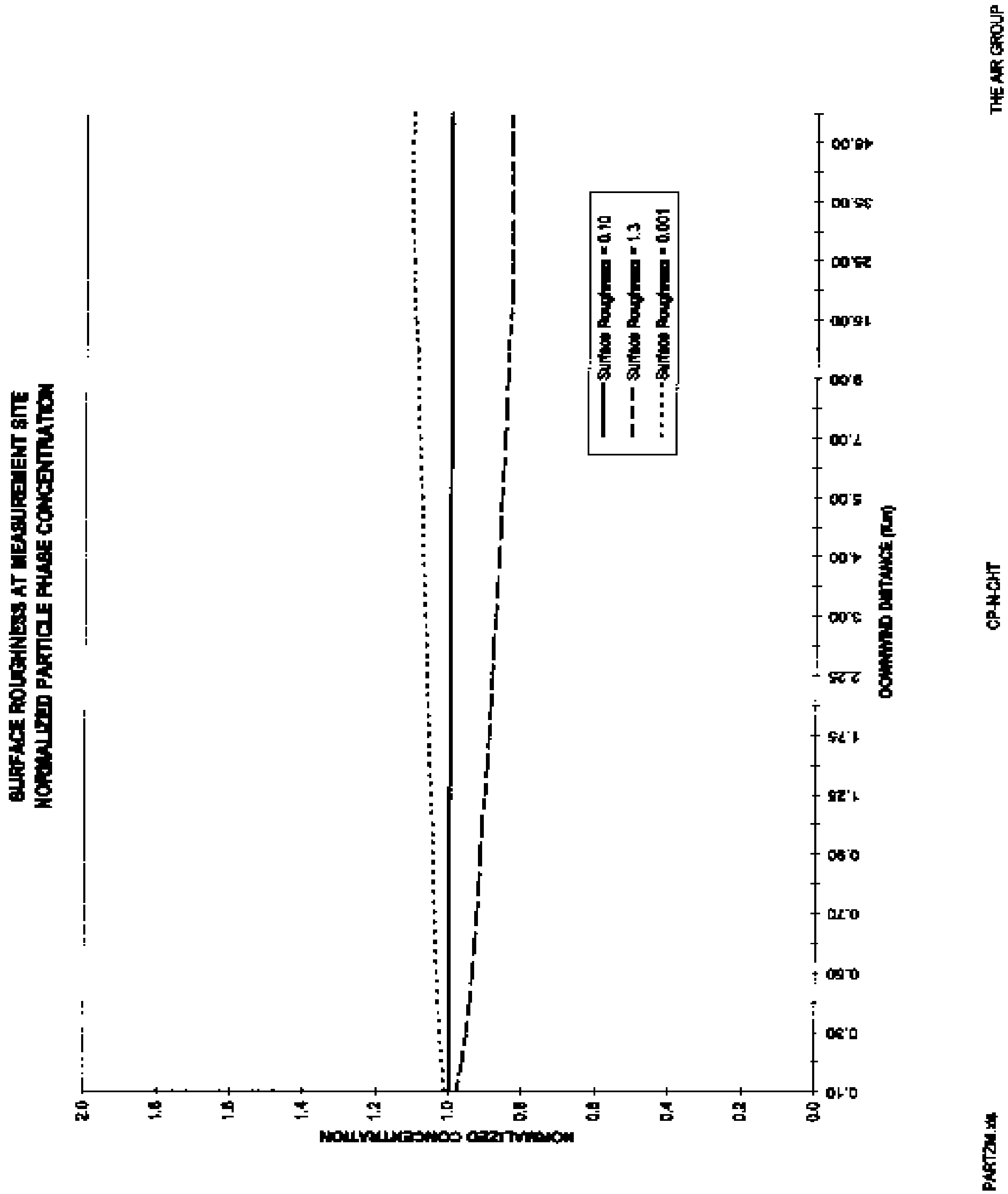
6.2.4.3 WET DEPOSITION

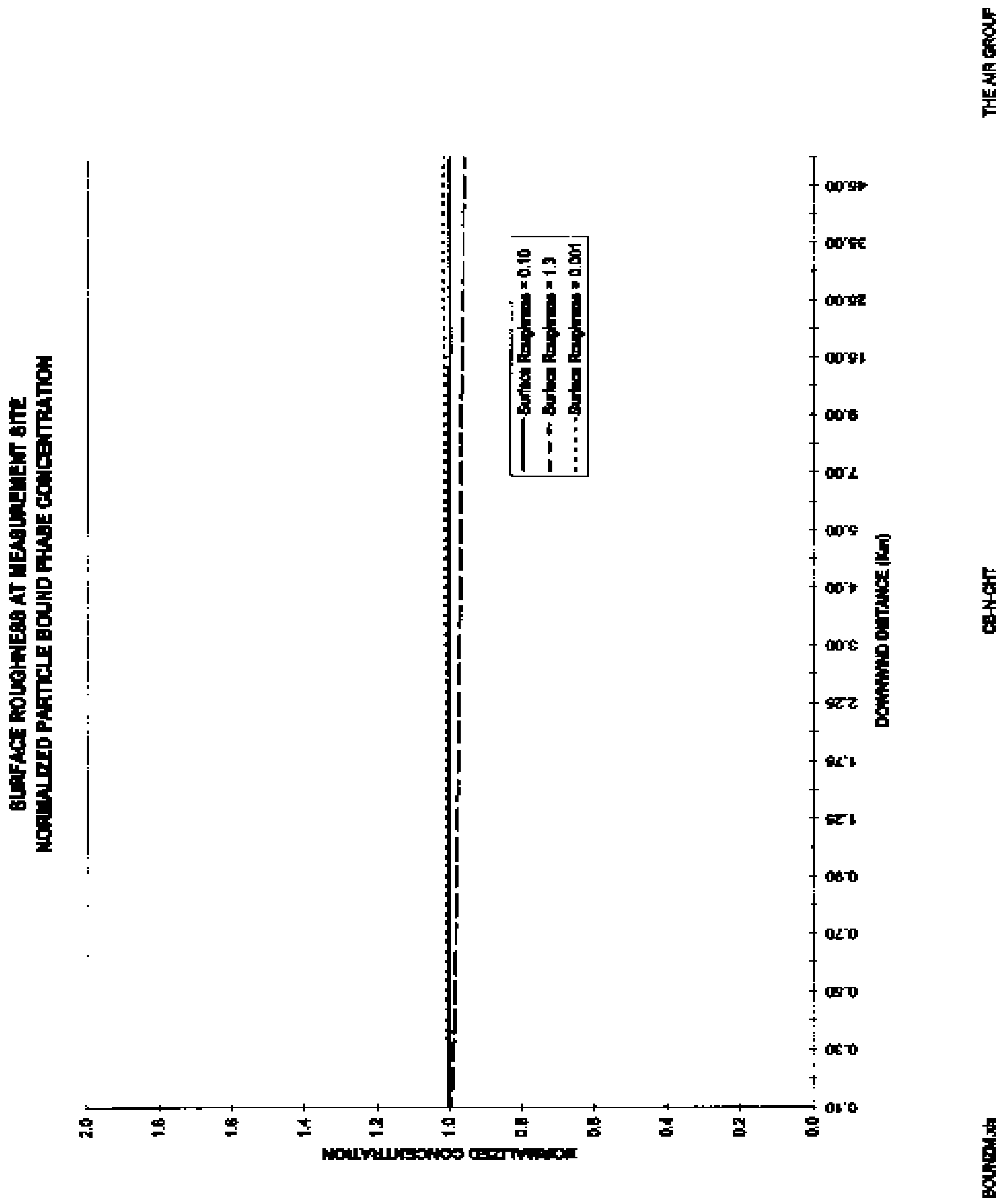
The results of the surface roughness at measurement site sensitivity analysis in terms of normalized wet deposition rates (test case wet deposition divided by base case wet deposition) versus downwind distance are presented in Figures at the end of this section. Tables of absolute wet deposition and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

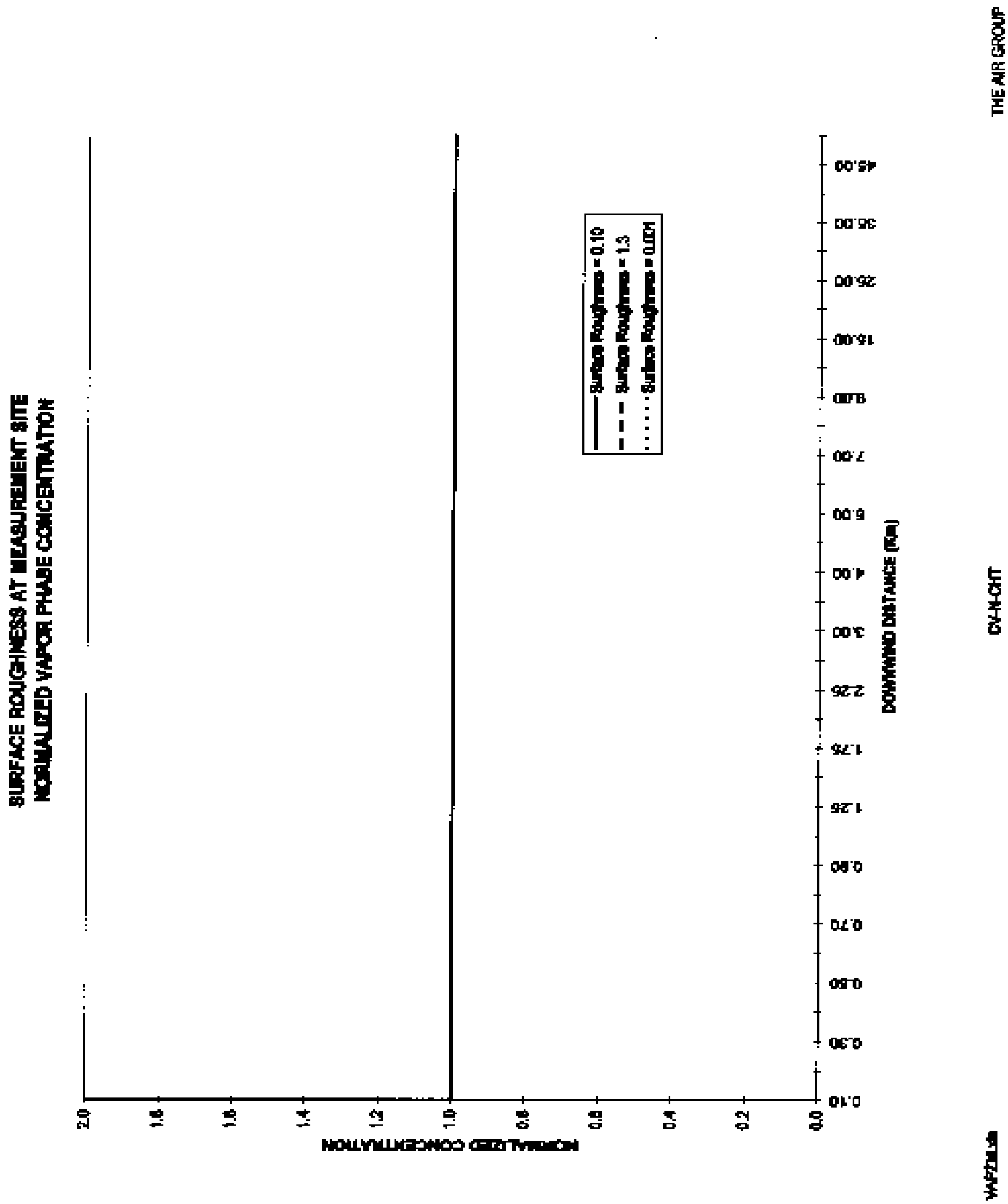
For both the particle and particle-bound phases, wet deposition rates for both of the test cases are within 2% of the base case out to a distance of 800 meters. For the maximum surface roughness case (Test Case 1), the wet deposition rates gradually decrease relative to the base case to a value of 17% lower than the base case at 50 kilometers from the source. For the minimum surface roughness case (Test Case 2), wet deposition rates are within 5% of the base case out to 5 kilometers from the source. The curve gradually continues to increase to a maximum of 108% of the base case at a distance of 50 kilometers from the source. Vapor phase wet deposition rates are unaffected by surface roughness height.

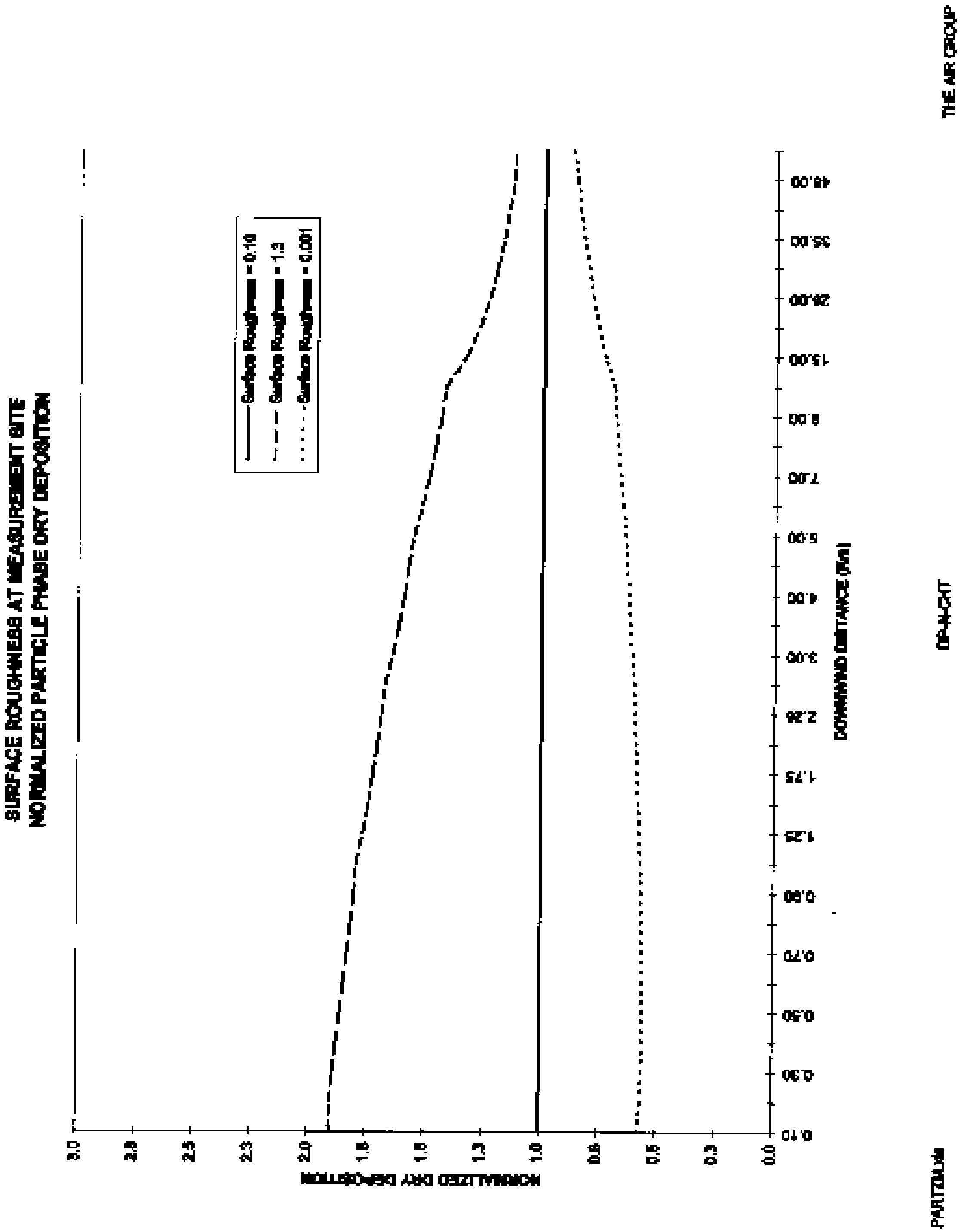
6.2.5 RECOMMENDATIONS

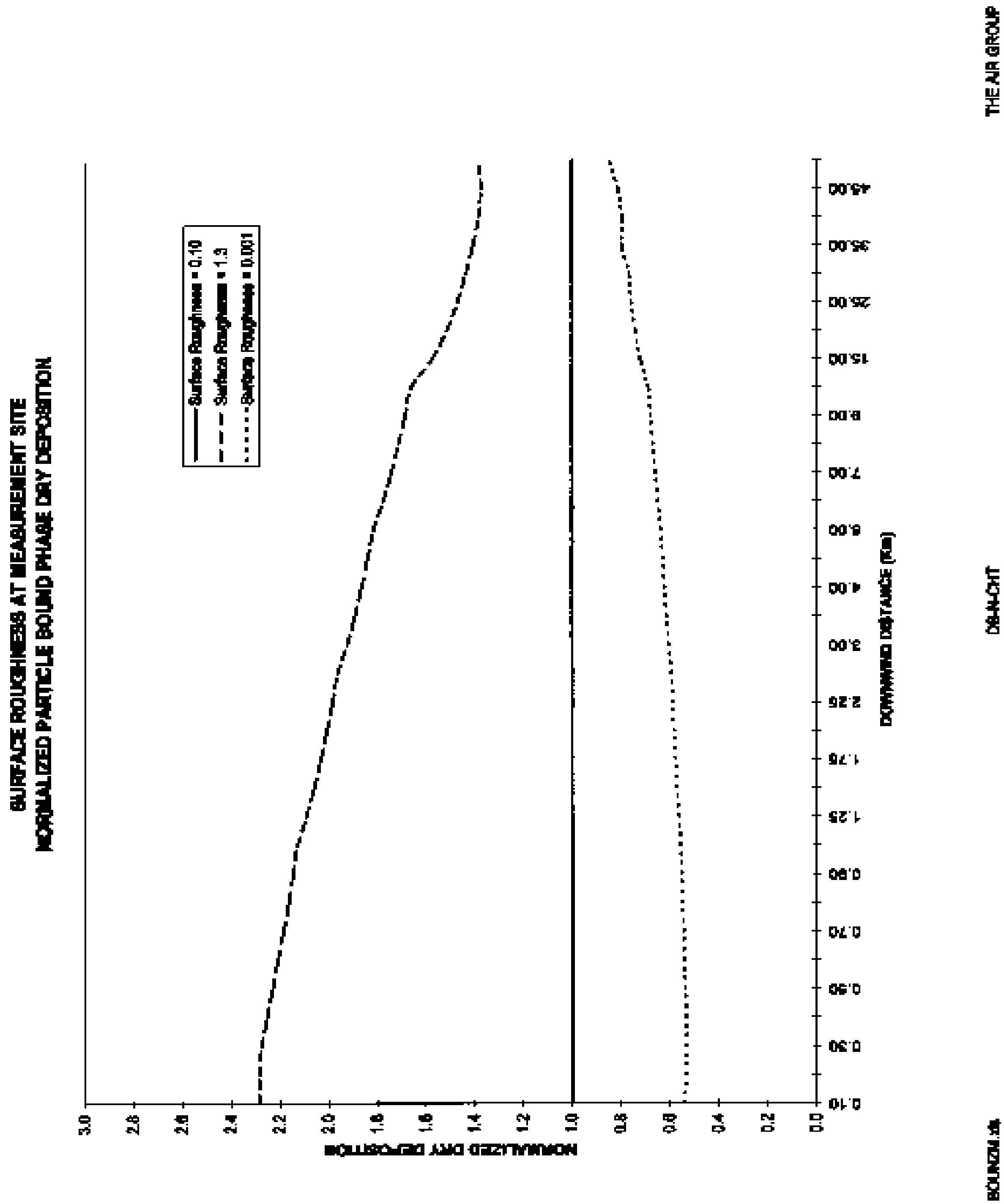
EPA should specify the use of a default value of 0.10 meters for surface roughness at the measurement site consistent with NWS siting criteria for unobstructed air flow near the wind sensors. Since dry deposition is very sensitive to surface roughness, only well-documented deviations from the default value should be allowed. Concentration and wet deposition are relatively unaffected by surface roughness close to the source. Farther away, concentration and wet deposition rates vary by as much as 17%. Dry deposition rates are the most affected by surface roughness at the measurement site, with modeled results varying by as much as 200% at close proximity to the source. The results indicate that if surface roughness at the measurement site is actually higher than the siting criteria would imply, use of the default surface roughness value specified in the Draft Protocol could cause the ISCST3 model to under-predict dry deposition rates by as much as 50%. Therefore, the modeler should verify that the surface roughness at the measurement site is actually 0.10 meters as the NWS siting criteria implies.

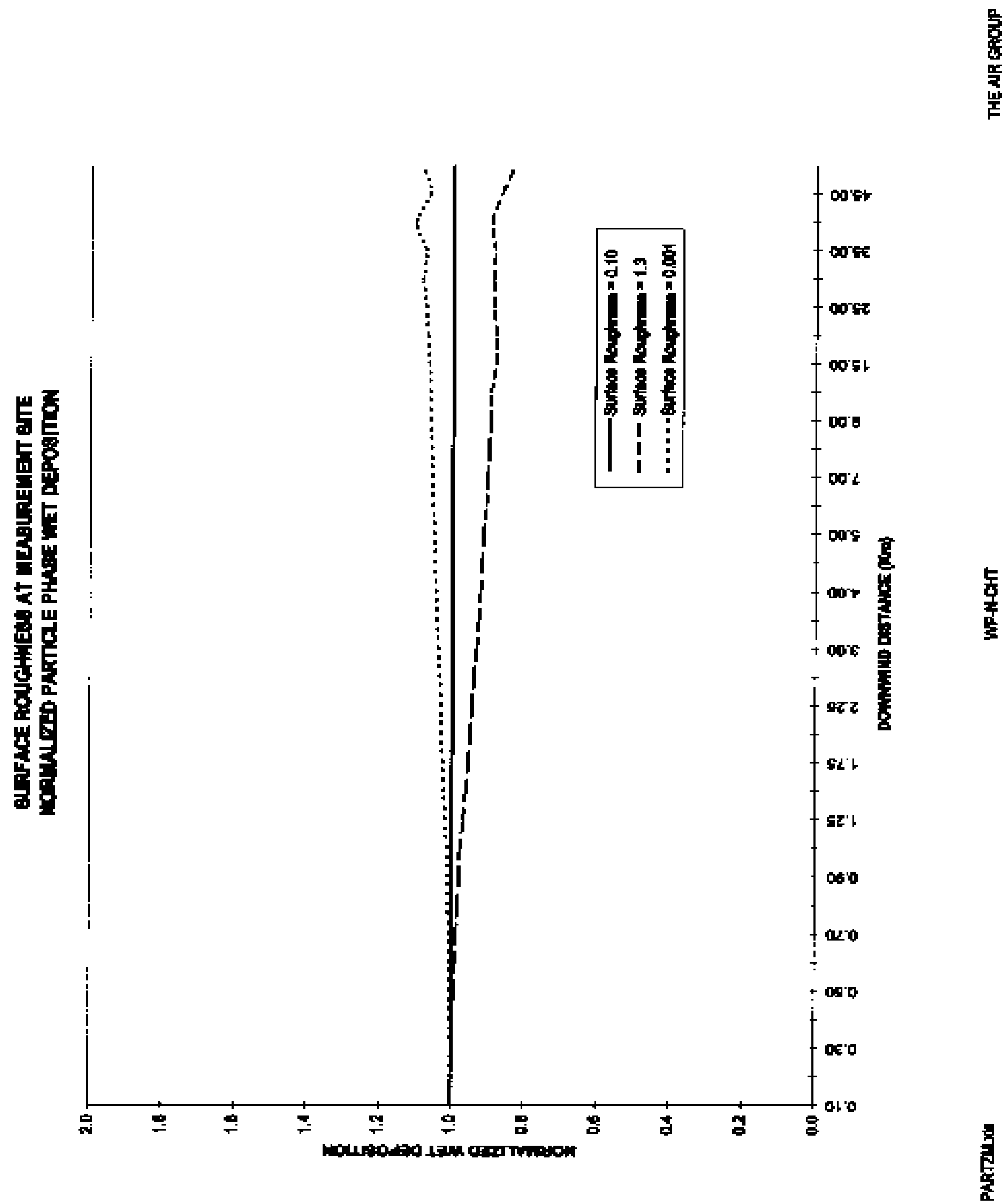

SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED PARTICLE PHASE CONCENTRATION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
CP-N-CHT

