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Technical Basis for Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants"

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Prepared by
W. G. Snell, R. W. Jubach

NUS Corporation
4 Research Place
Rockville, MD 20850

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TECHNICAL BASIS FOR REGULATORY GUIDE 1.145, ATMOSPHERIC DISPERSION MODELS FOR POTENTIAL ACCIDENT CONSEQUENCE ASSESSMENTS AT NUCLEAR POWER PLANTS

W. G. Snell and R. W. Jubach

ABSTRACT

Regulatory Guide 1.145, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants, presents several substantial changes in the previous methodology of atmospheric dispersion analyses described in Regulatory Guides 1.3 and 1.4. This new methodology discussed in Regulatory Guide 1.145 includes, 1) the reduction in estimated ground-level concentrations due to plume meandering during the occurrence of stable atmospheric stability conditions and light wind speeds, and 2) the recognition that atmospheric dispersion conditions are directionally dependent. As a result of these developments, the NRC Meteorology Staff conducted a parametric study to examine the consequences of these changes on previous and future licensing activities. This parametric study was instrumental in the determination of appropriate probability levels for the risk assessment methodology discussed in the guide. The technical basis for the new methodology and the results of the parametric study are documented in this NUREG. This documentation includes the relationship of the new approach to the previous methodology.

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*EOCR = Experimental Organic Cooled Reactor.

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I. INTRODUCTION

A. Purpose

The development of Regulatory Guide 1.145, Atmospheric Disperison Models for Potential Accident Consequence Assessments at Nuclear Power Plants (Ref. 1), was initiated in order to modify the methodology in Regulatory Guides 1.3 and 1.4 (Refs. 2 & 3) for accident assessments to reflect the recent developments in atmospheric dispersion modeling and more realistic considerations of site-specific meteorology.

The methodology in Regulatory Guide 1.145 allows for consideration of the directional variability of wind flow and diffusion conditions at a site, and also permits consideration of directional variability of Exclusion Area Boundary (EAB) and Low Population Zone (LPZ) distances. In addition, the guide incorporates the results of recent field tracer tests which indicate that under certain atmospheric conditions, horizontal dispersion is enhanced due to lateral plume spreading (i.e., meander effects).

Because the methodology described in the guide represents a substantial change from the approach described in Regulatory Guides 1.3 and 1.4, the NRC meteorology staff conducted a parametric study in the summer and fall of 1978 to examine the consequences of these changes on previous and future licensing activities. This NUREG discusses the basis for and development of these modifications including a parametric study that examines these changes. The purpose of this NUREG is to present information on which Regulatory Guide 1.145 is based and not to provide an indepth analysis of the scientific basis for any of the methodology proposed by the guide. Only the calculations of 0-2 hour relative concentrations are discussed.

Section B of the Introduction discusses the background of the atmospheric dispersion methodology for accident assessments in order to compare the Regulatory Guide 1.145 approach with the past methodology. Sections II and III discuss the development of the meander factor and the equations utilized in the guide. The parametric study provides insight to changes in methodology and the resultant effects on relative concentration calculations. The results of the parametric study were utilized in determining the probability level discussed in Section 2.1 of Regulatory Guide 1.145. This study is discussed in Section IV.

B. Background

The pre-Regulatory Guide 1.145 (hereafter "direction-independent") methodology to characterize atmospheric dispersion conditions for licensing and siting of nuclear power plants had been developed through a series of changes to a simple model used in the 1950's and early 1960's. The simple model is described in TID-14844 (Ref. 4) and referenced in 10 CFR Part 100 (Ref. 5). The meteorological conditions assumed in TID-14844 were a very stable atmosphere and a light wind speed corresponding closely to Pasquill Type "F" stability (see Regulatory Guide 1.23, Ref. 6, for a discussion of atmospheric stability classification), and a 1 meter/second wind speed. This stability and wind speed combination represents an infrequent and conservative atmospheric dispersion situation. During the 1960's these assumptions were changed to reflect more reasonable atmospheric dispersion conditions allowing for variations in wind speed, atmospheric stability, and wind direction.