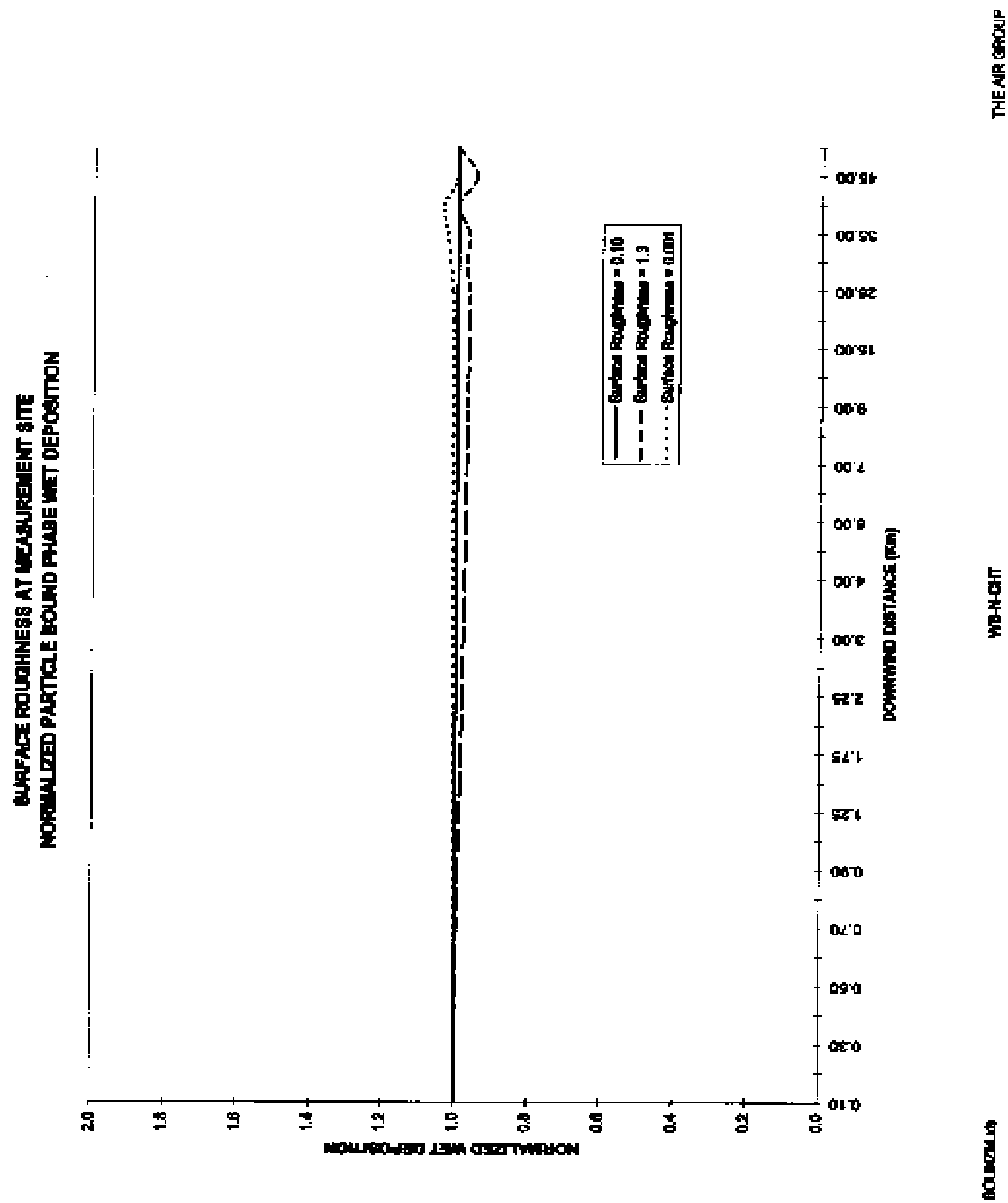

SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED CONCENTRATION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
CS-N-CHT


SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED VAPOR PHASE CONCENTRATION
Surface Roughness = 0.10
Surface Roughness = 1.3
DOWNWIND DISTANCE (Km)
NORMALIZED CONCENTRATION
THE AIR GROUP
CV-N-CHT


SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
DB-N-CHT
BOUNZM.xls


SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED PARTICLE PHASE WET DEPOSITION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
WP-N-CHT


SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WB-N-CHT
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
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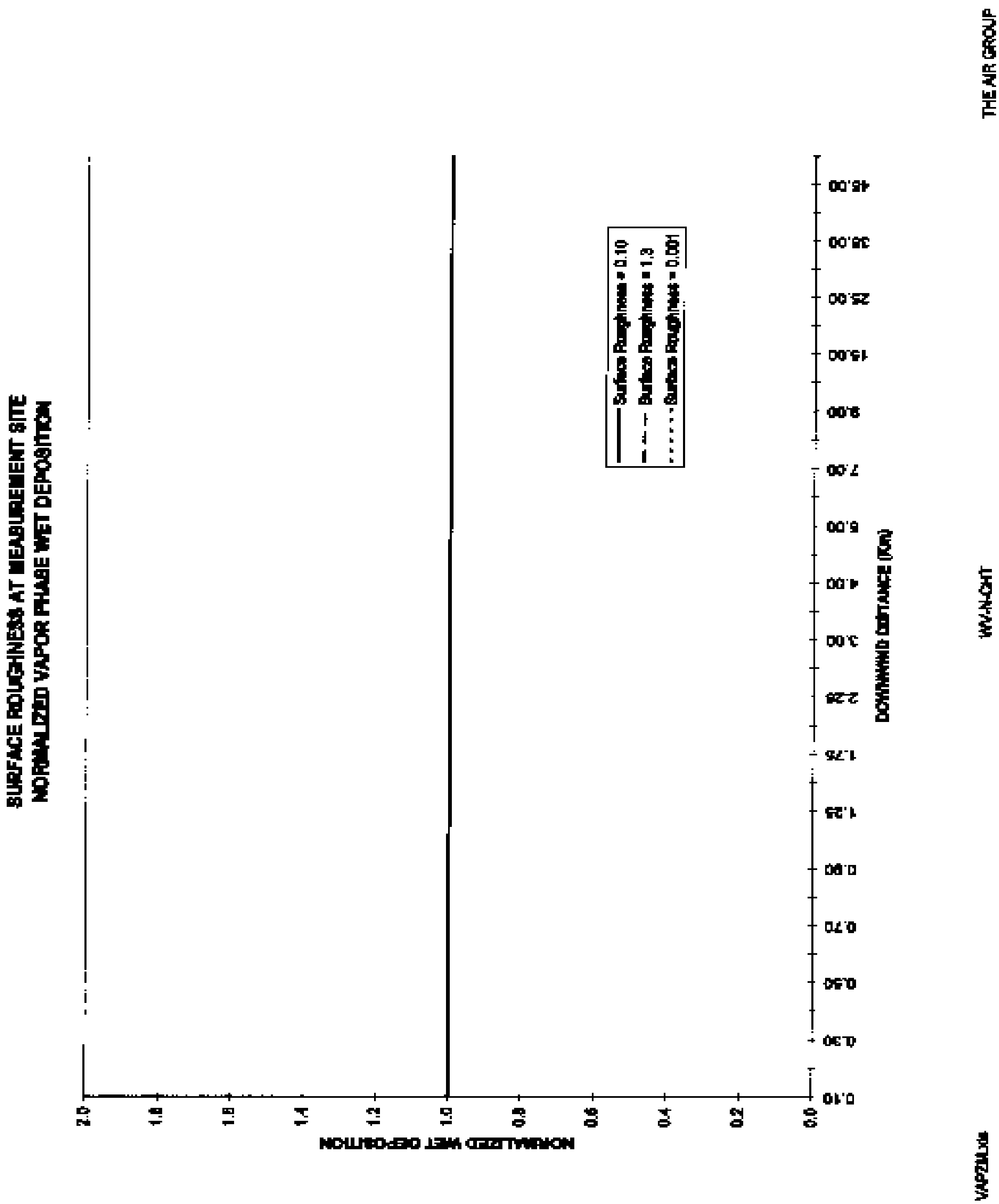
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00


SURFACE ROUGHNESS AT MEASUREMENT SITE
NORMALIZED VAPOR PHASE WET DEPOSITION
Surface Roughness = 0.10
Surface Roughness = 1.3
Surface Roughness = 0.001
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WV-N-CHT
VAPZ0.xls

6.3 NOON-TIME ALBEDO

6.3.1 TECHNICAL OBJECTIVE

The technical objective of the noon-time albedo sensitivity analysis is to determine the sensitivity of modeled results to variations of noon-time albedo values within the range specified in Table 3-2 of the Draft Protocol.

6.3.2 THEORETICAL BASIS

Noon-time albedo is used in calculating hourly net heat balance at the surface for calculating hourly values of Monin-Obukhov length. A highly reflective surface with snow or light snad cover will reduce the amount of solar radiation heating the surface, thus leading to more stable surface layers of air flow. The default values do not vary significantly from rural to urban, but the impact on modeled results is currently unknown.

6.3.3 METHODOLOGY

6.3.3.1 BASE CASE - TYPICAL NOON-TIME ALBEDO

The base case model runs described in Section 4 are used as the base case for this analysis. The base case includes Protocol recommended methods and values, rural meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact, and the flat terrain option. A typical noon-time albedo value of 0.18 representing grassland during the summer is used in the base case.

6.3.3.2 TEST CASE I - MINIMUM NOON-TIME ALBEDO

Test Case 1 is identical to the base case, except a minimum noon-time albedo of 0.10 representing a water surface during the summer is used to process the meteorological data.

6.3.3.3 TEST CASE 2 - MAXIMUM NOON-TIME ALBEDO

Test Case 1 is identical to the base case, except a maximum noon-time albedo of 0.60 representing snow-covered grass in the winter is used to process the meteorological data.

6.3.4 RESULTS

6.3.4.1 CONCENTRATION

The results of the noon-time albedo sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized concentration versus downwind distance are presented in Appendix A for all cases.

Concentrations are virtually unaffected by variations in noon-time albedo.

6.3.4.2 DRY DEPOSITION

The results of the noon-time albedo sensitivity analysis in terms of normalized dry deposition (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

Dry deposition rates are only slightly affected by noon-time albedo. The greatest variation occurs with the maximum noon-time albedo (Test Case 2), with dry deposition rates approximately 6% lower than the base case at close proximity to the source. This variation gradually decreases to zero at large distances from the source.

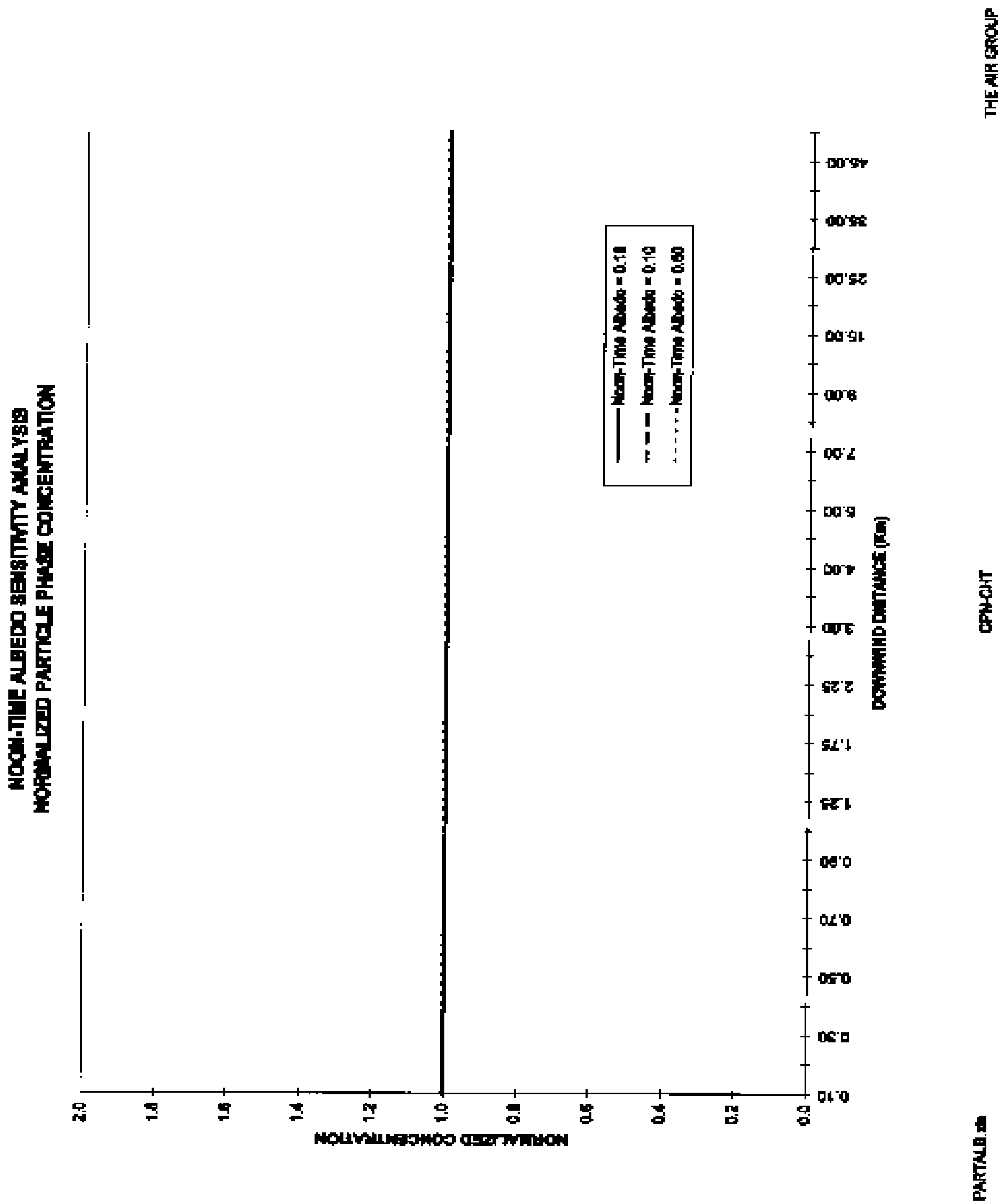
6.3.4.3 WET DEPOSITION

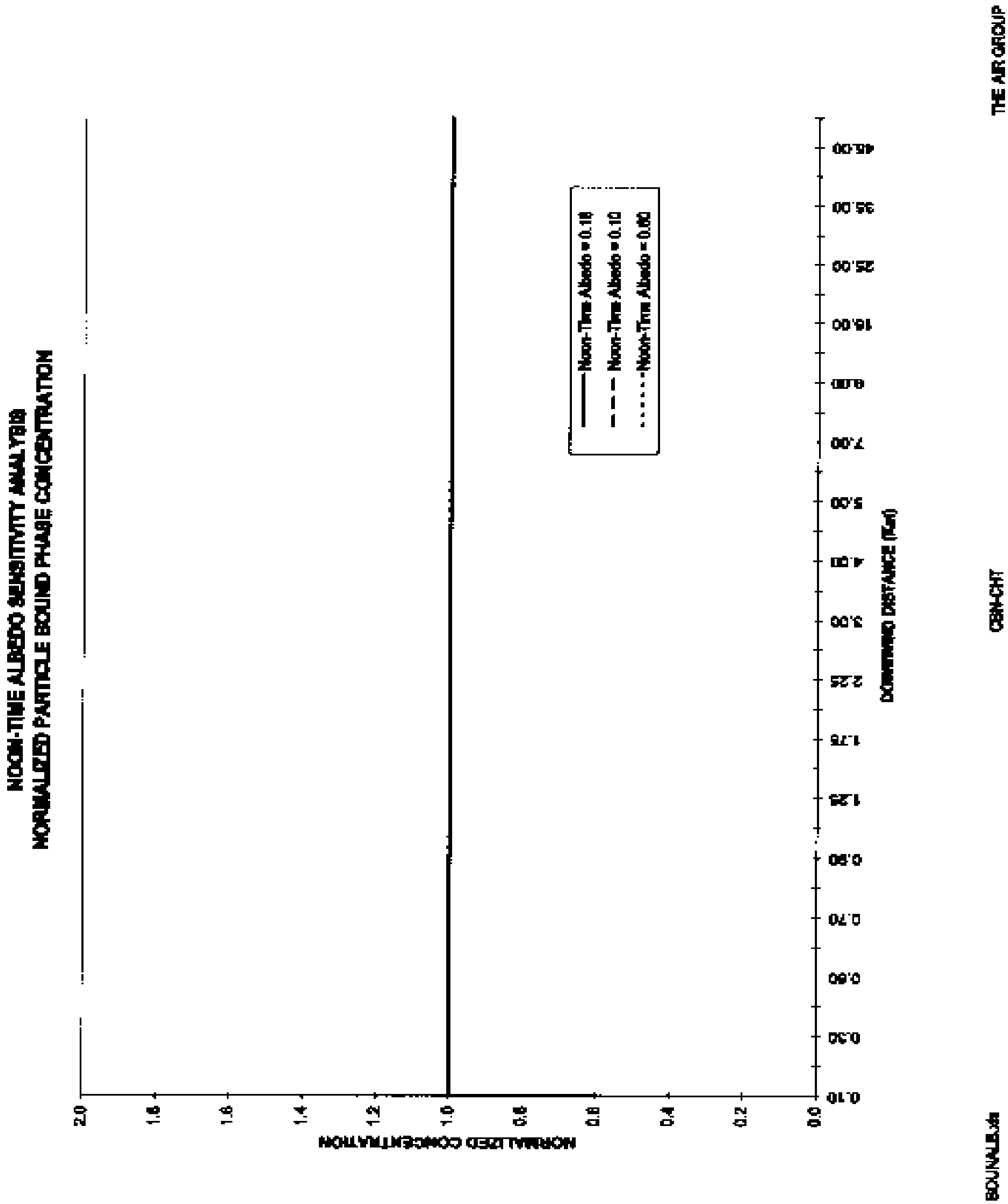
The results of the noon-time albedo sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

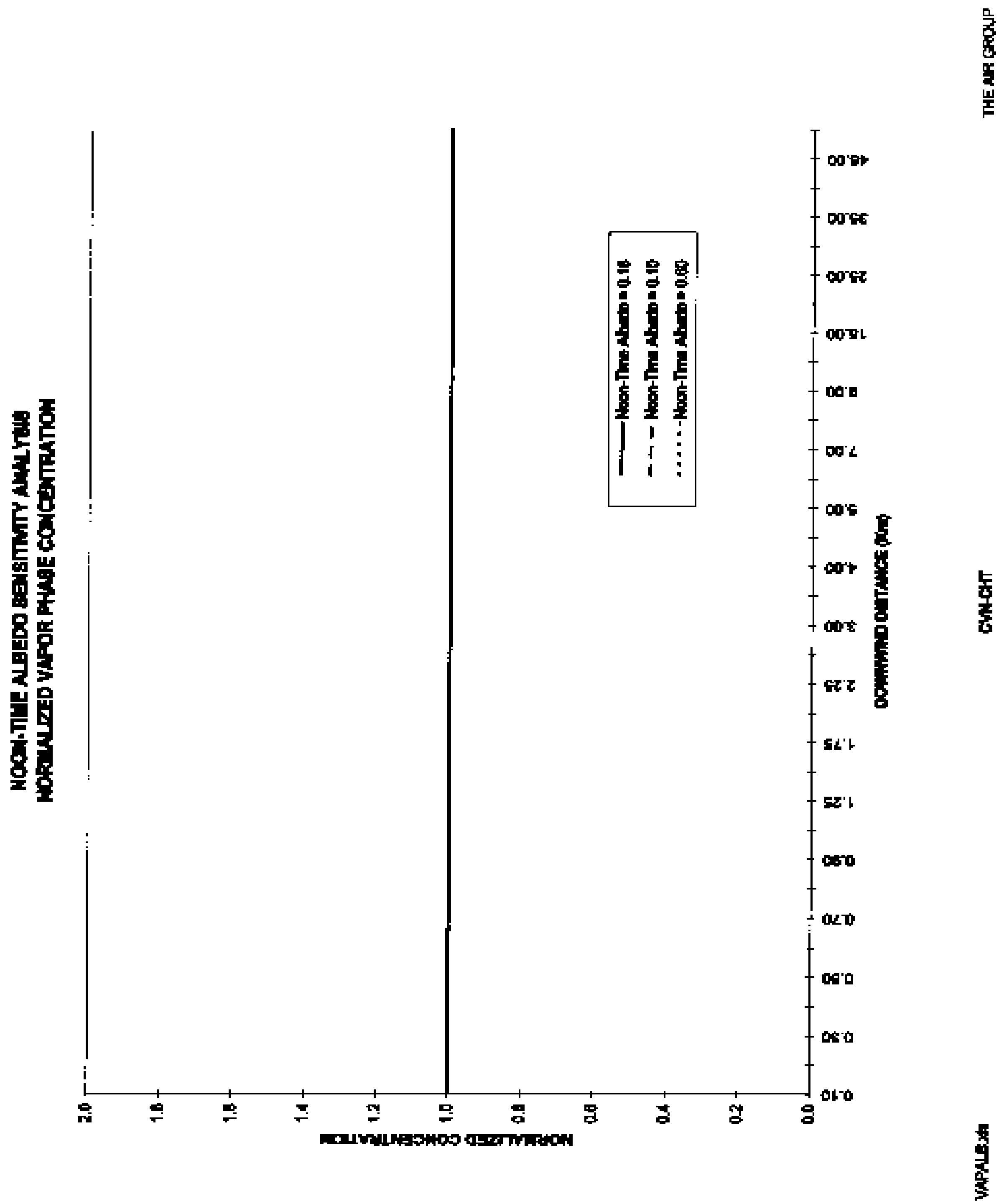
Wet deposition rates are unaffected by variations in noon-time albedo.

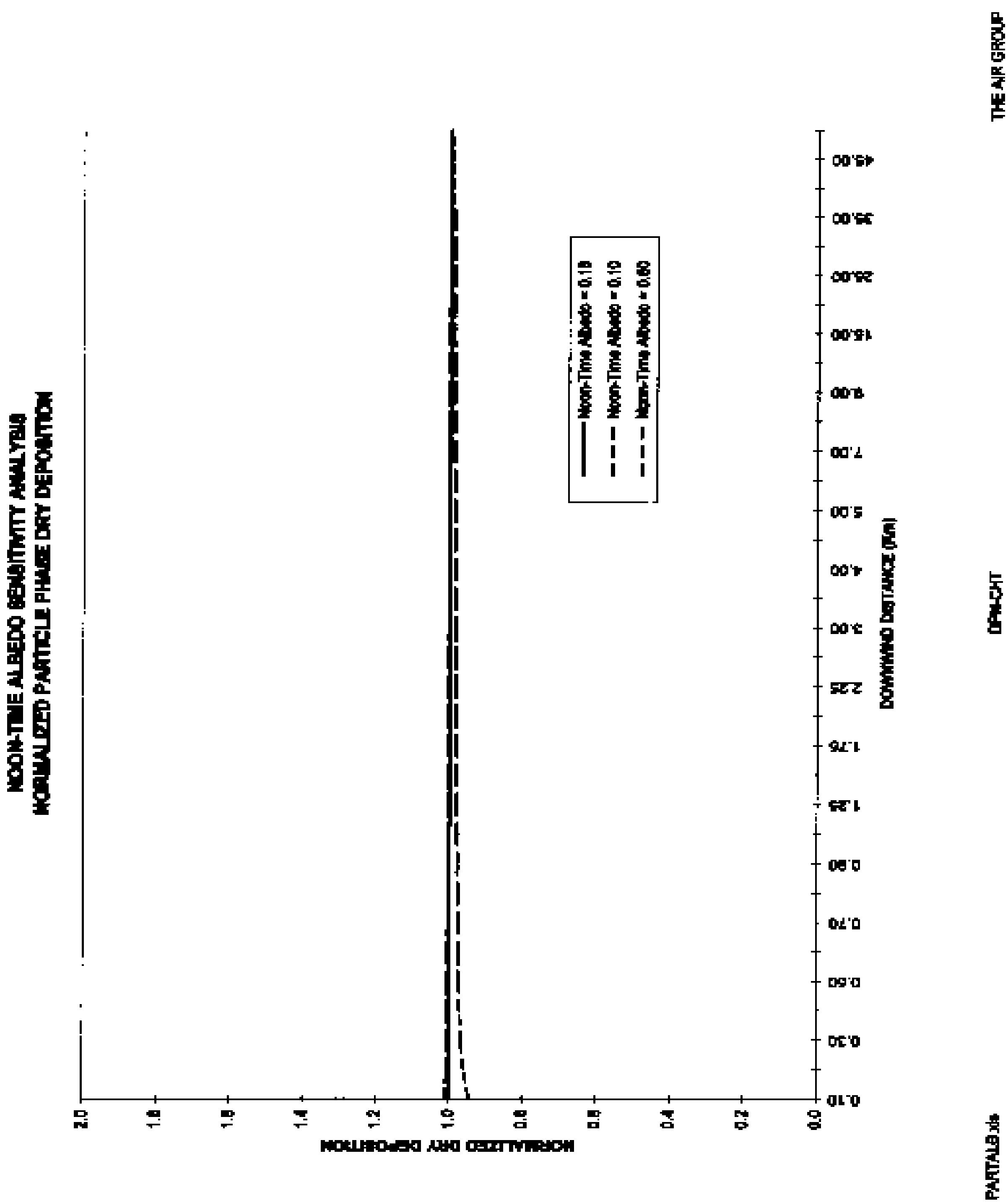
6.3.5 RECOMMENDATIONS

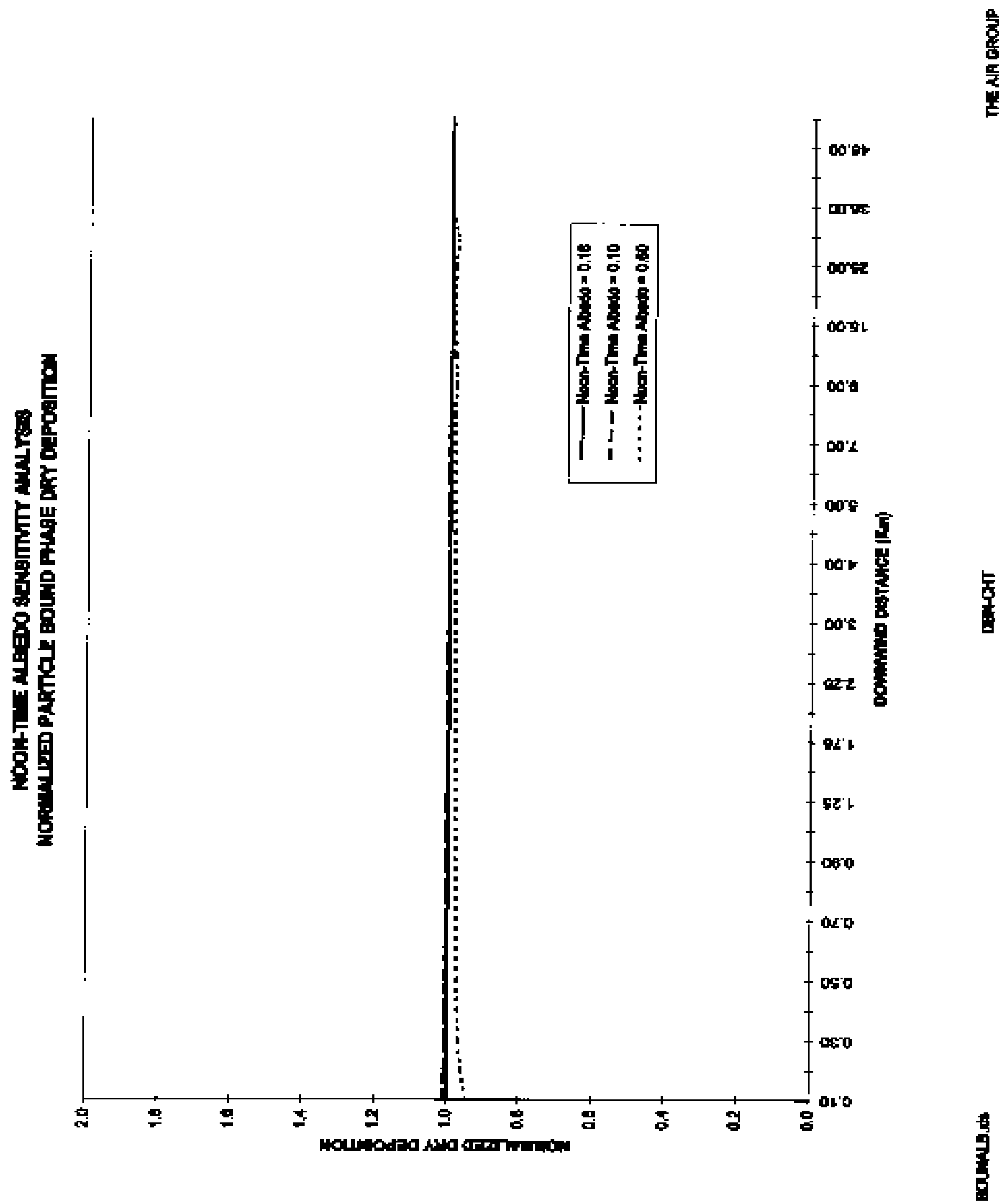
Refinement or enhancement of the noon-time albedo values in Table 3-2 of the Draft Protocol can be given low priority, as this parameter has little effect on modeled impacts.

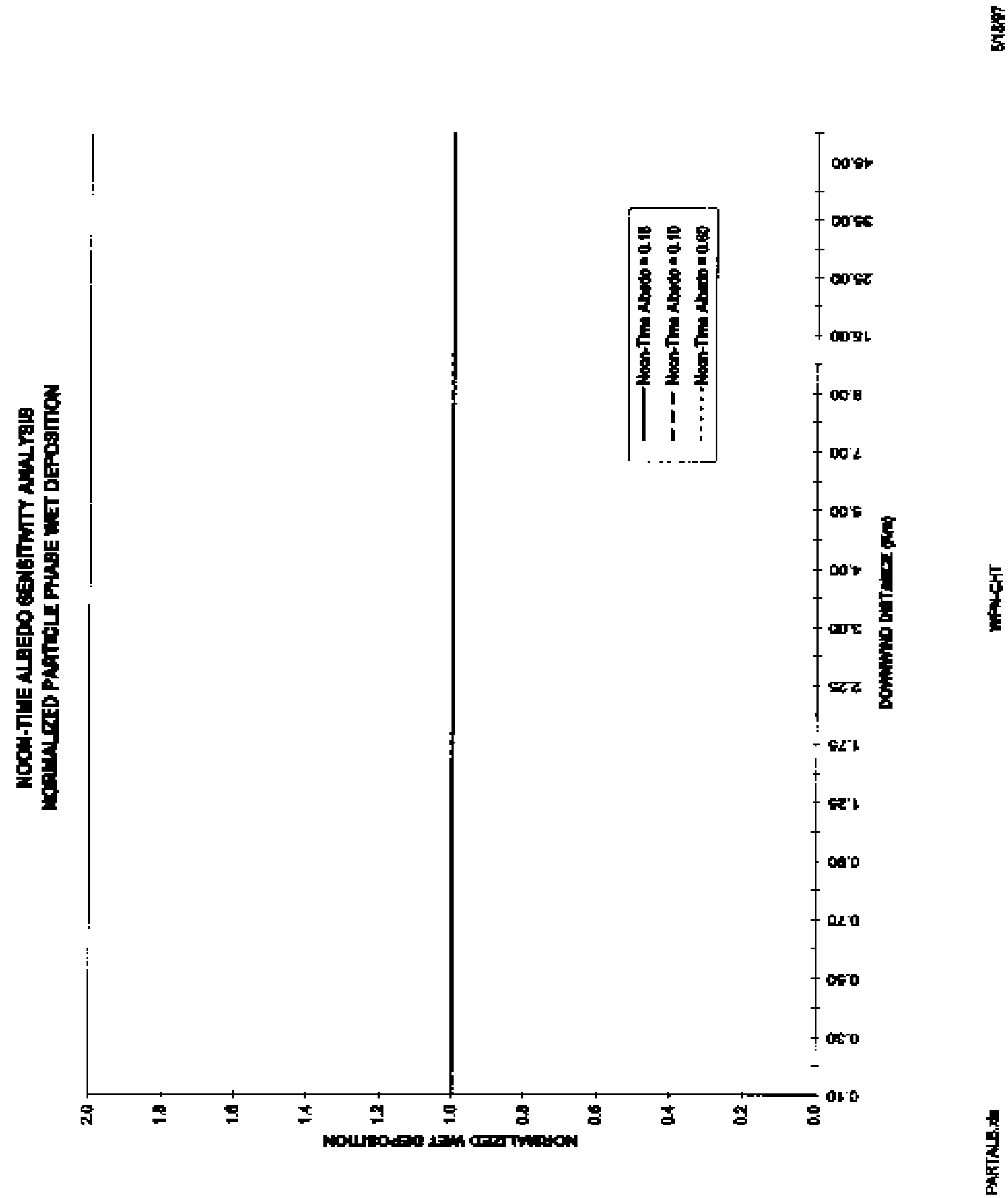

NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATION
Noon-Time Albedo
Noon-Time Albedo
Noon-Time Albedo
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
CPN-CHT
PARTALB

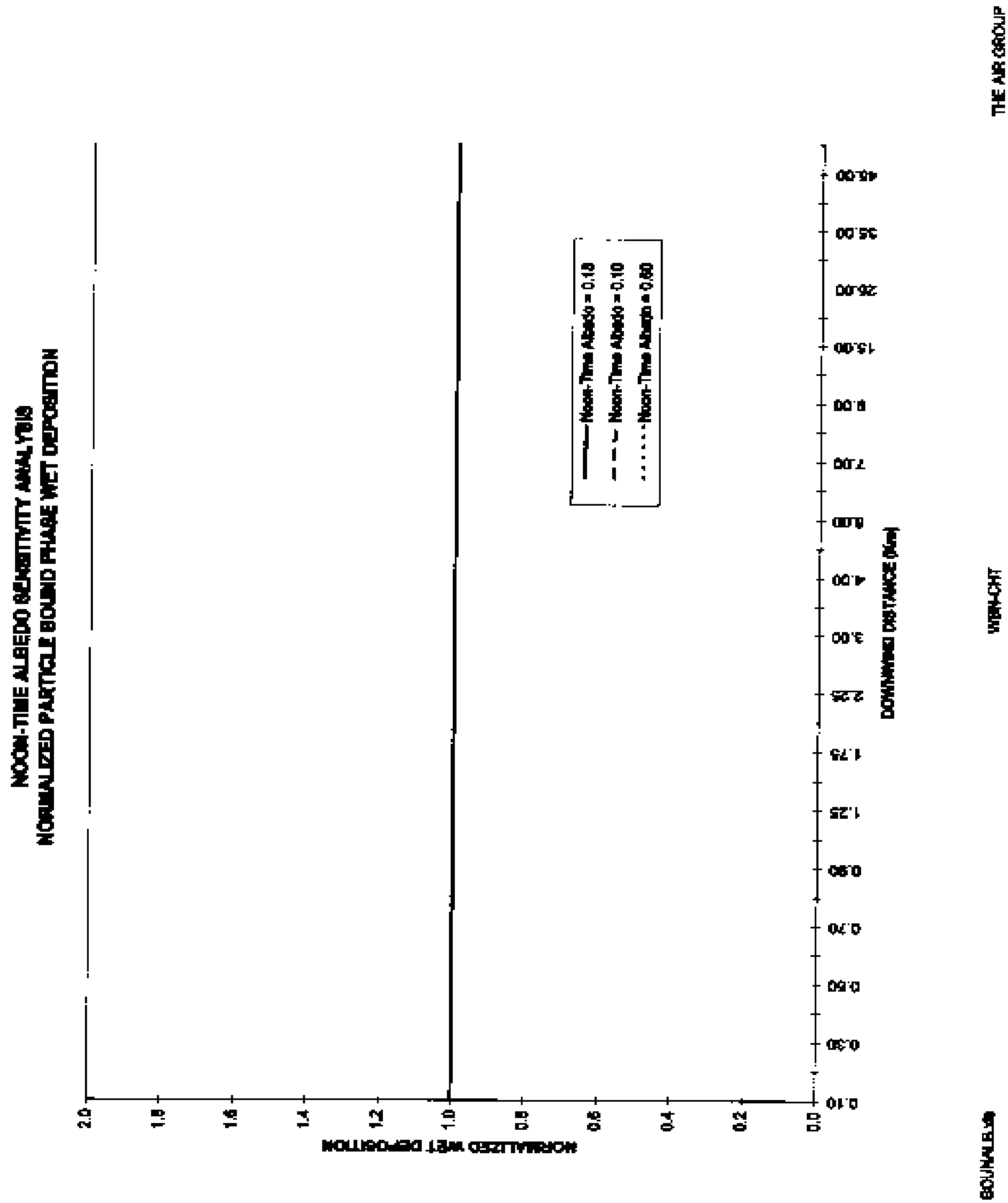

NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP

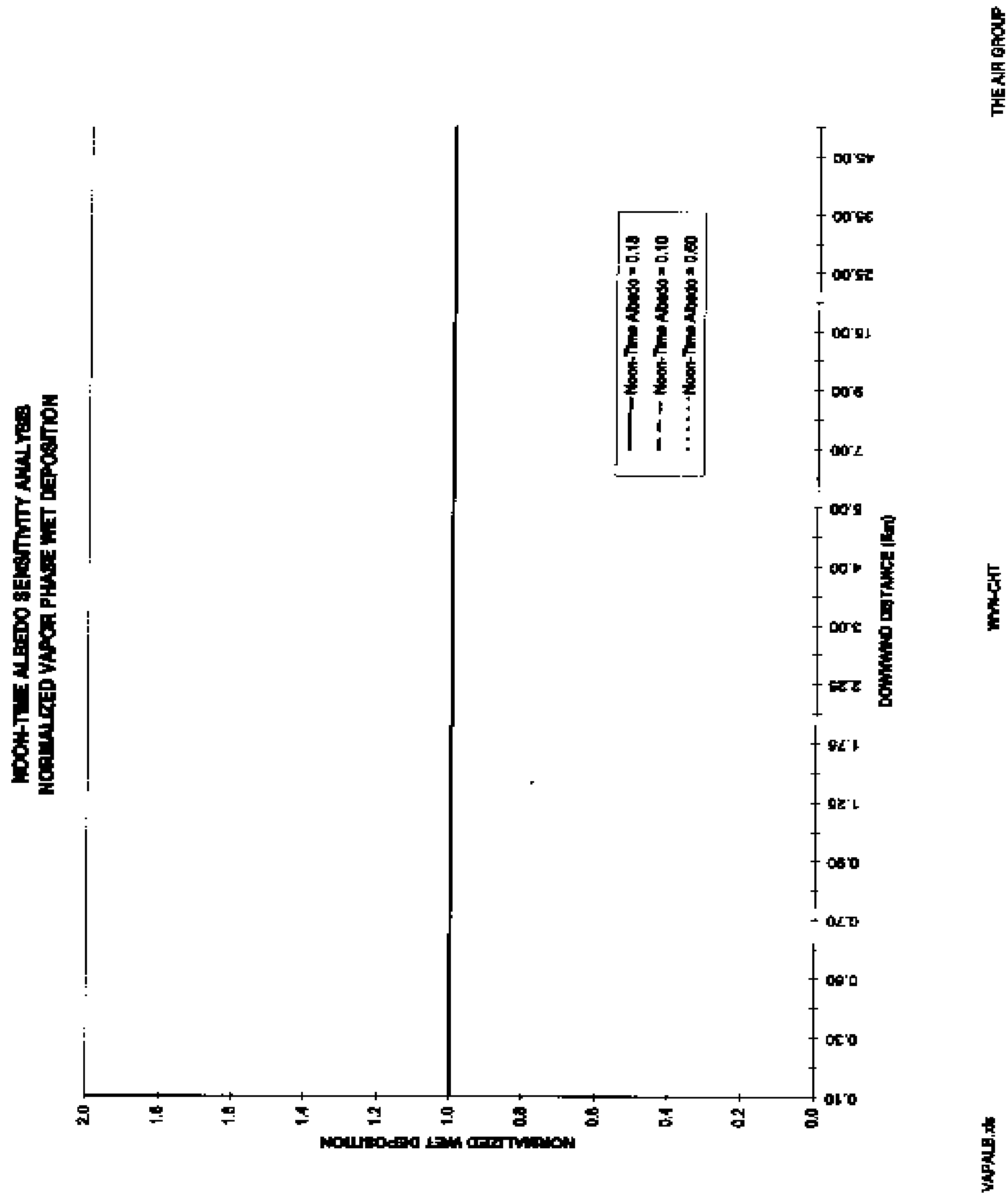

NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
Noon-Time Albedo = 0.16
Noon-Time Albedo = 0.10
Noon-Time Albedo = 0.60
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (km)
THE AIR GROUP
VAPALB.xls


NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
DPN-CHT
PARTALB.xls


NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Noon-Time Albedo = 0.16
Noon-Time Albedo = 0.10
Noon-Time Albedo = 0.60
NORMALIZED DRY DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
Noon-Time Albedo = 0.18
Noon-Time Albedo = 0.10
PARTALB.xls


NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Noon-Time Albedo = 0.18
Noon-Time Albedo = 0.10
Noon-Time Albedo = 0.60
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


NOON-TIME ALBEDO SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Noon-Time Albedo = 0.18
Noon-Time Albedo = 0.10
Noon-Time Albedo = 0.50
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WYN-CHT
VAPALB.xls

6.4 BOWEN RATIO

6.4.1 TECHNICAL OBJECTIVE

The technical objective of the Bowen ratio sensitivity analysis is to determine the sensitivity of modeled results to variations of Bowen ratio within the range specified in Table 3-3 of the Draft Protocol.

6.4.2 THEORETICAL BASIS

The availability of surface moisture to evaporate as latent heat instead of producing sensible heat cools the surface during high solar radiation. The Bowen ratio is a measure of the amount of moisture at the surface that affects the hourly Monin-Obukhov length calculated by PCRAMMET. High Bowen ratios should cause higher Monin-Obukhov lengths and thus higher deposition rates. Conversely, low Bowen ratios should associate with lower dry deposition rates.

6.4.3 METHODOLOGY

6.4.3.1 BASE CASE - TYPICAL BOWEN RATIO

The base case model runs described in Section 4 are used as the base case for this analysis. The base case includes Protocol recommended methods and values, rural meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact, and the flat terrain option. A typical Bowen ratio of 0.7 representing grassland under average moisture conditions is used in the base case.

6.4.3.2 TEST CASE I - MAXIMUM BOWEN RATIO

Test Case 1 is identical to the base case except a maximum Bowen ratio of 4.0 representing dry moisture conditions during the summer is used to process the meteorological data.

6.4.3.3 TEST CASE 2 - MINIMUM BOWEN RATIO

Test Case I is identical to the base case, except a minimum Bowen ratio of 0.1 representing water bodies is used to process the meteorological data.

6.4.4 RESULTS

6.4.4.1 CONCENTRATION

The results of the Bowen ratio sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized concentration versus downwind distance are presented in Appendix A for all cases.

Concentrations are virtually unaffected by variations in Bowen ratio.

6.4.4.2 DRY DEPOSITION

The results of the Bowen ratio sensitivity analysis in terms of normalized dry deposition (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

Dry deposition rates are only slightly affected by Bowen ratio. Dry deposition rates vary by a maximum of 8.5% from the test cases to the base case at close proximity to the source. This variation gradually decreases to zero at remote distances from the source.

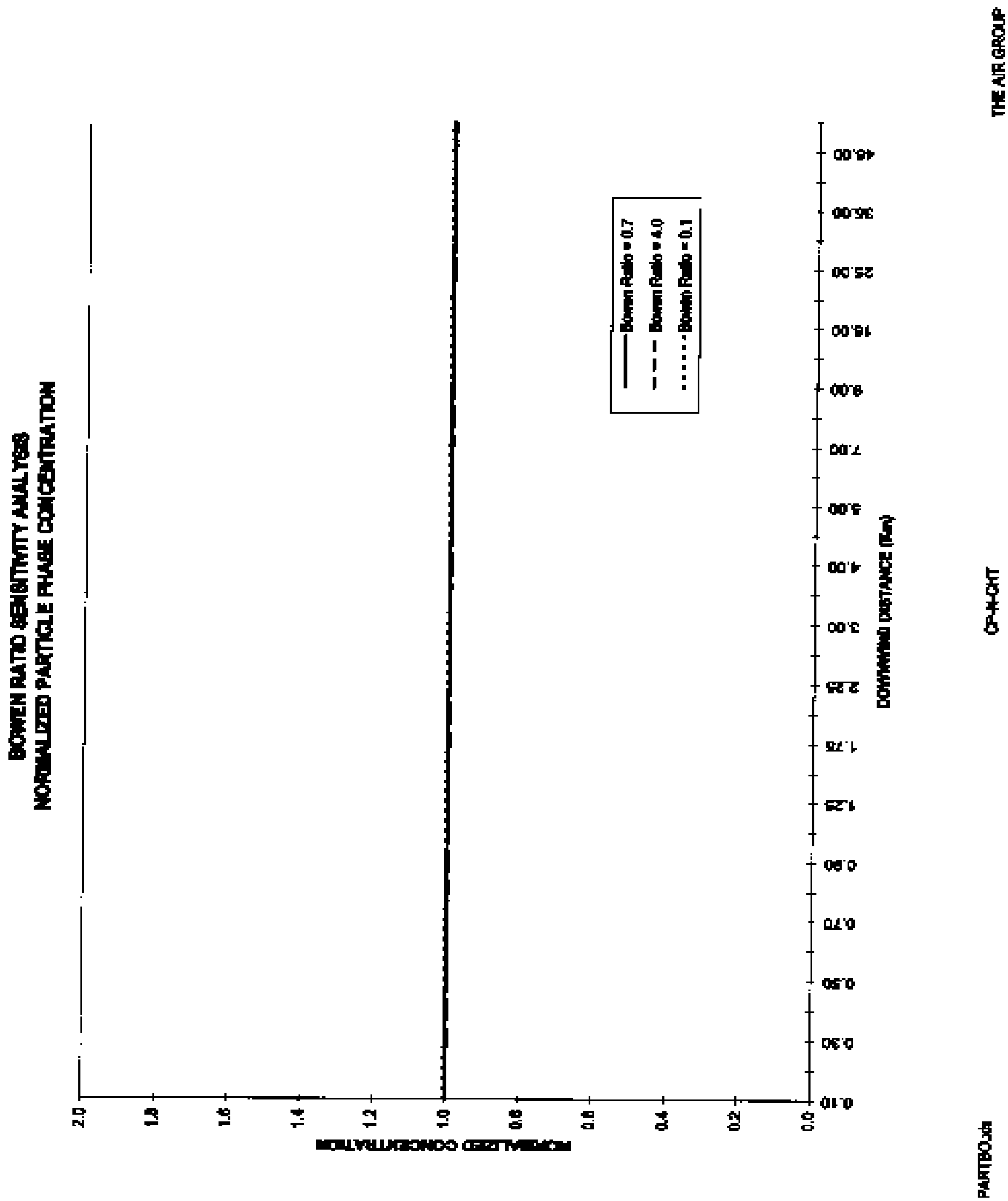
6.4.4.3 WET DEPOSITION

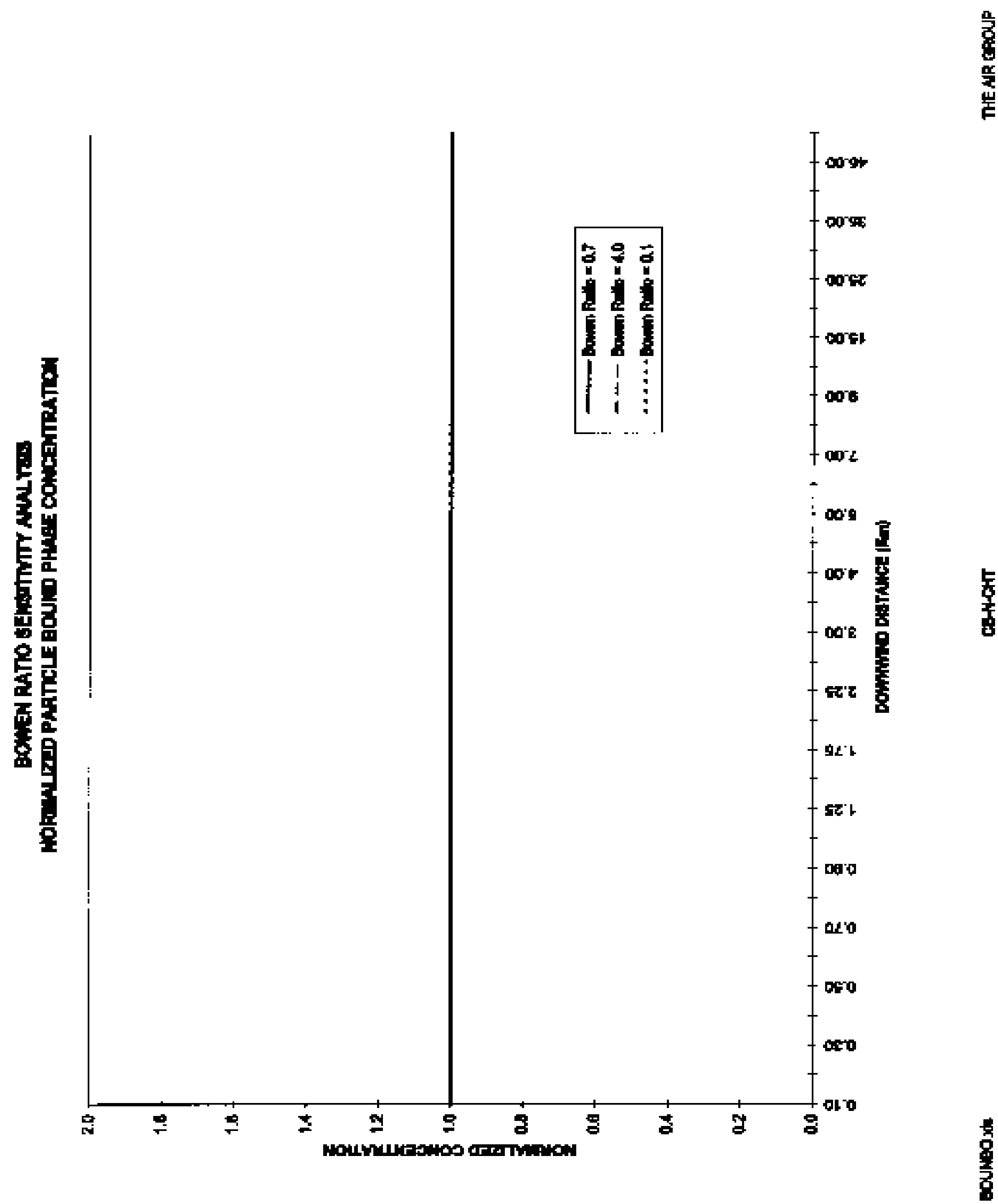
The results of the Bowen ratio sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

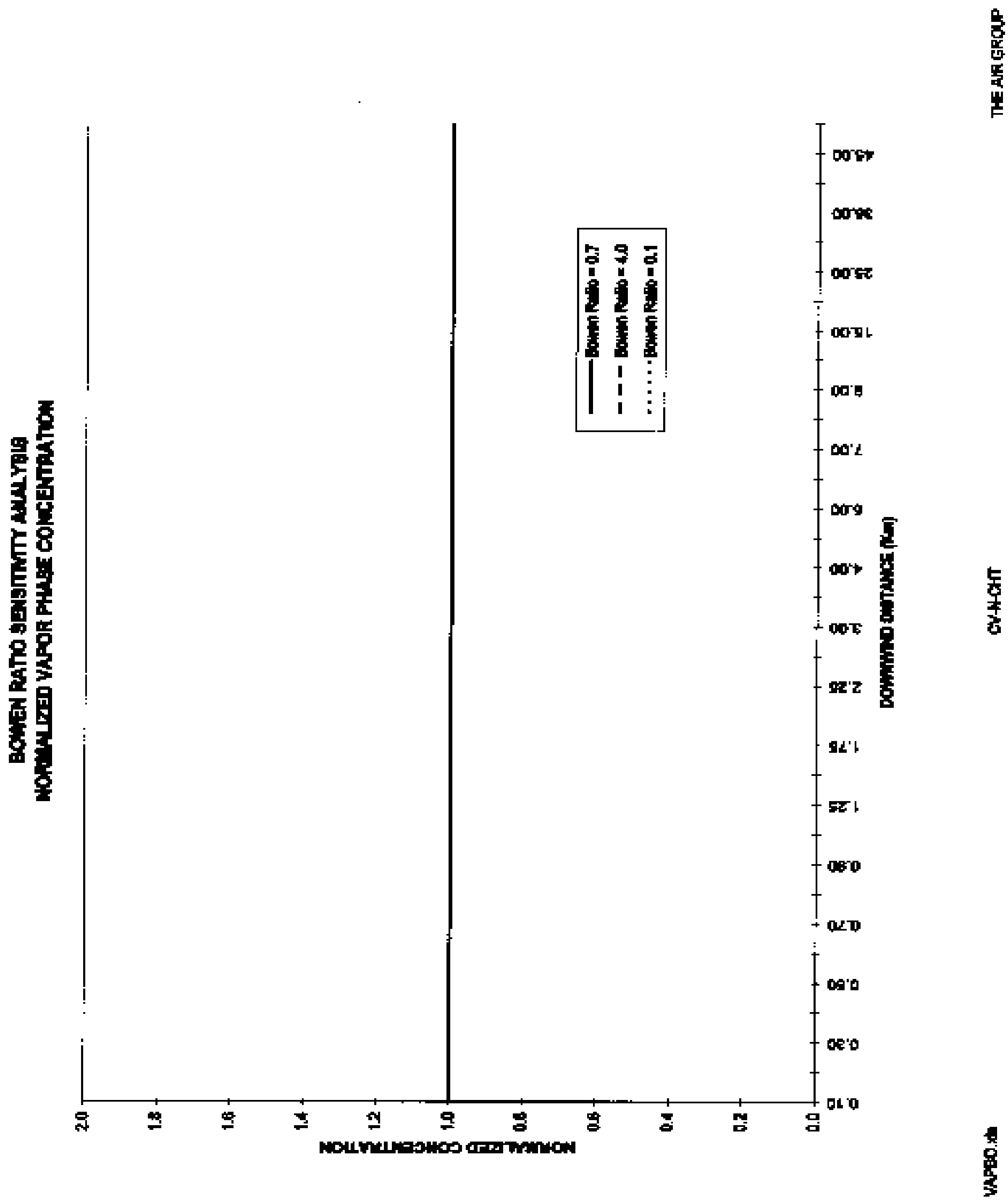
Wet deposition rates are unaffected by variations in Bowen ratio.

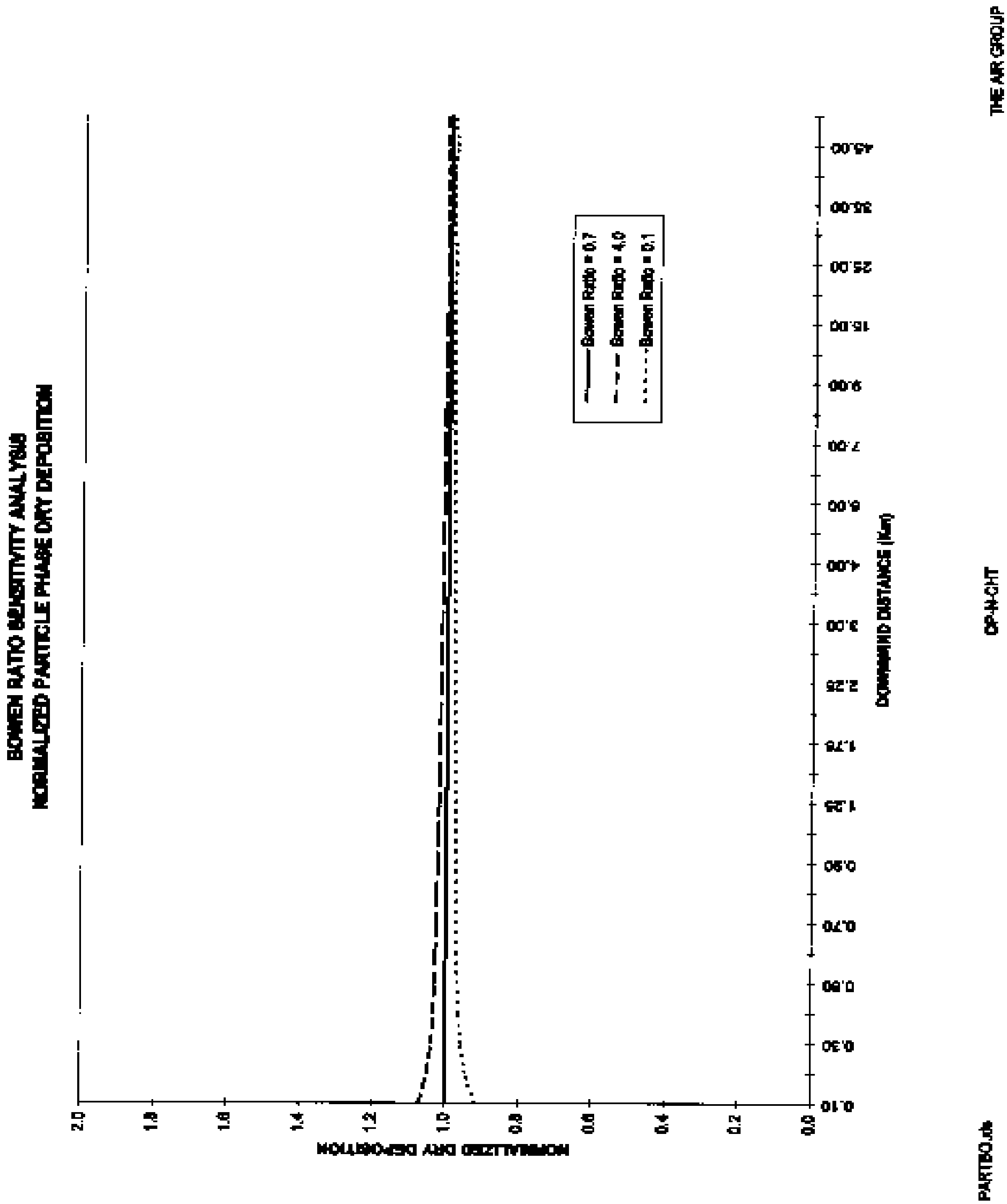
6.4.5 RECOMMENDATIONS

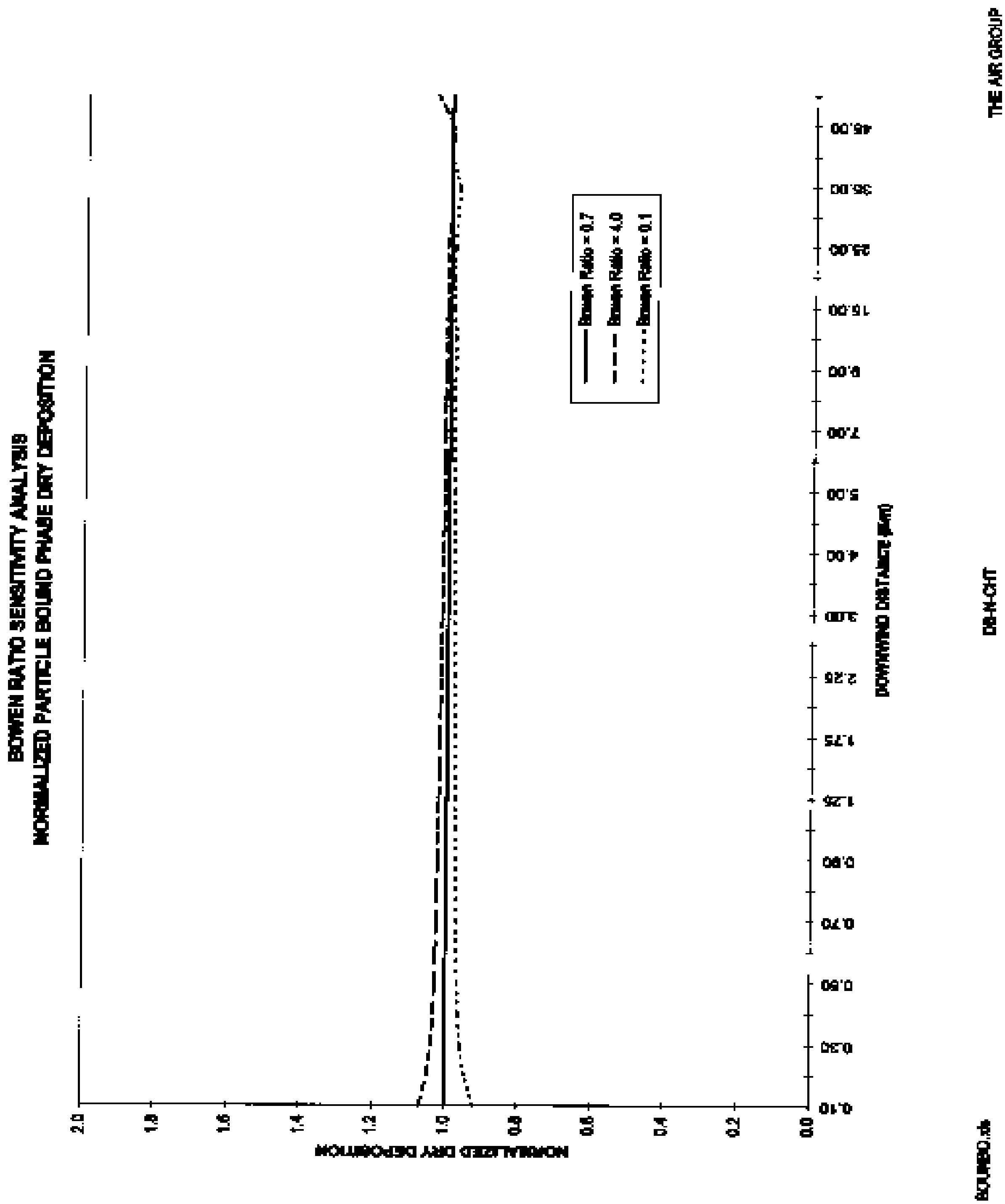
Refinement or enhancement of the Bowen ratios in Table 3-3 of the Draft Protocol can be given low priority as this parameter has little effect on modeled impacts.

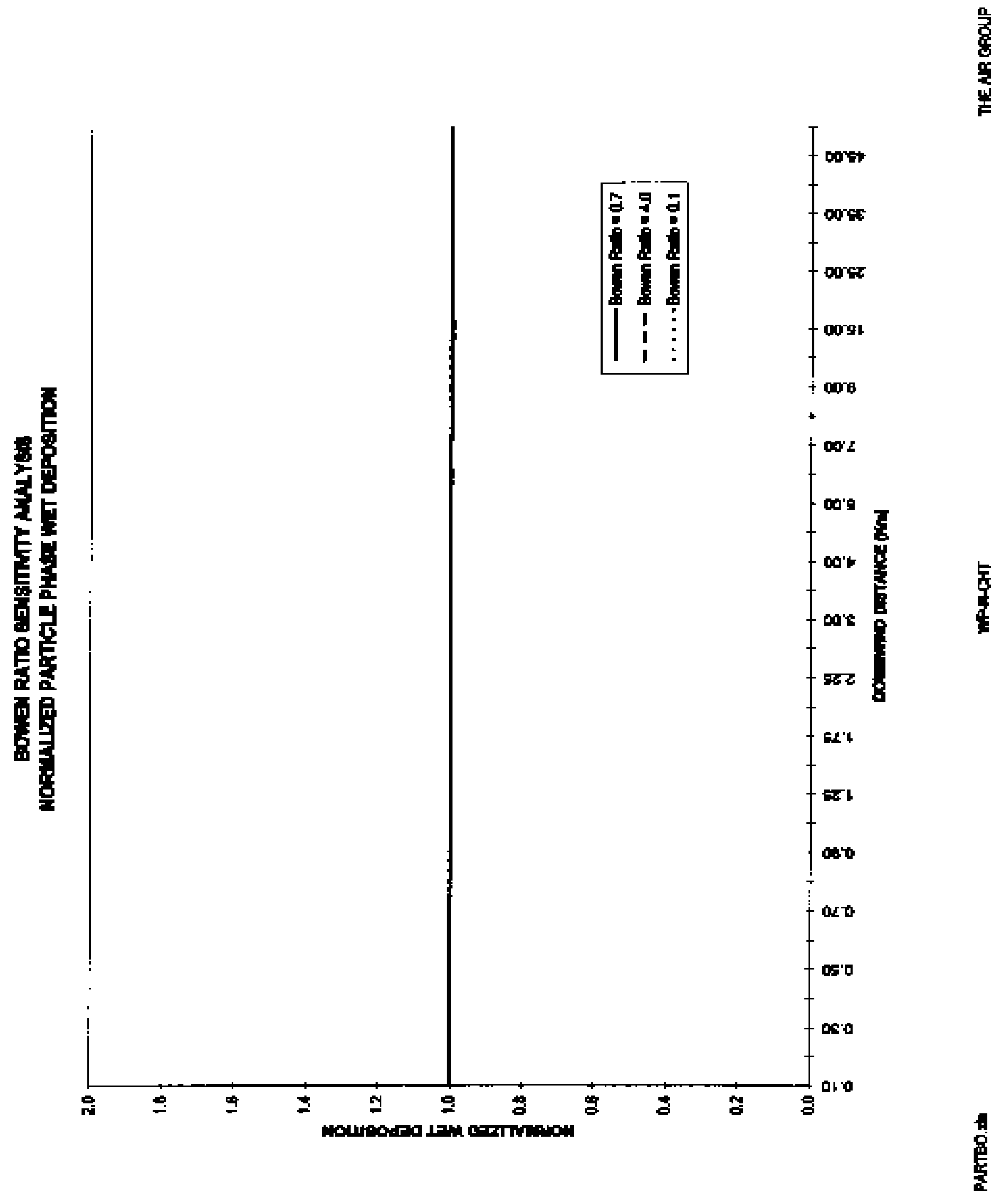

BOWEN RATIO SENSITIVITY ANALYSES
NORMALIZED PARTICLE PHASE CONCENTRATION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP

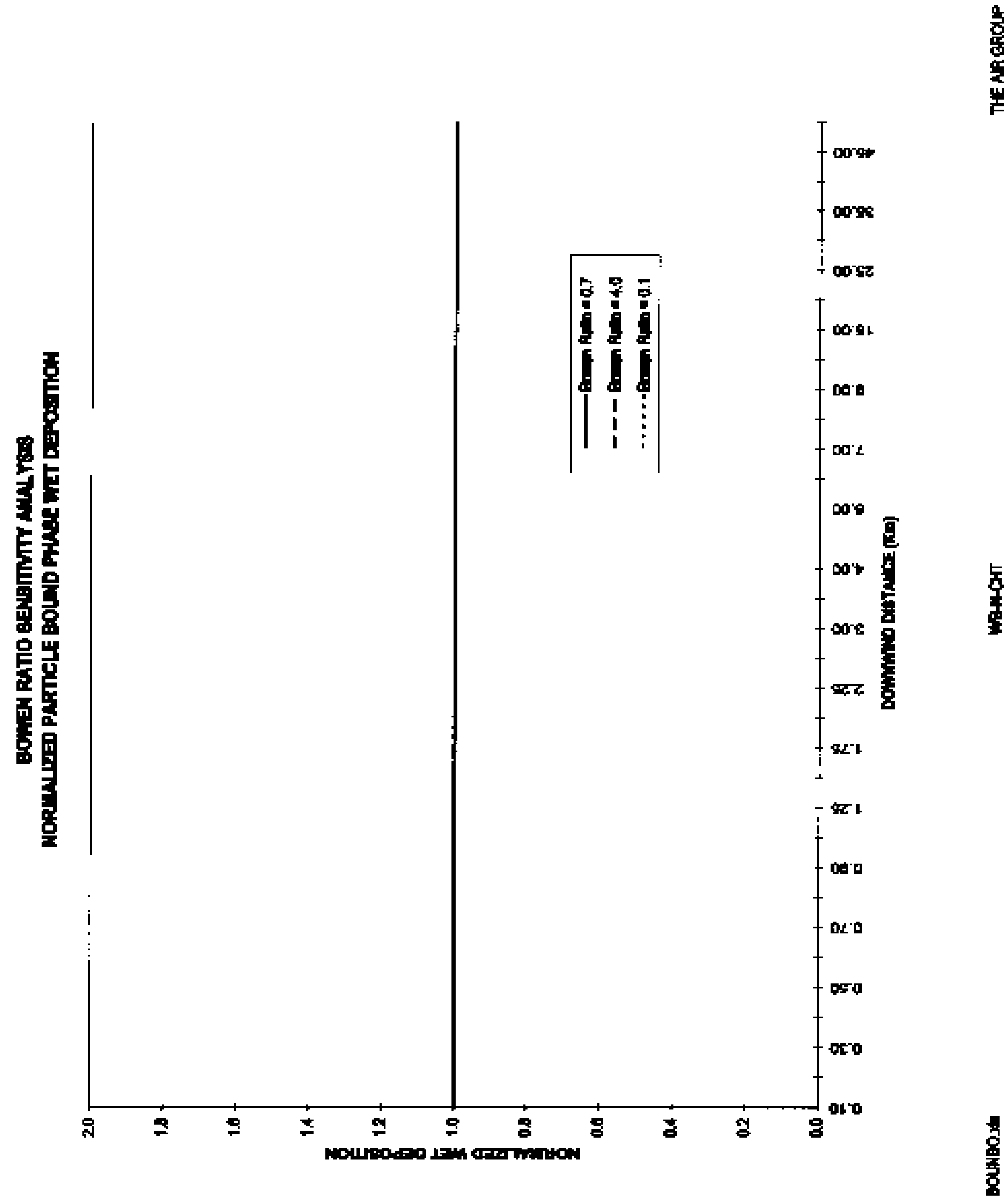

BOWEN RATIO SENSITIVITY ANALYSES
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP

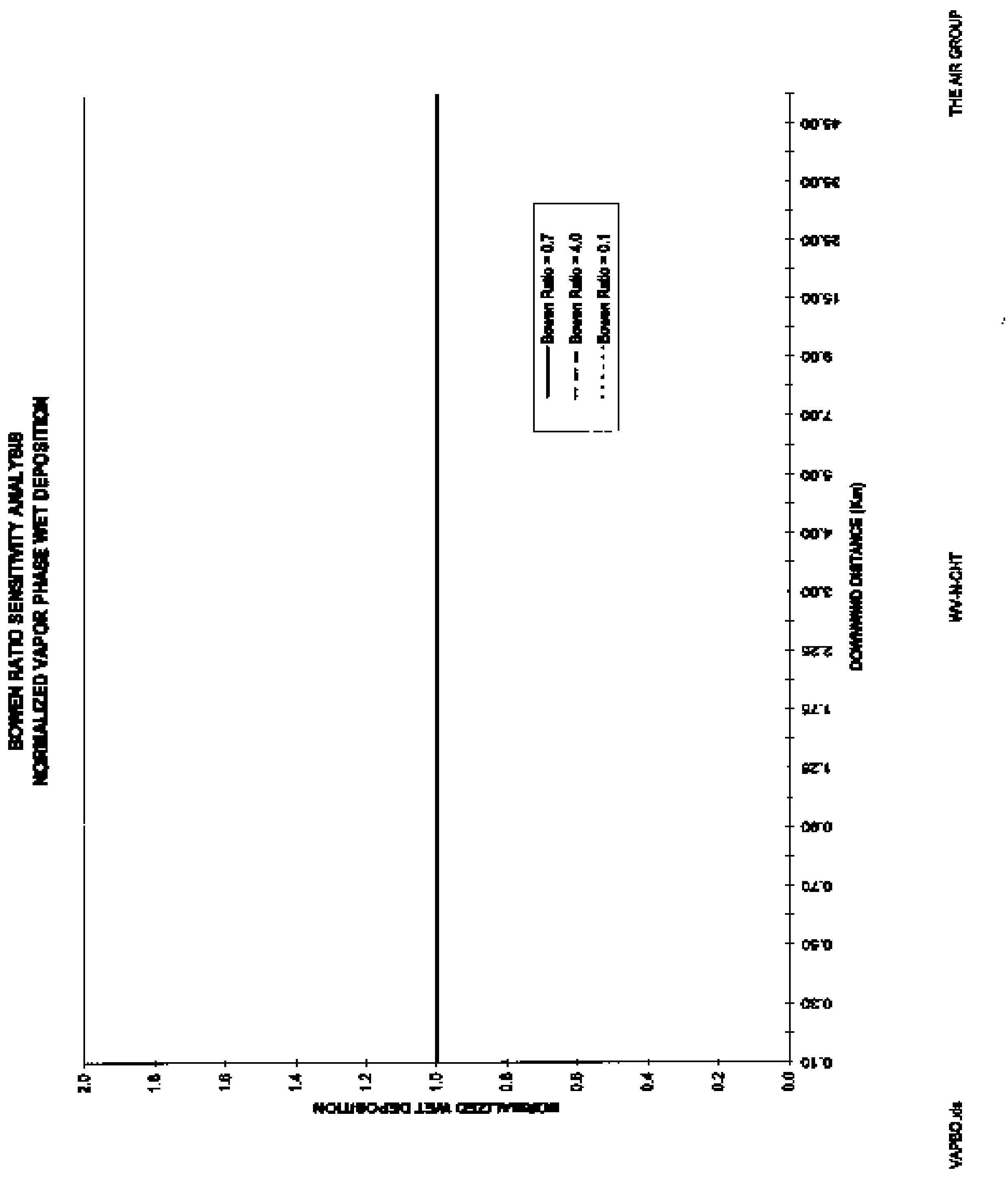

BOWEN RATIO SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED CONCENTRATION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
8.00
15.00
25.00
35.00
45.00
THE AIR GROUP
CV-N-CHT
VAPBO.xls


BOWEN RATIO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE DRY DEPOSITION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
THE AIR GROUP


BOWEN RATIO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (km)
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
DB-N-CHT


BOWEN RATIO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP


BOWEN RATIO SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


BOWEN RATIO SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Bowen Ratio = 0.7
Bowen Ratio = 4.0
Bowen Ratio = 0.1
NORMALIZED WET DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
THE AIR GROUP
VAPBO.xls

6.5 ANTHROPOGENIC HEAT FLUX

6.5.1 TECHNICAL OBJECTIVE

The technical objective of the anthropogenic heat flux sensitivity analysis is to determine the sensitivity of modeled results to variations of anthropogenic heat flux within the range specified in Table 3-4 of the Draft Protocol.

6.5.2 THEORETICAL BASIS

As with the other parameters which affect surface heat balance, and thus Monin-Obukhov length, anthropogenic heat flux is the surface heating caused by human activity in urban areas. High surface heating will increase dry deposition rates due to instability in the lower layers of the air flow.

6.5.3 METHODOLOGY

Anthropogenic heat flux is always zero in rural areas. For urban areas, there are various choices for anthropogenic heat flux depending on the population and energy use of a particular city. Therefore, urban conditions are evaluated in this study.

6.5.3.1 BASE CASE - SOUTHERN U.S. CITY

The base case model runs utilize Protocol recommended methods and values, urban meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact, and the flat terrain option. An anthropogenic heat flux of 20 watts/m , representing a large city in southern United States similar to Los Angeles is used in the base case to process the meteorological data.

6.5.3.2 TEST CASE I - NORTHERN U.S. CITY

Test Case I is identical to the base case, except an anthropogenic heat flux of 198 watts/m^2, representing a large city in northern United States is used to process the meteorological data.

6.5.4 RESULTS

6.5.4.1 CONCENTRATION

The results of the anthropogenic heat flux sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized concentration versus downwind distance are presented in Appendix A for all cases. Concentrations are unaffected by variations in anthropogenic heat flux.

6.5.4.2 DRY DEPOSITION

The results of the anthropogenic heat flux sensitivity analysis in terms of normalized dry deposition (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

Dry deposition rates are unaffected by variations in anthropogenic heat flux.

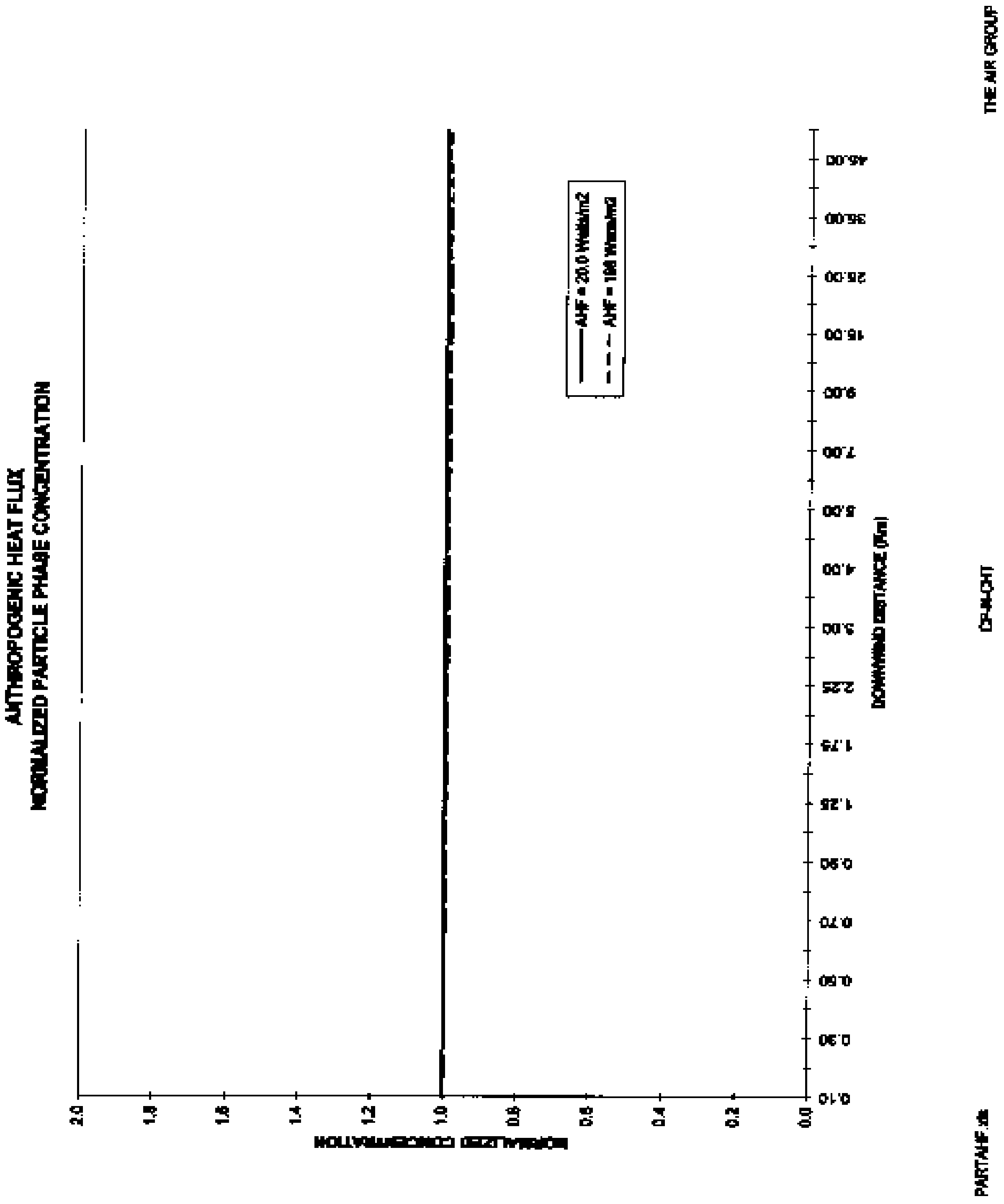
6.5.4.3 WET DEPOSITION

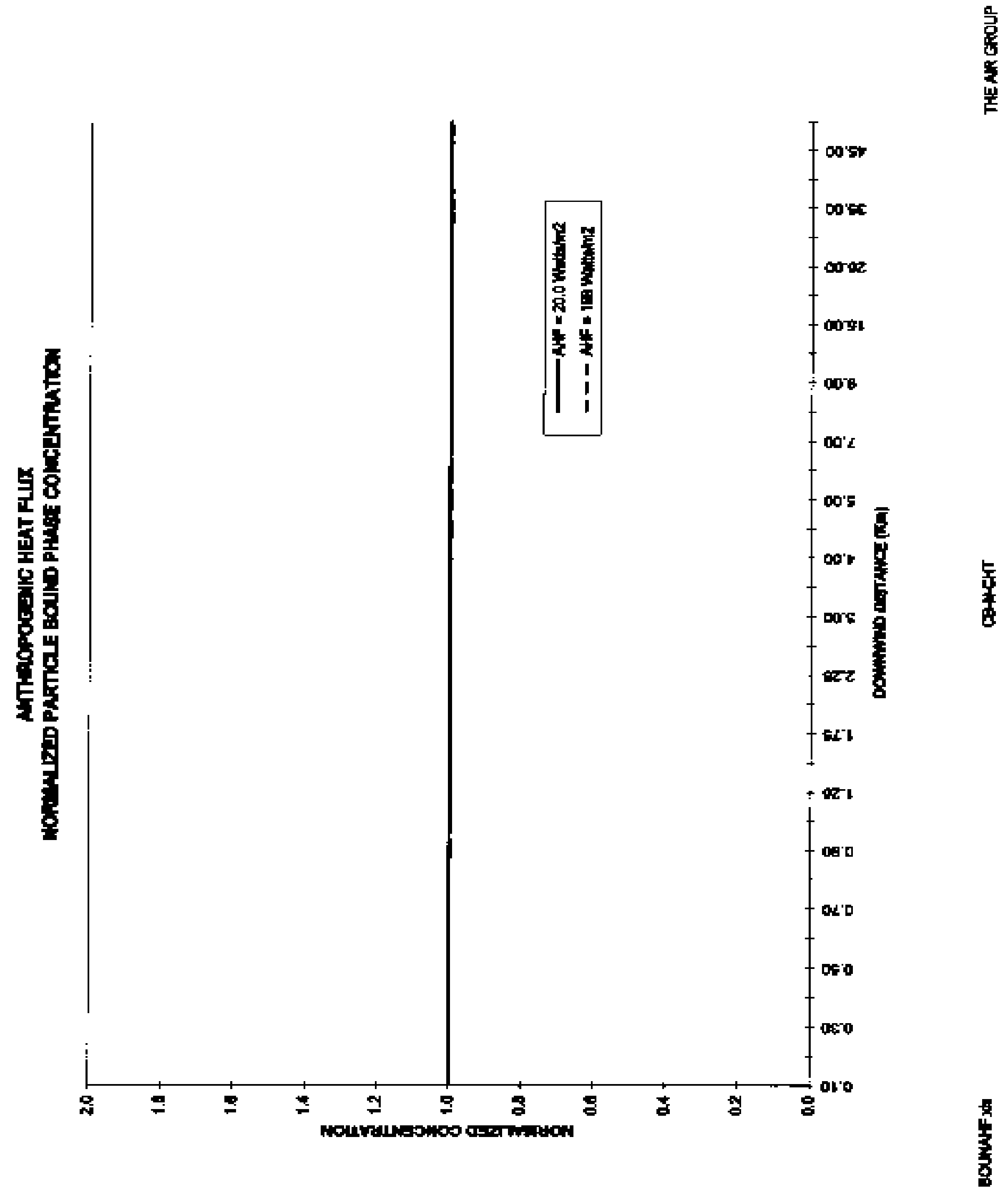
The results of the anthropogenic heat flux sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

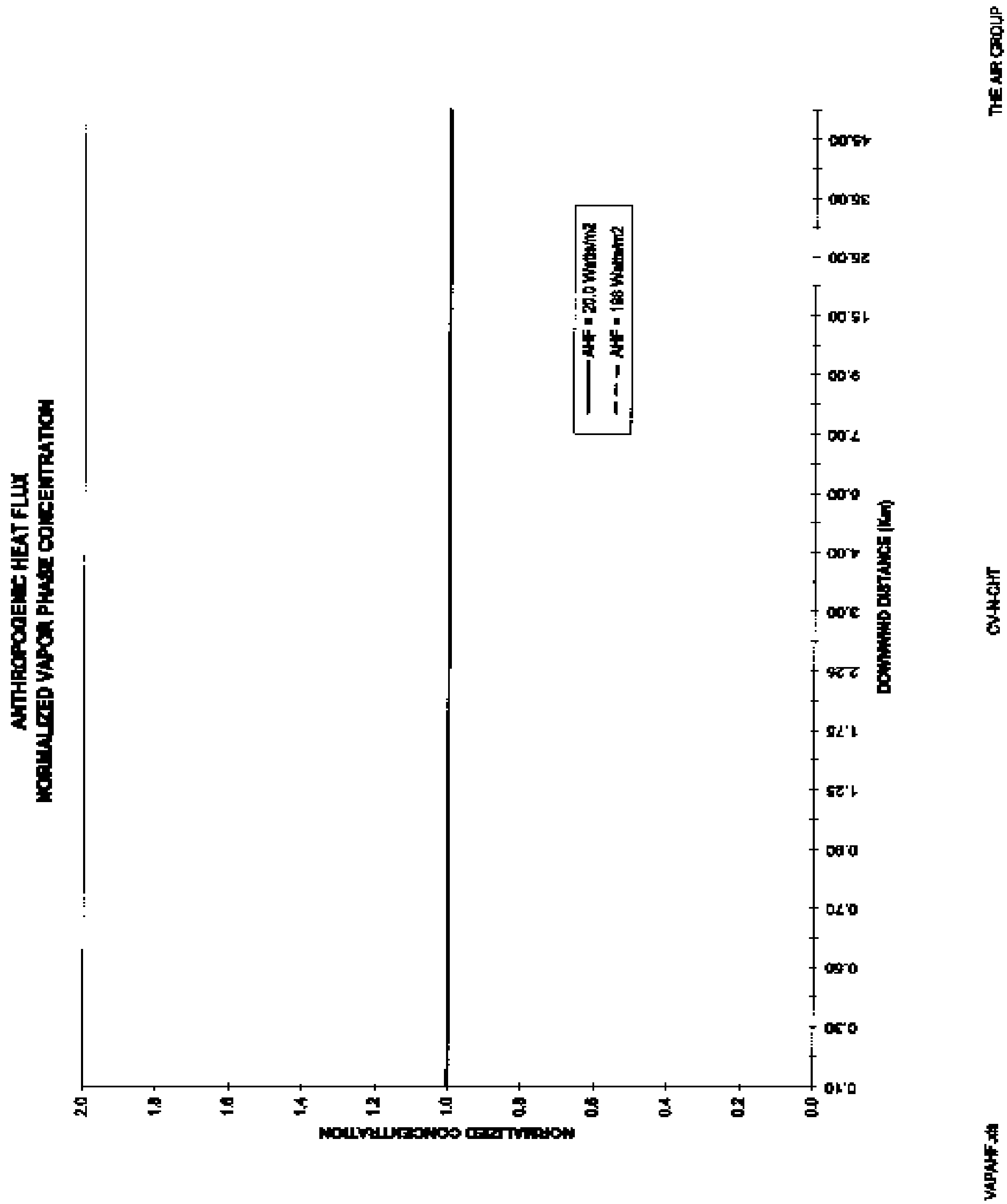
Wet deposition rates are unaffected by variations in anthropogenic heat flux.

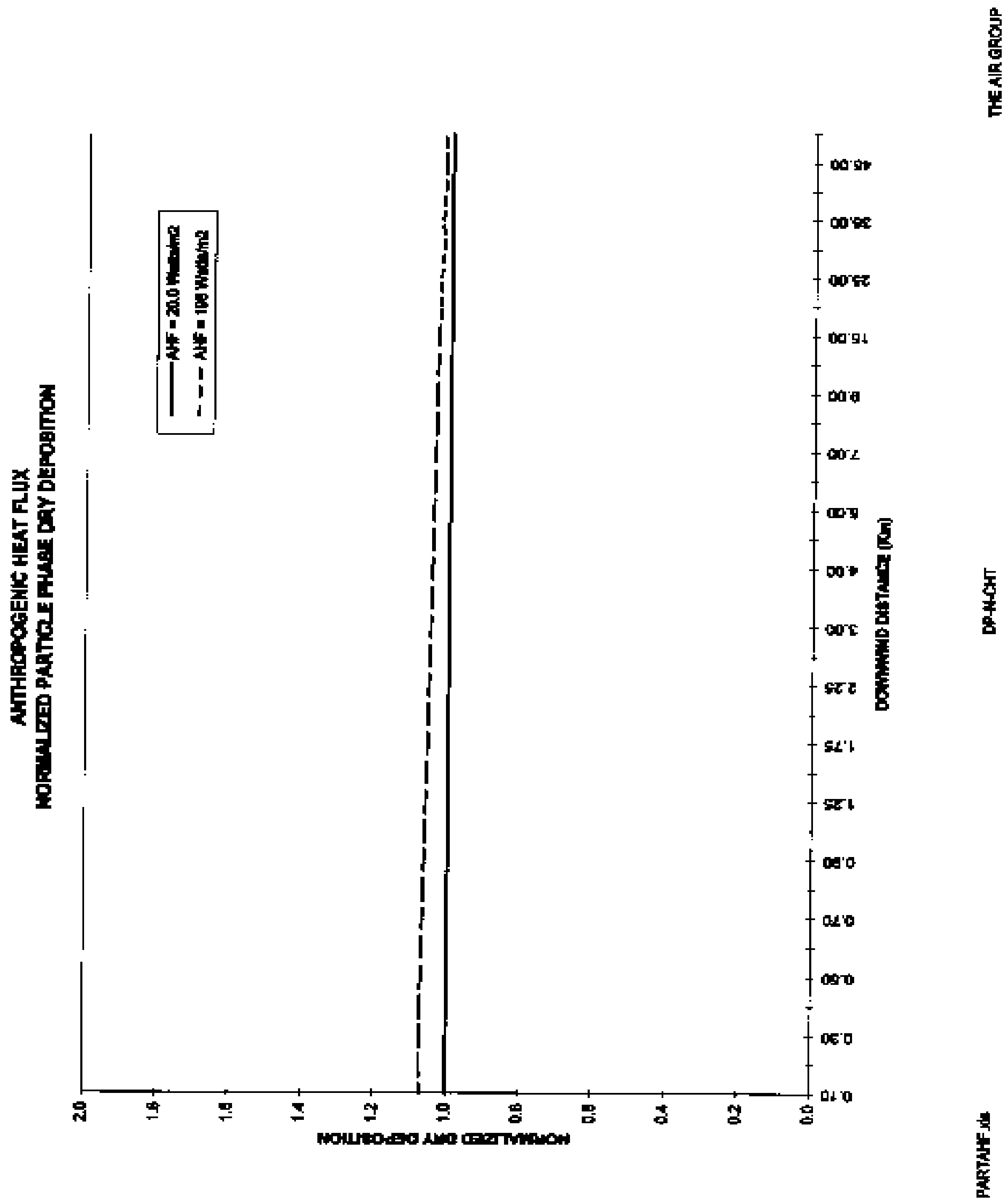
6.5.5 RECOMMENDATIONS

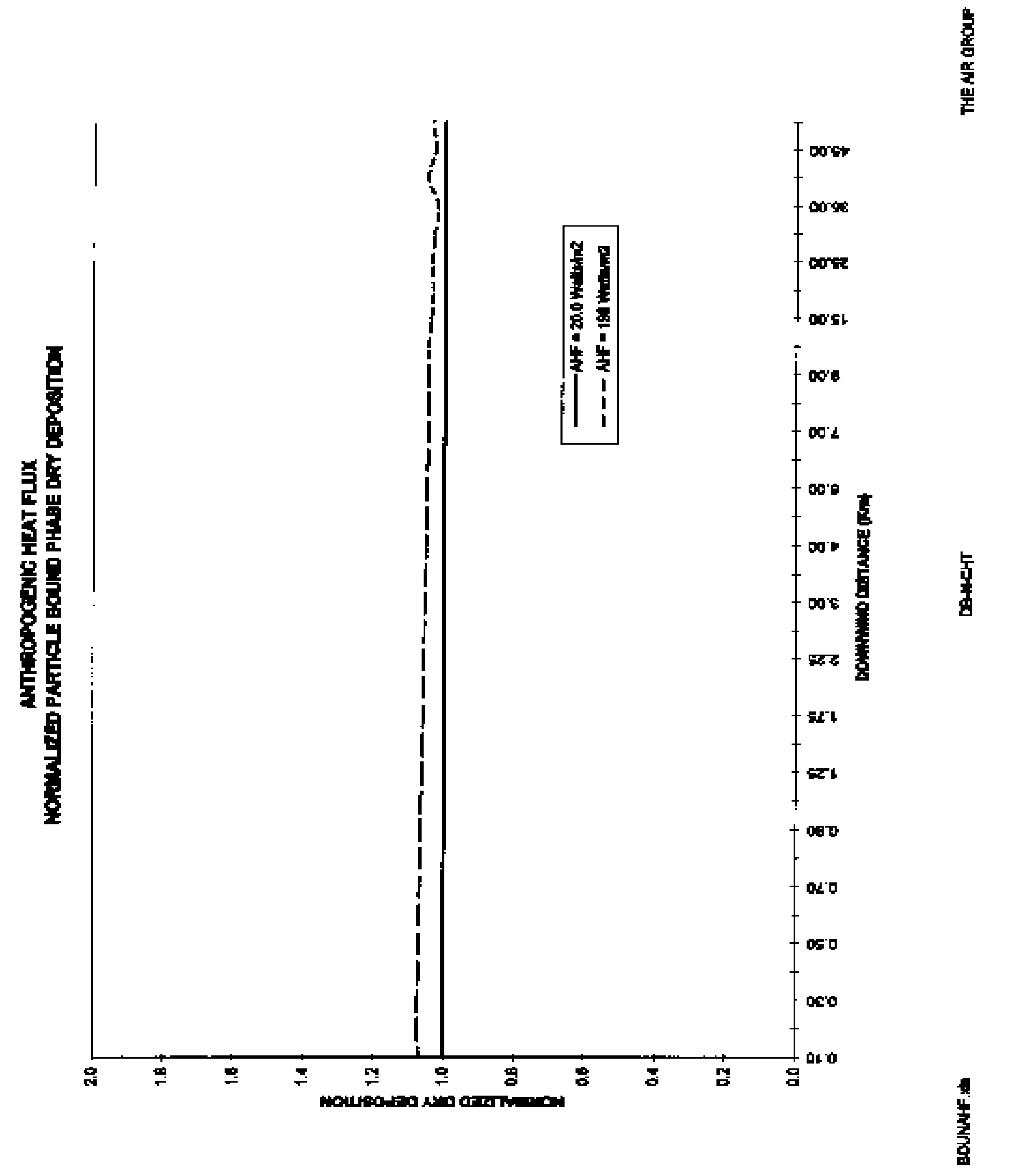
Refinement or enhancement of the values in Table 3-4 of the Draft Protocol is not necessary because anthropogenic heat flux has no effect on modeled results.


ANTHROPOGENIC HEAT FLUX
NORMALIZED PARTICLE PHASE CONCENTRATION
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP

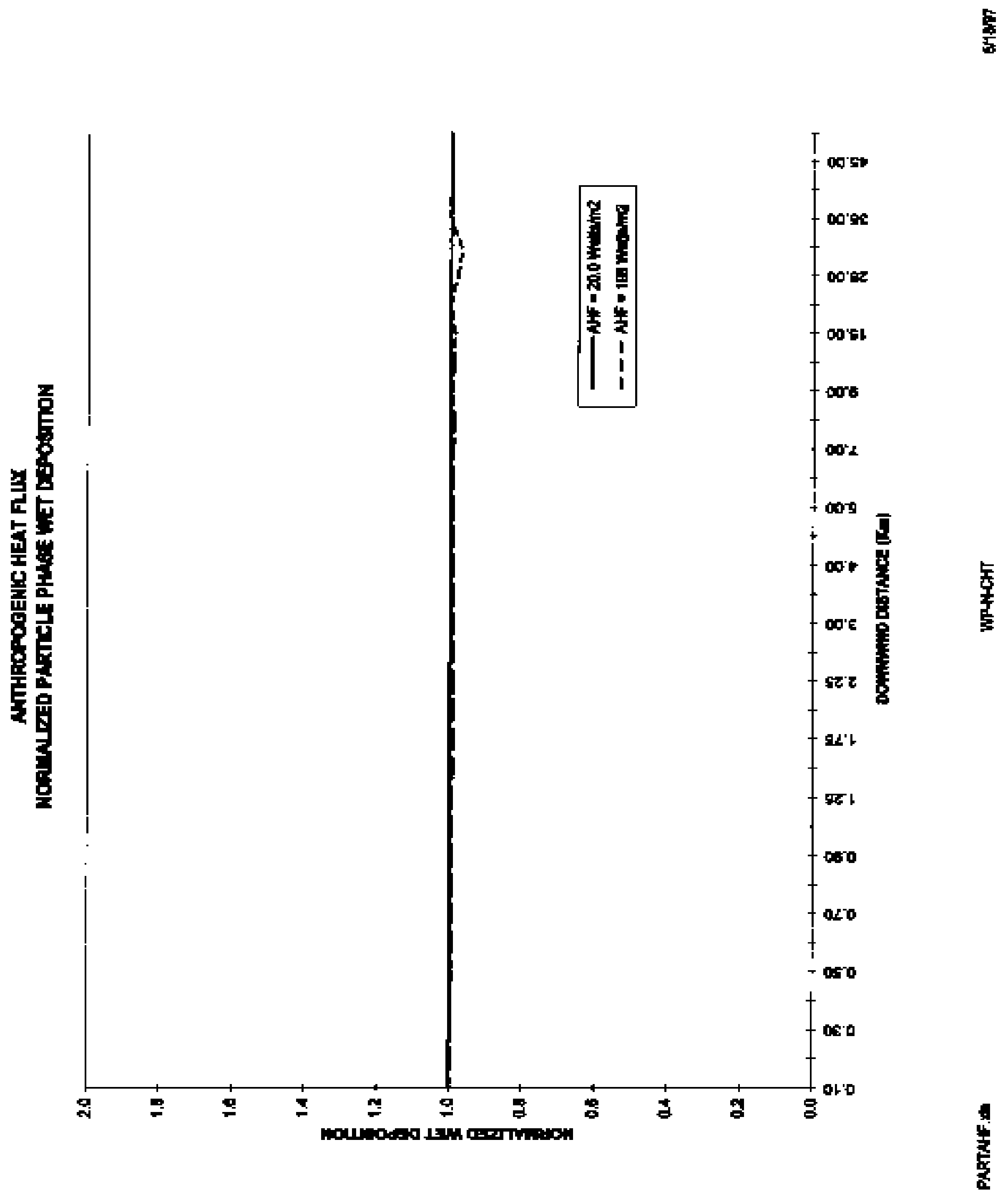

ANTHROPOGENIC HEAT FLUX
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP

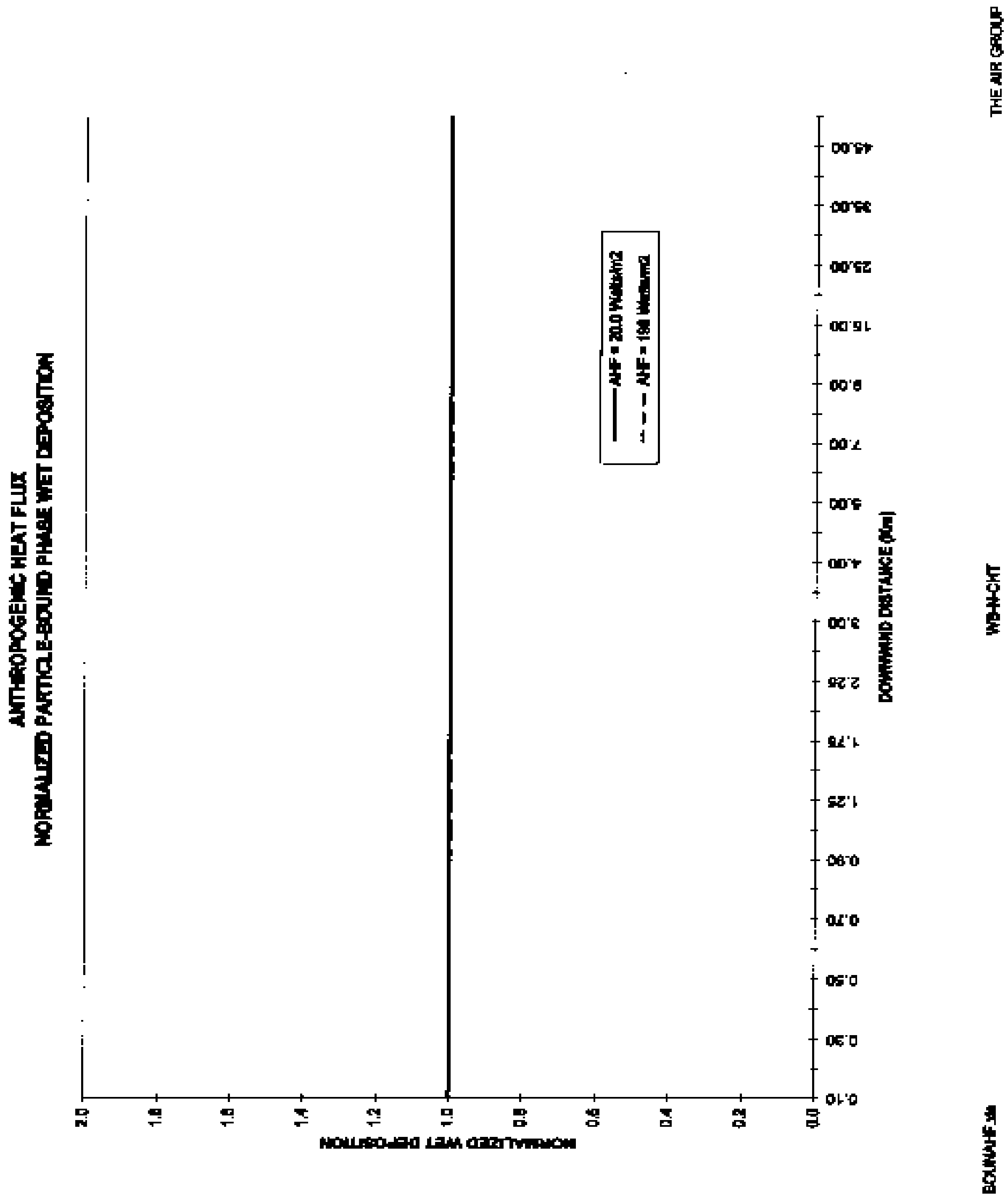

ANTHROPOGENIC HEAT FLUX
NORMALIZED VAPOR PHASE CONCENTRATION
AHF = 20.0 Watts/m2
AHF = 198 Watts/m2
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP

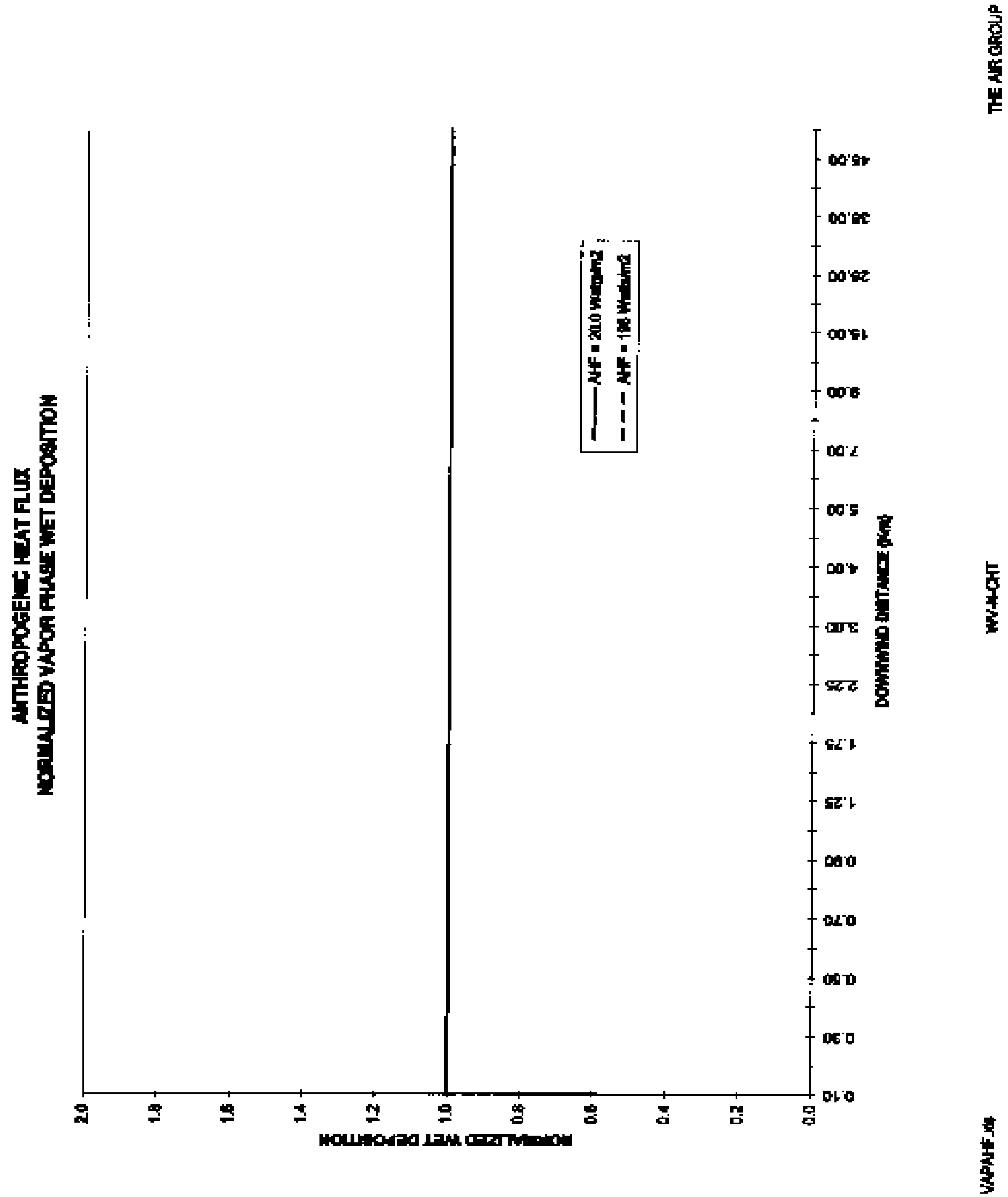

ANTHROPOGENIC HEAT FLUX
NORMALIZED PARTICLE PHASE DRY DEPOSITION
AHF = 20.0 Watts/m2
AHF = 100 Watts/m2
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
THE AIR GROUP
DP-N-CHT
PARTAHF.xls



ANTHROPOGENIC HEAT FLUX
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
6.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP
BOUNAHF.xls


ANTHROPOGENIC HEAT FLUX
NORMALIZED PARTICLE PHASE WET DEPOSITION
AHF = 20.0 Watts/m2
NORMALIZED WET DEPOSITION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
WP-N-CHT


ANTHROPOGENIC HEAT FLUX
NORMALIZED PARTICLE-BOUND PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


ANTHROPOGENIC HEAT FLUX
NORMALIZED VAPOR PHASE WET DEPOSITION
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP

6.6 FRACTION OF NET RADIATION ABSORBED AT THE GROUND

6.6.1 TECHNICAL OBJECTIVE

The technical objective of the sensitivity analysis of fraction of net radiation absorbed at the ground is to determine the sensitivity of modeled results to variations of net radiation within the range specified in Table 3-4 of the Draft Protocol.

6.6.2 THEORETICAL BASIS

The fraction of net radiation absorbed at the ground is used for calculating hourly values of Monin-Obukhov length. High absorption rates will increase surface heating, which increases instability, which increase dry deposition rates.

6.6.3 METHODOLOGY

U.S. EPA recommends only one value for net radiation fraction in rural areas. For urban areas, several choices are available. Therefore, this study evaluates only urban conditions.

6.6.3.1 BASE CASE - URBAN NET RADIATION FRACTION

The base case model runs utilize Protocol recommended methods and values, urban meteorology and dispersion coefficients, a linear receptor grid in the direction of maximum impact, and the flat terrain option. A net radiation fraction of 0.27, the Protocol recommended value for urban conditions is used in the base case to process the meteorological data.

6.6.3.2 TEST CASE I - SUBURBAN NET RADIATION FRACTION

Test Case I is identical to the base case, except a net radiation fraction of 0.22 representing suburban conditions is used to process the meteorological data.

6.6.4 RESULTS

6.6.4.1 CONCENTRATION

The results of the net radiation fraction at ground level sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute concentration and normalized concentration versus downwind distance are presented in Appendix A for all cases.

Concentrations are unaffected by variations in fraction of net radiation at ground level.

6.6.4.2 DRY DEPOSITION

The results of the net radiation fraction at ground level sensitivity analysis in terms of normalized dry deposition (test case dry deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute dry deposition and normalized dry deposition versus downwind distance are presented in Appendix A for all cases.

Dry deposition rates are unaffected by variations in fraction of net radiation at ground level.

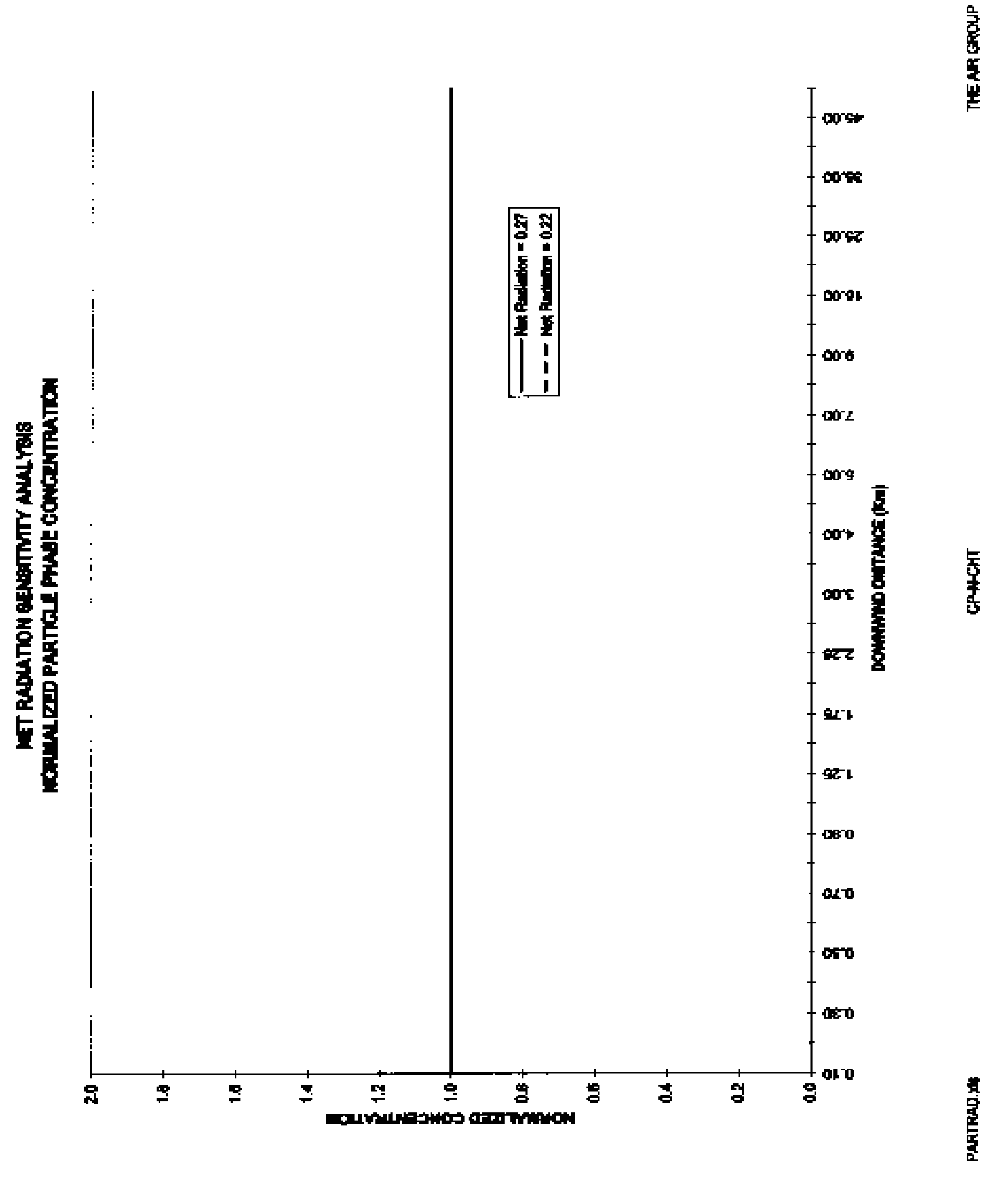
6.6.4.3 WET DEPOSITION

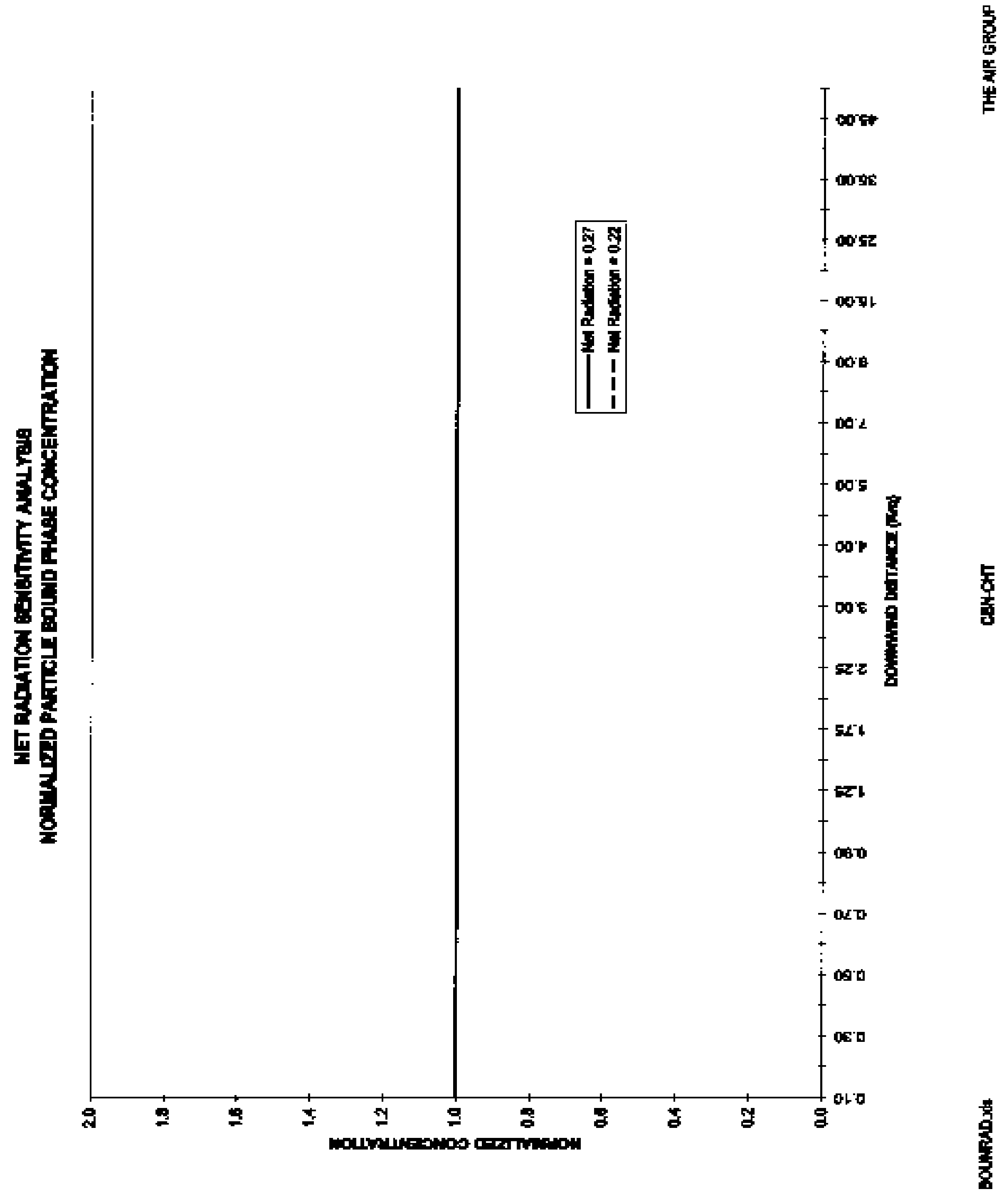
The results of the fraction of net radiation at ground level sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute wet deposition and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.

Wet deposition rates are unaffected by variations in fraction of net radiation at ground level.

6.6.5 RECOMMENDATIONS

Refinement or enhancements of the net radiation values in Table 3-4 is unnecessary, as this parameter has negligible affect on modeled impacts.


NET RADIATION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE CONCENTRATION
Net Radiation = 0.27
Net Radiation = 0.22
DOWNWIND DISTANCE (Km)
NORMALIZED CONCENTRATION
THE AIR GROUP



NET RADIATION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
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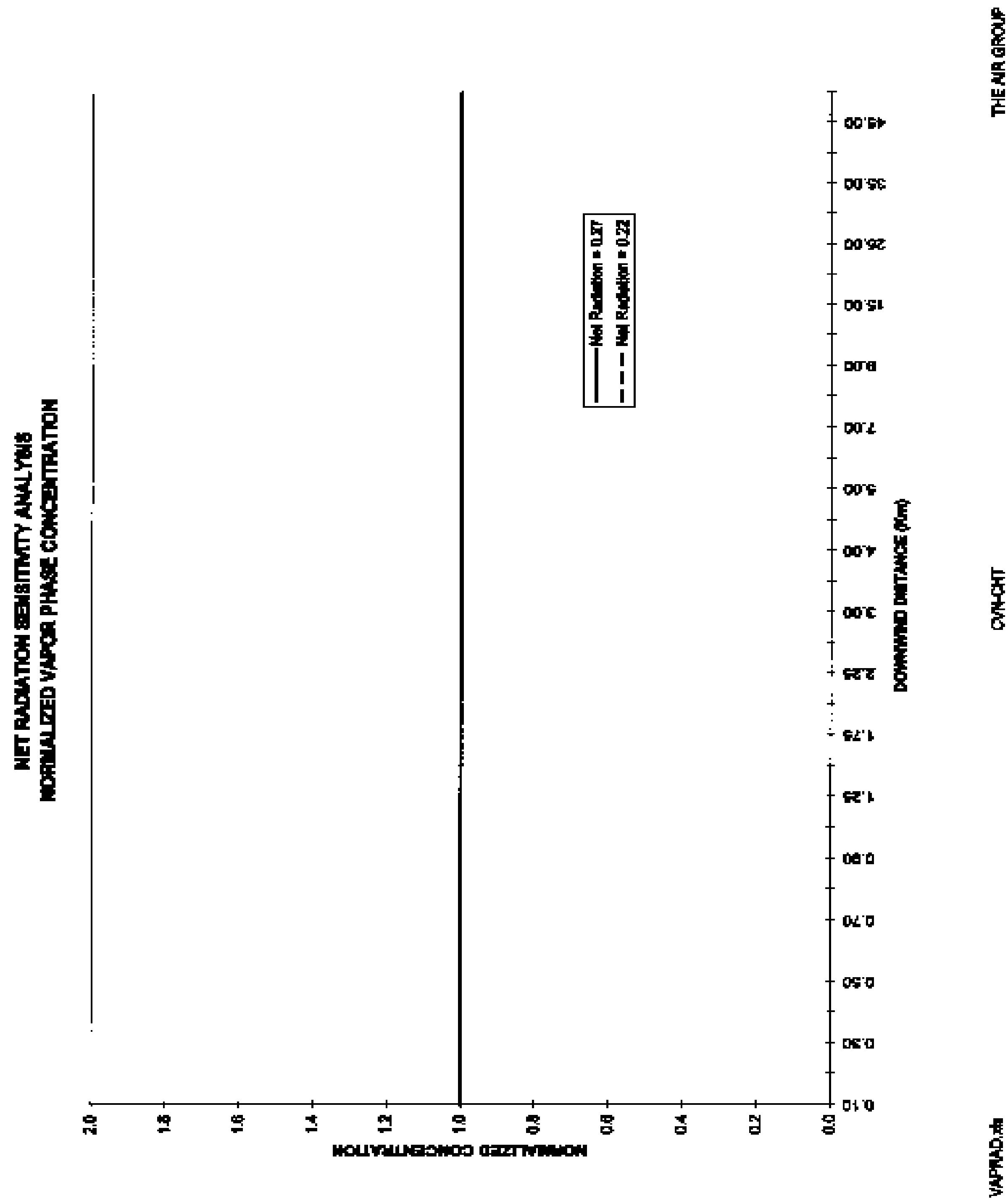
Net Radiation = 0.22
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
CBN-CHT
BOUNRAD.xls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NORMALIZED VAPOR PHASE CONCENTRATION
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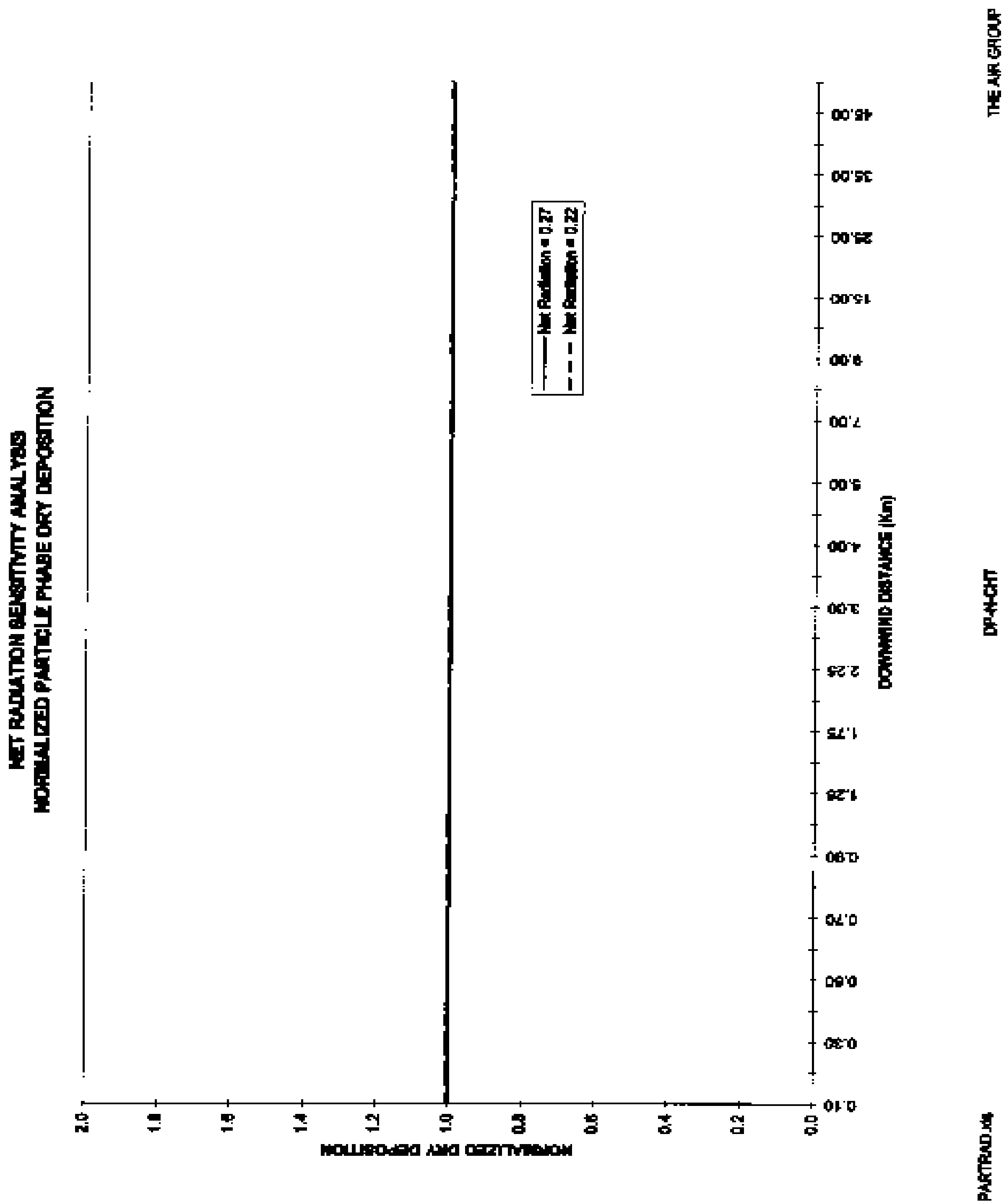
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (Km)
THE AIR GROUP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NORMALIZED PARTICLE PHASE DRY DEPOSITION
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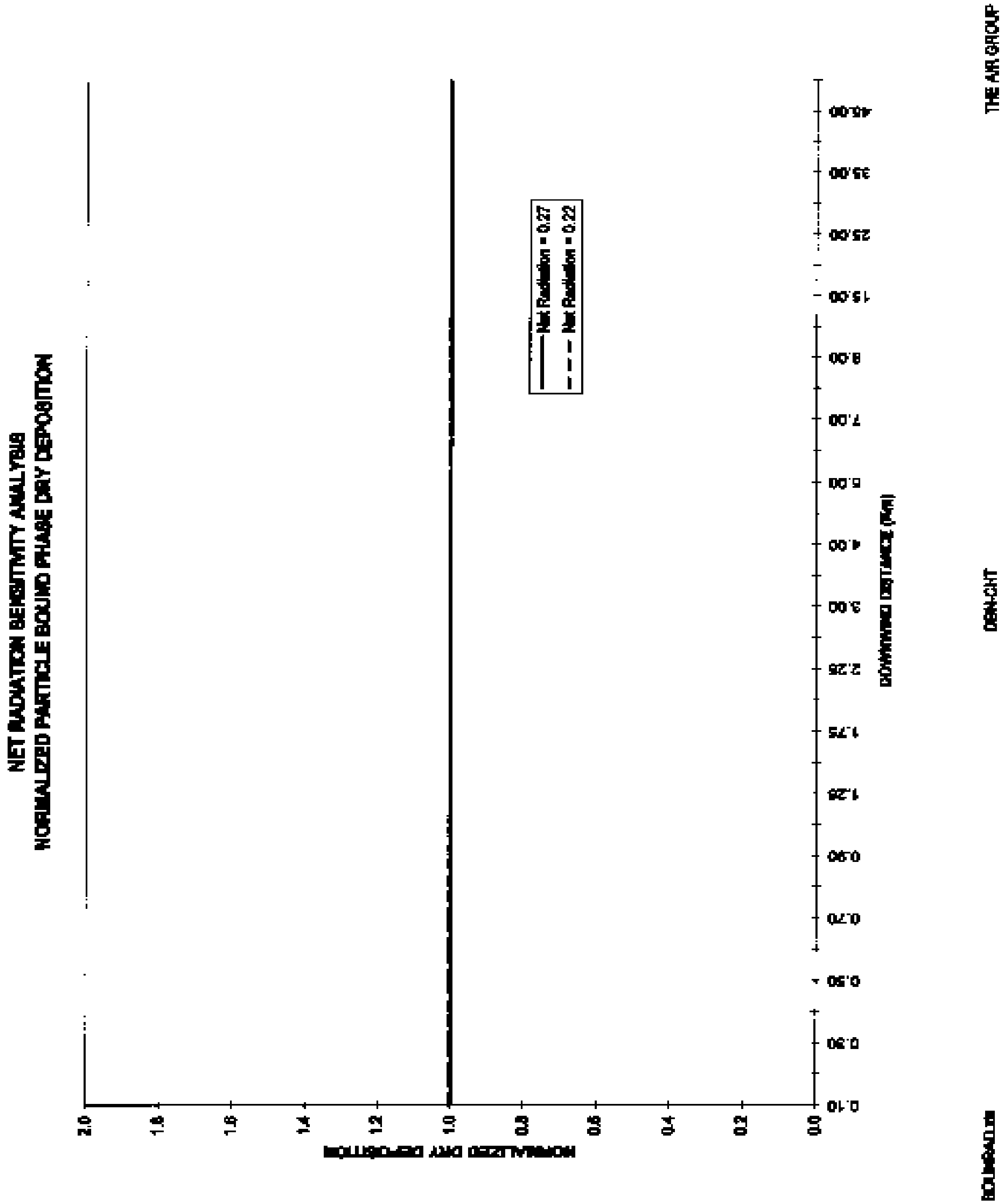
Net Radiation = 0.22
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
DOWNWIND DISTANCE (Km)
THE AIR GROUP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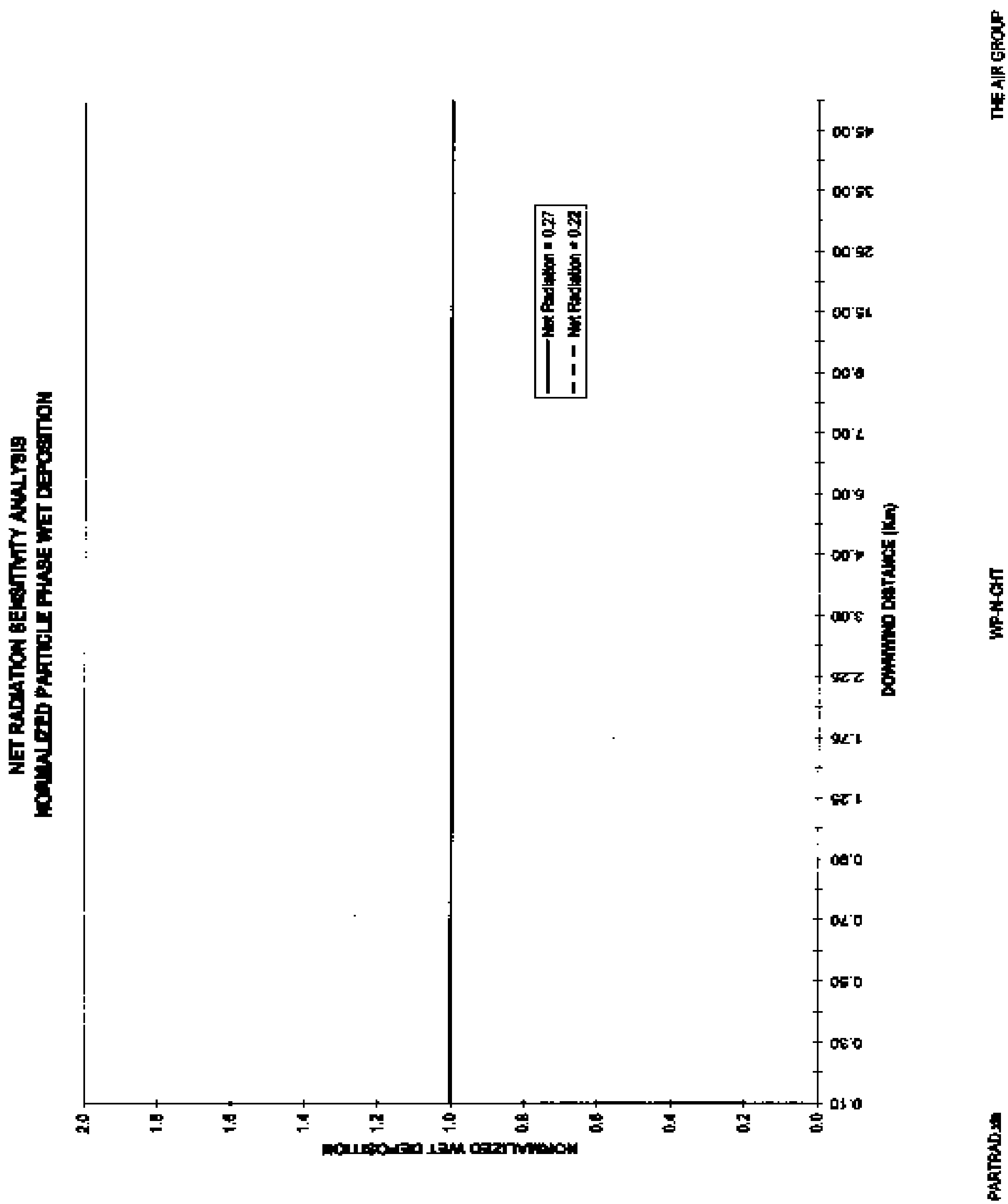
NORMALIZED PARTICLE BOUND PHASE DRY DEPOSITION
Net Radiation = 0.27
Net Radiation = 0.22
NORMALIZED DRY DEPOSITION
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
DOWNWIND DISTANCE (Km)
0.10
0.30
0.50
0.70
0.90
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
THE AIR GROUP


NET RADIATION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
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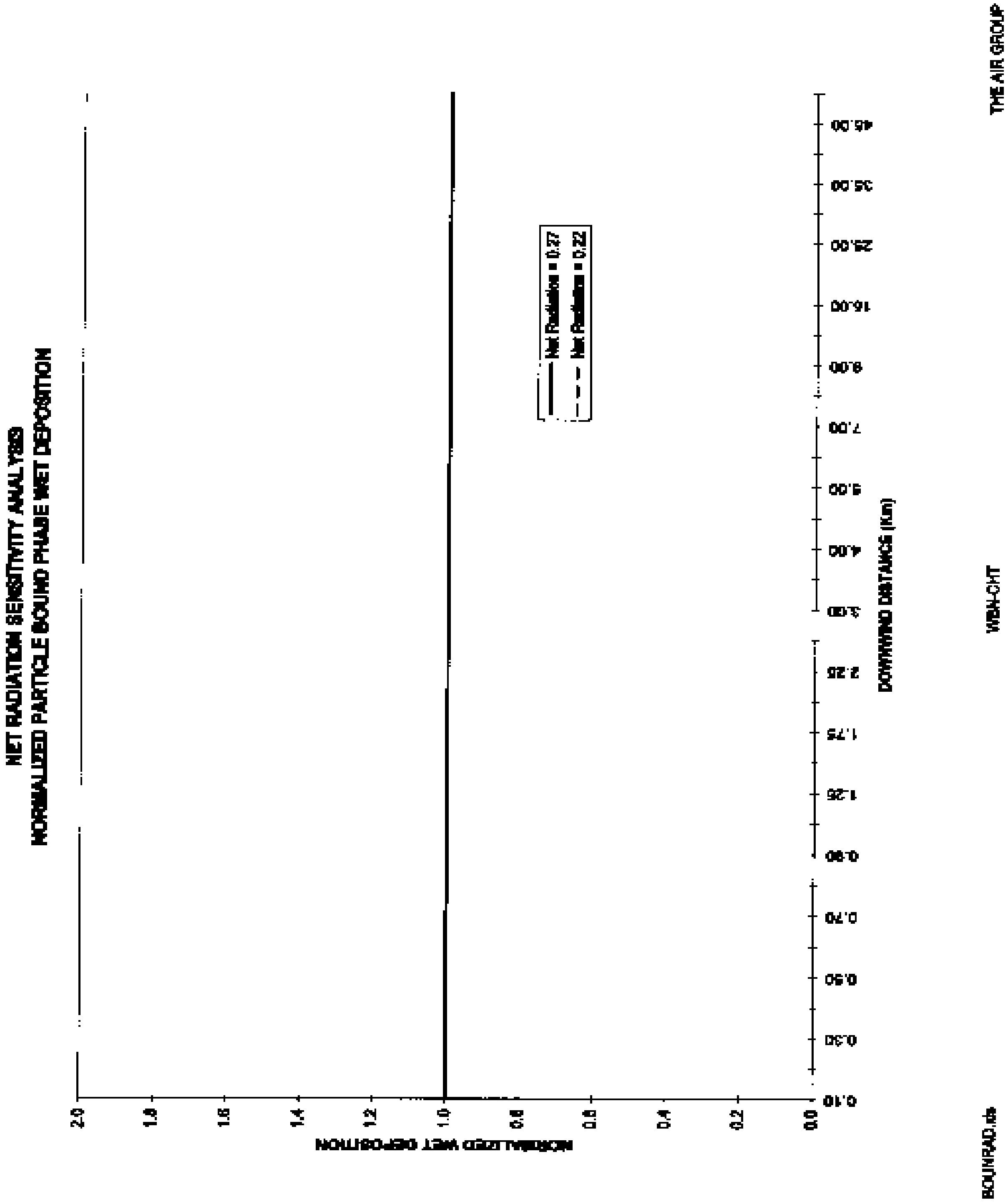
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WP-N-CHT


NET RADIATION SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
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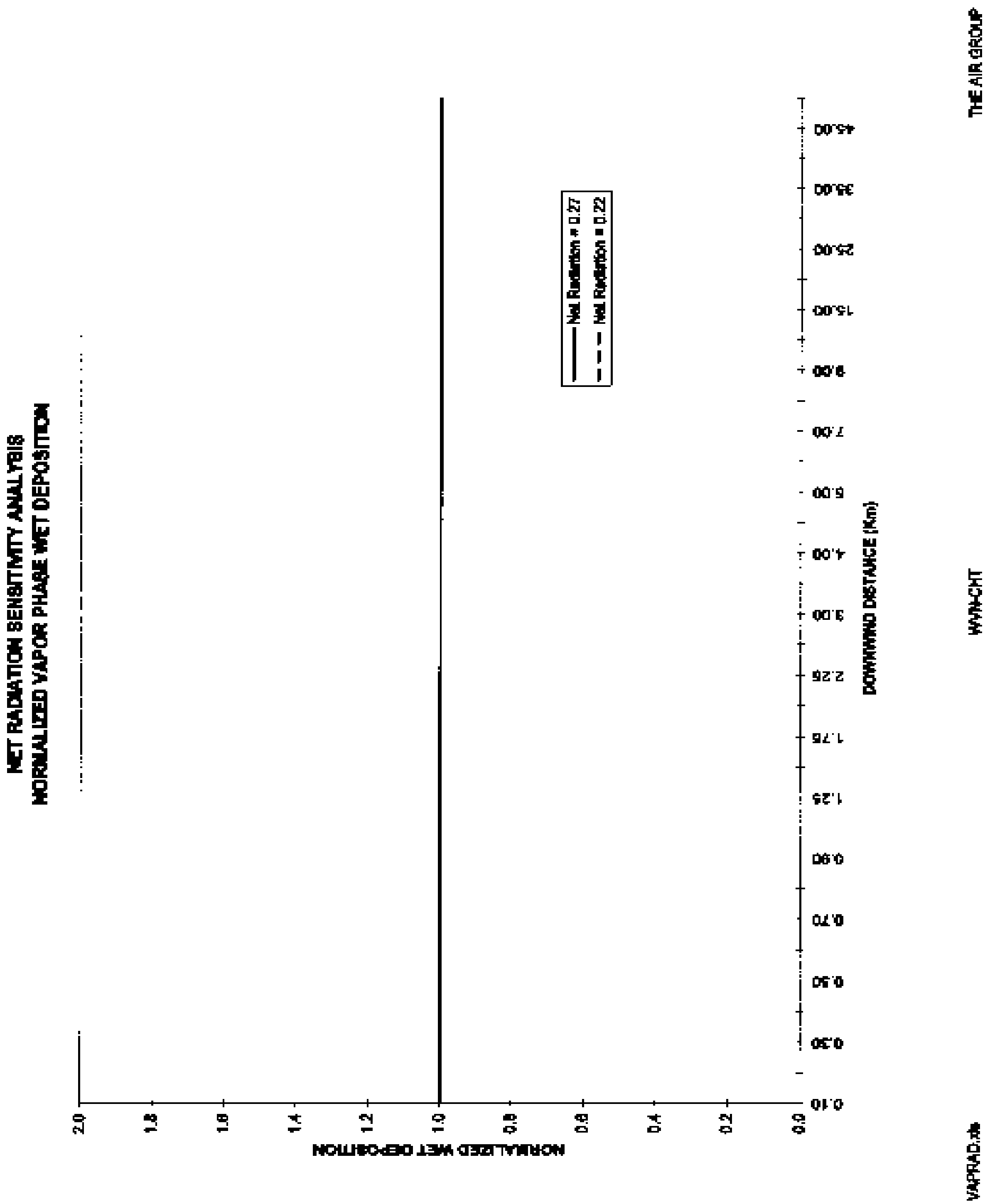
Net Radiation = 0.22
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WBN-CHT
BOUNRAD.xls


NET RADIATION SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Net Radiation = 0.27
Net Radiation = 0.22
DOWNWIND DISTANCE (Km)
NORMALIZED WET DEPOSITION
THE AIR GROUP

6.7 SCAVENGING COEFFICIENTS

6.7.1 TECHNICAL OBJECTIVE

The technical objective of the scavenging coefficient sensitivity analysis is to compare the Protocol recommended method of assuming that ice scavenging coefficients are one third those of liquid coefficients with the more conservative assumption that ice scavenging coefficients are equal to liquid scavenging coefficients.

6.7.2 THEORETICAL BASIS

Wet deposition flux is calculated by multiplying a scavenging ratio by the vertically integrated concentration. The scavenging ratio is the product of a scavenging coefficient and a precipitation rate. The ISCST3 model distinguishes between liquid and frozen scavenging coefficients. As a conservative estimate, the frozen scavenging coefficients are assumed to be equal to the liquid scavenging coefficients. However, research has indicated that frozen precipitation scavenging coefficients are about one-third that of liquid precipitation.

6.7.3 METHODOLOGY

To adequately compare frozen (ice) scavenging coefficients to liquid scavenging coefficients, a specific precipitation event was evaluated. The event consists of 1/2" of snow falling during a one-hour period.

6.7.3.1 BASE CASE - PROTOCOL RECOMMENDED METHOD

The base case model runs described in Section 4 are used as the base case for this analysis, with the exception of the meteorological data set. Instead of modeling a 5-year period, the one-hour frozen precipitation event is modeled. The wind flow vector was arbitrarily assumed to be toward the north. For the base case, the ice scavenging coefficients are set at one third of the liquid coefficients.

6.7.3.2 TEST CASE I - CONSERVATIVE METHOD

Test Case I is identical to the base case, except the ice scavenging coefficients are set equal to the liquid coefficients.

6.7.4 RESULTS

6.7.4.1 CONCENTRATION

The results of the scavenging coefficient sensitivity analysis in terms of normalized concentration (test case concentration divided by base case concentration) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized concentration versus downwind distance are presented in Appendix A for all cases.

Concentrations are equivalent for the base case and the test case in the immediate vicinity of the source. However, concentrations for Test Case 1 quickly decrease significantly with distance from the source compared to the base case. At a distance of 50 kilometers, Test Case 1 concentrations are virtually zero, whereas the base case concentrations are on the order of 0.01 $ug/m^3/g/s$ at that distance.

6.7.4.2 DRY DEPOSITION

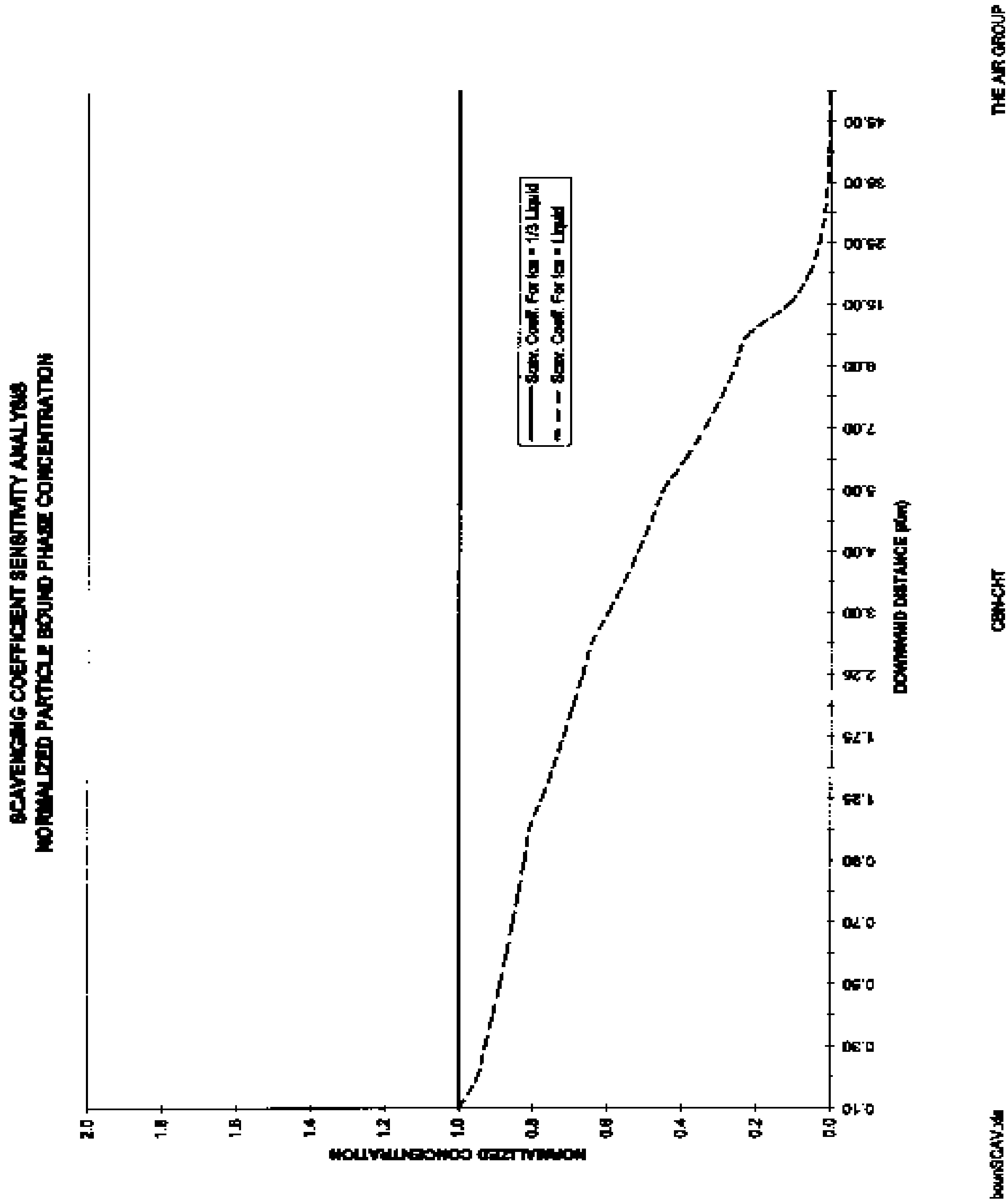
Dry deposition rates are zero for the 1-hour precipitation event, as expected, and are therefore unaffected by variations in ice scavenging coefficients.

6.7.4.3 WET DEPOSITION

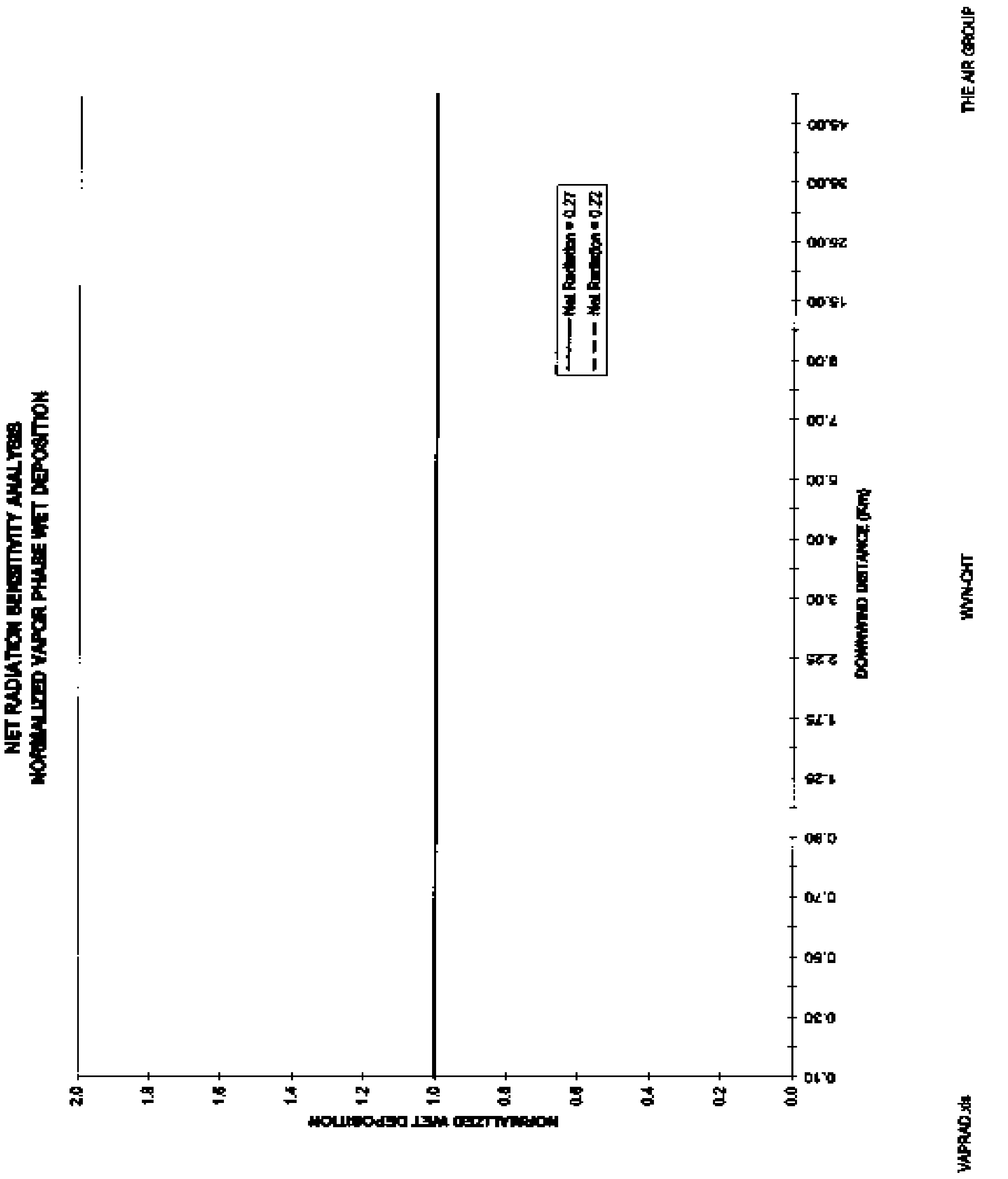
The results of the scavenging coefficient sensitivity analysis in terms of normalized wet deposition (test case wet deposition divided by base case dry deposition) versus downwind distance are presented in figures at the end of this section. Tables of absolute and normalized wet deposition versus downwind distance are presented in Appendix A for all cases.
Wet deposition rates are significantly affected by variations in ice scavenging coefficients. Test Case 1 wet deposition rates are nearly 300% of the base case values at close proximity to the source. As distance from the source increases, Test Case I wet deposition decreases significantly compared to the base case, but remain higher than the base case until a distance of 1.5 to 7 kilometers, depending on the phase. Wet deposition rates for Test Case 1 are lower than the base case beyond 7 kilometers for all phases, dropping to zero at 15 to 20 kilometers from the source.

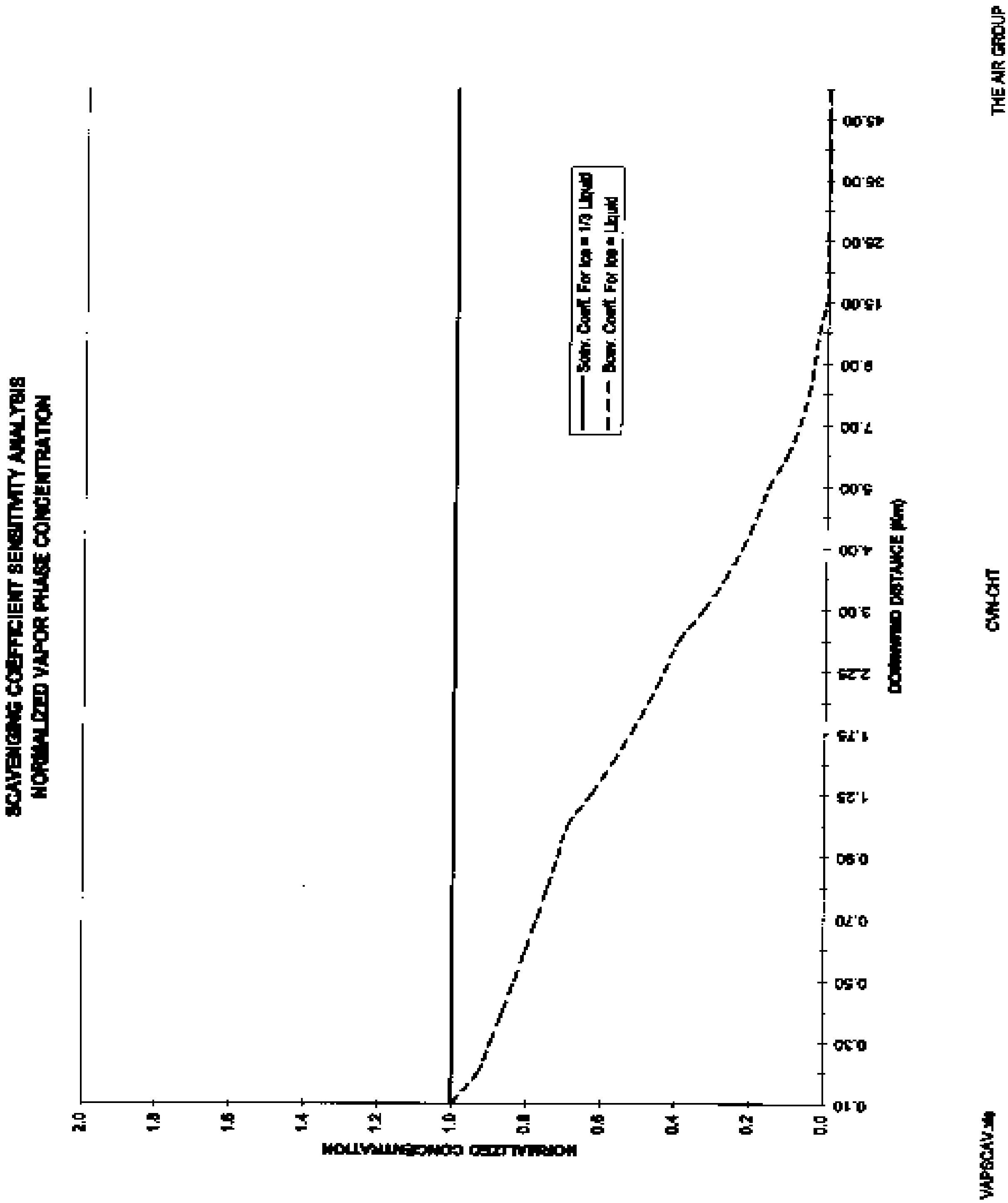
6.7.5 RECOMMENDATIONS

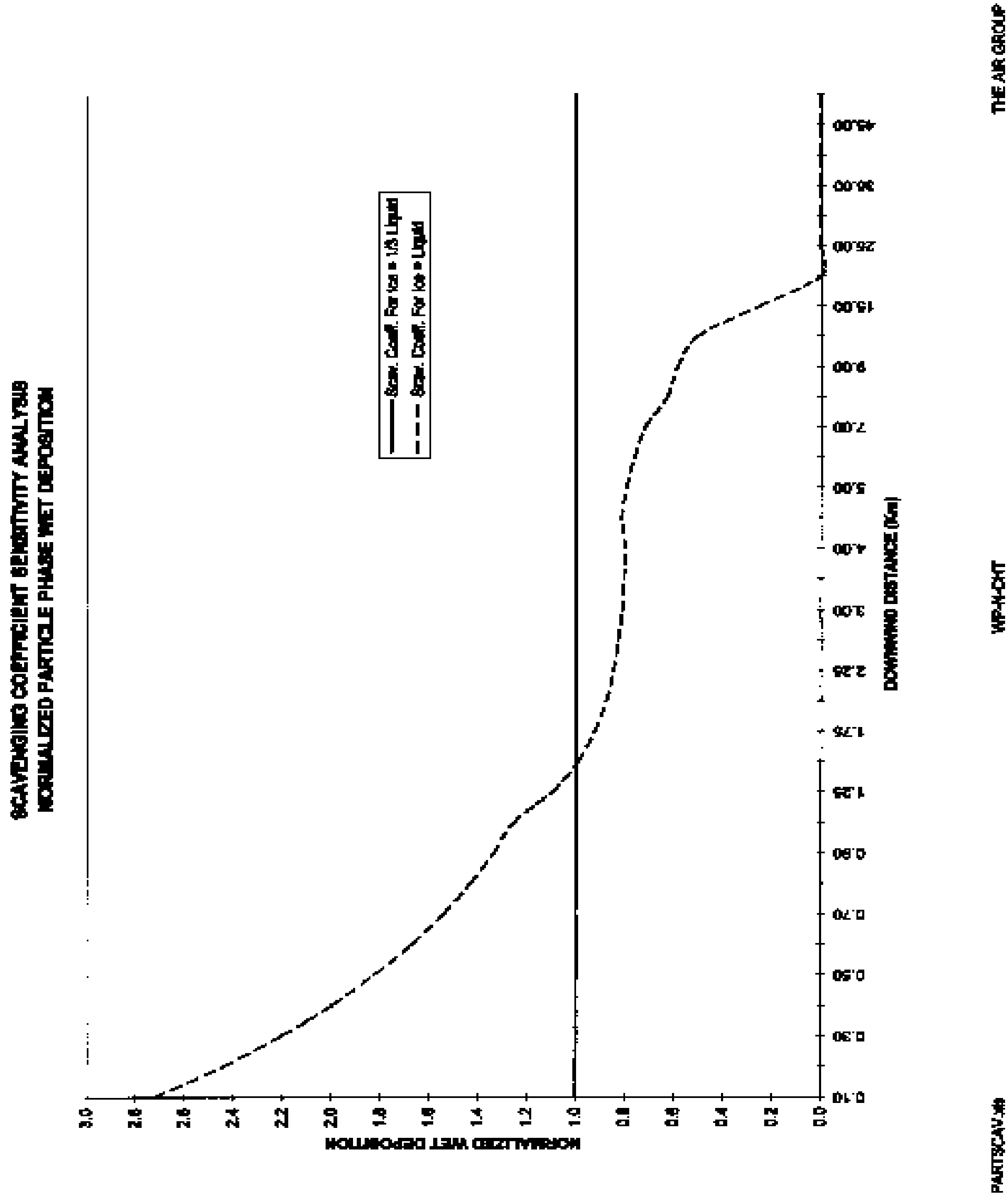
The frozen scavenging coefficients affect the deposition rate in almost direct proportion to the ratio of liquid scavenging to frozen scavenging. Assuming the less conservative value for frozen of one-third of the liquid coefficient results in deposition rates one-third of the less conservative assumption of equal coefficients. In Region 6, frozen precipitation events will probably not contribute significantly to long term risk assessments. Therefore, to be conservative it is recommended to use a value equal to the liquid coefficient. This recommendation would change to Protocol guidance as currently written. However, if no commentors identify this issue as critical, no change in the Protocol will have little effect on the screening risk assessments.

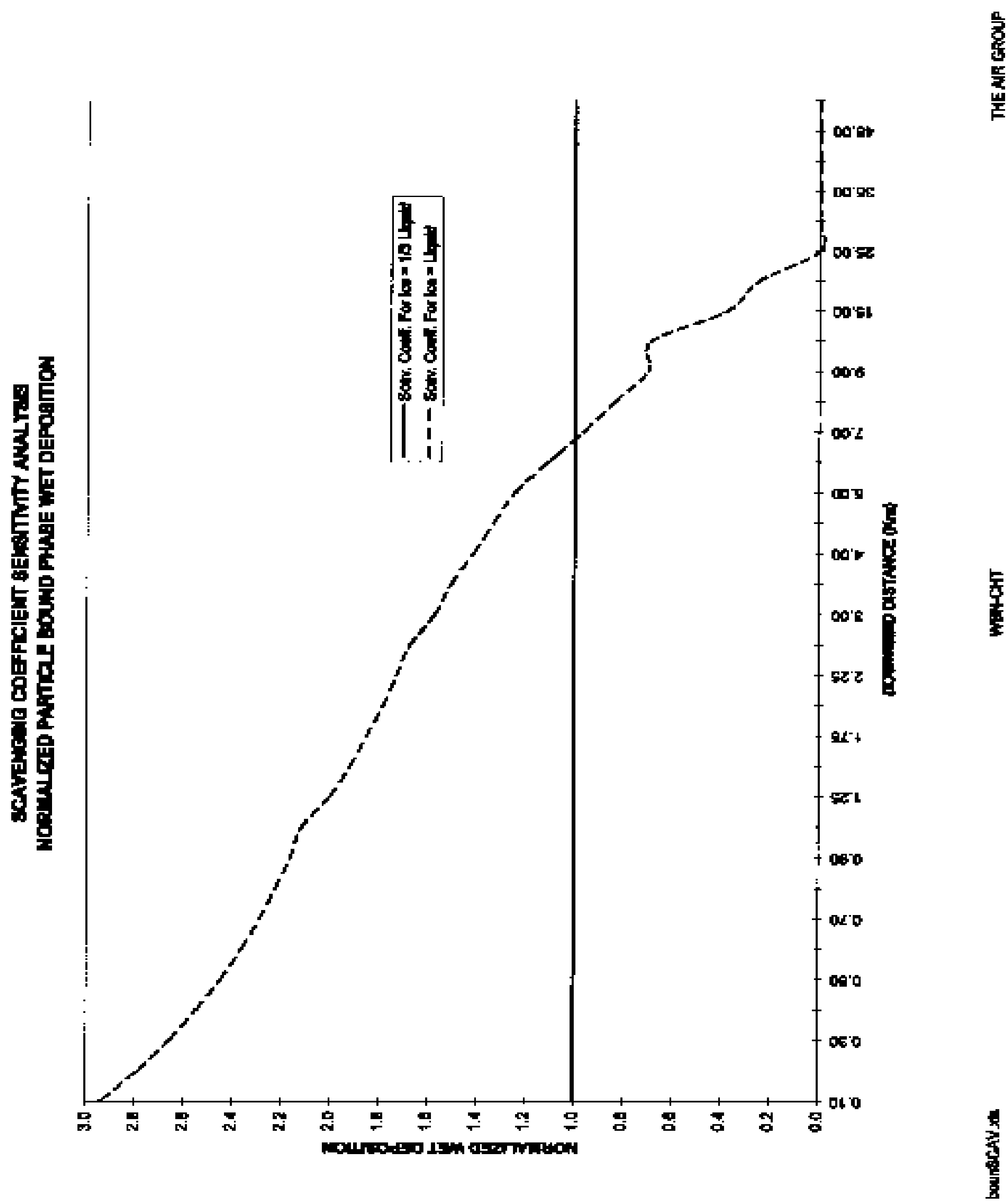


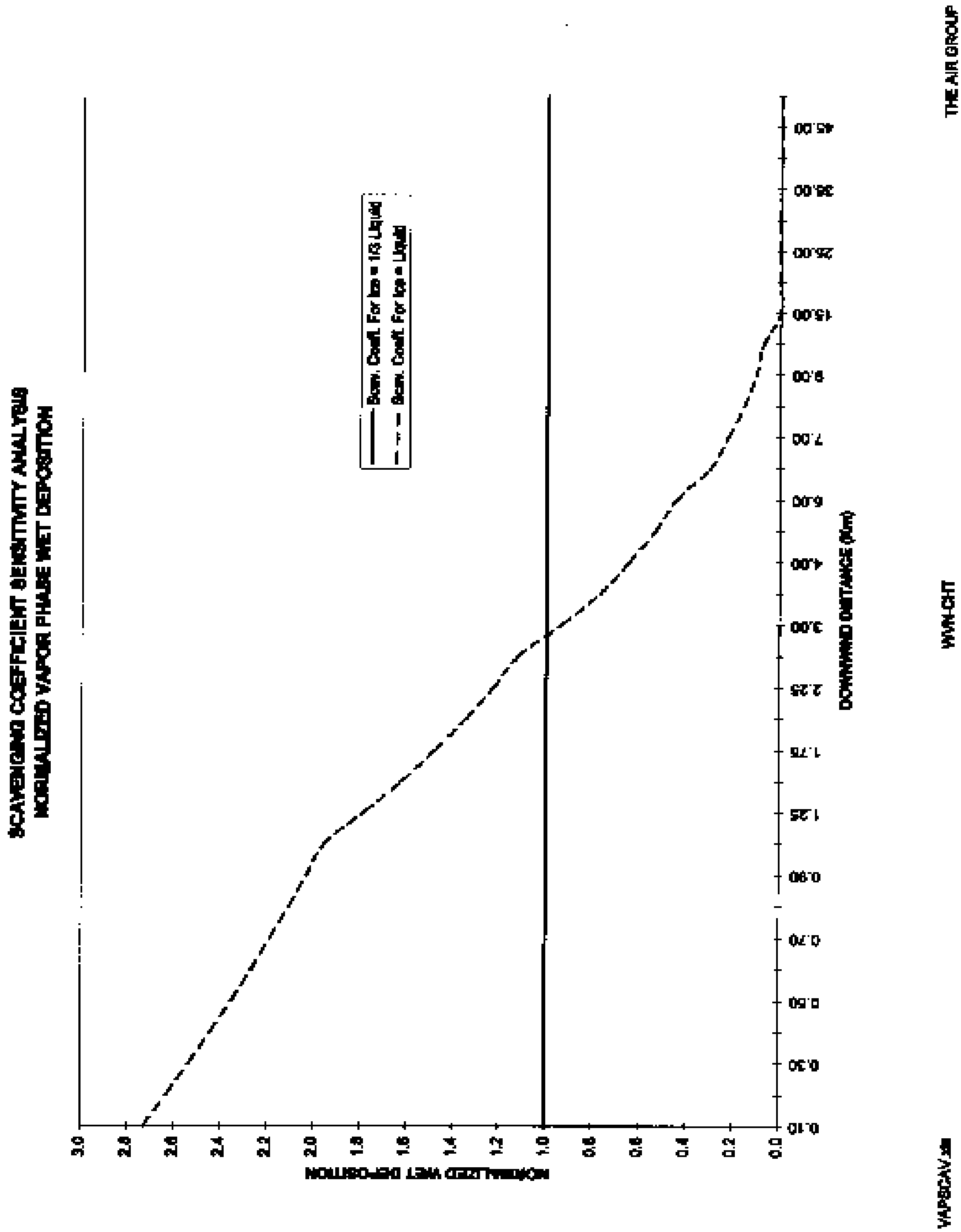
SCAVENGING COEFFICIENT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE CONCENTRATION
Scav. Coeff. For Ice = 1/3 Liquid
Scav. Coeff. For Ice = Liquid
NORMALIZED CONCENTRATION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DOWNWIND DISTANCE (km)
0.10
0.30
0.50
0.70
0.80
1.25
1.75
2.25
3.00
4.00
5.00
7.00
9.00
15.00
25.00
35.00
45.00
bounSCAV.xls
CSN-CHT
THE AIR GROUP


NET RADIATION SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Net Radiation = 0.27
Net Radiation = 0.22
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WVN-CHT
VAPRAD.xls


SCAVENGING COEFFICIENT SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE CONCENTRATION
Scav. Coeff. For Ice = 1/3 Liquid
Scav. Coeff. For Ice = Liquid
NORMALIZED CONCENTRATION
DOWNWIND DISTANCE (km)
THE AIR GROUP


SCAVENGING COEFFICIENT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE PHASE WET DEPOSITION
Scav. Coeff. For Ice = 1/3 Liquid
Scav. Coeff. For Ice = Liquid
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP


SCAVENGING COEFFICIENT SENSITIVITY ANALYSIS
NORMALIZED PARTICLE BOUND PHASE WET DEPOSITION
Scav. Coeff. For Ice = 1/3 Liquid
Scav. Coeff. For Ice = Liquid
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
boundSCAV.xls


SCAVENGING COEFFICIENT SENSITIVITY ANALYSIS
NORMALIZED VAPOR PHASE WET DEPOSITION
Scav. Coeff. For Ice = 1/3 Liquid
Scav. Coeff. For Ice = Liquid
NORMALIZED WET DEPOSITION
DOWNWIND DISTANCE (Km)
THE AIR GROUP
WVN-CHT
VAPSCAV.xls

7. SUMMARY OF SENSITIVITY ANALYSIS

The EPA-developed ISCST3 model is recommended in the Draft SLHHRA Protocol (2/28/97) for performing air dispersion and deposition modeling. ISCST3 modeled outputs for ambient air concentration and wet and dry deposition rates provide the inputs to evaluate COPC fate and transport. ISCST3 requires the modeler to select many input parameter values for which technical descriptions and ranges of values are provided with no information on the sensitivity of modeled results to selected values. Similarly, the EPA-developed meteorological preprocessor program PCRAMMET requires numerous parameter specifications within ranges of values identified from reference literature without identifying model sensitivity.

This sensitivity analysis provides comparisons of ISCST3 modeled results using the Protocol recommended values to modeled results using the upper and lower range values for identified elements. The eight priority and seven secondary elements are selected by EPA Region 6 considering the availability of information for selection, experience on prior risk analyses, and anticipated impact on modeled results. The Protocol recommended values represent typical site characteristics that may be used to model conservative screening results without collecting site-specific data. However, the modeler may elect to collect site-specific data to refine model results.

The following table provides a qualitative summary of the sensitivity of modeled results to variations in the selected values for the fifteen elements evaluated in this study. The sensitivity is 'slight' for variations less than 10% in ISCST3 modeled results using the element range limits compared to the Protocol recommended values. Sensitivity is 'moderate' for variations less than 50% from Protocol results. Sensitivity is 'severe' for variations greater than 50% from Protocol results. Seven elements produce slight or no variations from the Protocol results. Two elements produce moderate variations. Six elements produce severe variations from Protocol results. The two moderate elements require consideration by EPA Region 6 for ensuring the Protocol recommendations represent the desired level of conservativeness for a screening level risk assessment. The six severe elements should have required values specified in the Protocol or always require collection of site-specific data.

PARAMETER	SENSITIVITY	RECOMMENDATION
Elevated vs. Flat Terrain	Severe	Must include terrain < 1-2 km; Hills > stack height only if > 5 km
Rural vs. Urban Air Dispersion Coefficients	Severe	Detailed land use analysis required
Surface Roughness (Application Site)	Severe	EPA-required method, or site-specific justification
Watershed Size and Proximity	Severe	Use actual watershed area near source; use representative points >10 km away
Anemometer Height	Moderate	Under estimates < I km
Particle Size Distribution and Density	Moderate	Require stack test data for particle size and density
Polar vs. Cartesian Grid Nodes	Slight	Applicant selects grid
Terrain Grid File	None	No impact on model results
Minimum Monin-Obukhov Length	Slight	Specify default values
Surface Roughness (Measurement Site)	Severe	EPA-required value for NWS site of 0. I0 meters
Noon-time Albedo	Slight	Specify default values
Bowen Ratio	Slight	Specify default values
Anthropogenic Heat Flux	None	No impact on model results
Fraction of Net Radiation Absorbed	None	No impact on model results
Scavenging Coefficients	Severe	Isolated events 300%, but rare occurrence in EPA 6

8. RECOMMENDATIONS

This sensitivity analysis quantifies air dispersion and deposition impacts due to variations in model input elements. Modeled results are 'severely' sensitive to seven study elements with air concentration, dry and/or wet deposition rates that vary by at least 50% from the Protocol base case. Some elements result in modeled impacts several times larger near the facility emission source. For severely sensitive elements it is recommended that:

1. EPA require all facilities to model with actual terrain elevations out to 5 kilometers from the facility sources. Terrain elevations are also required for grid nodes with elevations above stack top elevation beyond 5 kilometers from the source.
2. EPA require a detailed land use analysis which addresses vegetation and structure types surrounding the facility. EPA air modeling guidance identifies a method after Auer with classifications of use within 3 kilometers to determine rural or urban predominance. Similar methods for determining surface roughness as proposed in the Protocol should be reviewed and consolidated into a single method to provide for all necessary inputs into the modeling and risk assessment decision process.
3. EPA require that watersheds be defined and approved for waterbodies near the facility (within 10 kilometers). Total watershed area should be used to average impacts and avoid severe model overestimates. Beyond 10 kilometers a representative location on the waterbody closest to the source may be used with no loss in model estimate accuracy.

4. EPA require that all facilities use 0.10 meters for the surface roughness value at the measurement site representing a properly exposed NWS weather station.
5. EPA specify a frozen scavenging coefficient as equal to or one-third the liquid coefficient. For Region 6 with few snow events this parameter has nominal impact.

For 'moderately' sensitive elements (less than 50% variation), EPA should require all modeling studies to use the correct anemometer height for the meteorological station and stack test data be provided for particle size and density. The other elements have negligible effects and should be addressed in the Protocol default values.