Safety Guides 3 and 4 (now Regulatory Guides 1.3 and 1.4), originally issued in 1970, recommended the use of Pasquill Type "F" stability, a wind speed of 1 meter/second, and an invariant wind direction to represent atmospheric dispersion conditions for time periods less than 8 hours. The selection of these atmospheric dispersion conditions was based on examination of available meteorological data from a small number of reactor sites representing different topographical and meteorological regimes (i.e., inland, river valley, and coastal). The examination indicated that the short-term (0-2 hour) atmospheric dispersion conditions represented by Pasquill Type "F" stability associated with a wind speed equal to 1 meter/second, independent of wind direction, were exceeded an average of about 5 percent of the total time on an hourly basis. Subsequently, to acknowledge site-to-site variability in meteorological conditions, the "5-percentile criterion" was selected as the probability level of the atmospheric dispersion condition to be considered in a calculation to demonstrate compliance with the dose objectives specified in 10 CFR Part 100.

A relative concentration (X/Q) value which would not be expected to be exceeded more than 5 percent of the time on an annual basis at a minimum EAB radial distance and at the minimum distance to the outer boundary of the LPZ was used in this calculation. These X/Q values are functions of wind speed, atmospheric stability, distance from the effluent source to a potential receptor and lateral and vertical distance from the center of an airborne effluent plume. The distribution of the effluent plume about the plume centerline is assumed to be Gaussian, but with additional spreading of the plume in the wake of plant structures due to mechanical mixing of the atmosphere induced by air flows over and around these obstructions.

Using the direction-independent methodology, X/Q values are determined by first calculating individual X/Q values for hourly pairs (or joint frequency occurrences) of wind speed and atmospheric stability conditions, independent of direction, at a distance equal to the shortest radial distance between the reactor and the exclusion area boundary or outer boundary of the LPZ. These individual X/Q values are then ranked from highest to lowest and their associated frequencies are summed to generate a cumulative probability distribution of X/Q values. From this probability distribution, the X/Q value that is exceeded 5 percent of the time around the entire circumference (exclusion area or LPZ) is selected as appropriate for the Part 100 evaluation. The theoretical assumption was that this value was to be equalled or exceeded approximately 5 percent of the total time or 438 hours per year (5% x 8760 hours per year).

However, the frequency of occurrence of this X/Q value at any specific location on the exclusion area boundary is expected to be substantially less than 5 percent of the time annually, because the particular location is less than the entire circumference of the appropriate boundary. For example, if one considers a segment of a circular exclusion area boundary which extends only one fifth of the way around the circumference of the boundary, then the expected frequency of the X/Q value in that segment would be one fifth of 5 percent or 1 percent (approximately 88 hours) of the total time. This example, of course, does not consider any directional variability of meteorological conditions or variable distances to the boundary. The inclusion of such considerations might cause the frequency in the example sector to vary about the 1 percent level, but it would be very unlikely to approach 5 percent. It is evident then, that if an evaluation is to be made on a directional basis consistent with past practice for specified locations on a boundary, an appropriate percentile level for each direction segment which is much less than 5 percent must be selected.

II. DETERMINATION OF PLUME MEANDER METHODOLOGY

A. Introduction

The basic atmospheric dispersion model and methodology discussed in Section I.B have been developed for calculating relative concentrations (X/Q) to be used in assessments of the consequence of accidental releases from nuclear power plants (see Ref. 7). This model assumes that the plume spread has a Gaussian distribution in both the horizontal and vertical and, therefore, utilizes the standard deviations of plume concentration distribution in the horizontal (σ_y) and vertical (σ_z). Applications of this model normally utilize the traditional Pasquill-Gifford curves for σ_y and σ_z (Ref. 7) for estimating concentrations for release periods of nominally one hour. For ground-level releases the model calculates the highest effluent concentrations under low wind speed and stable atmospheric conditions. The Pasquill-Gifford dispersion coefficients, (σ_y and σ_z) are selected independent of wind speed and are based on diffusion test data for release periods of much less than one hour.

Quantitative atmospheric tracer studies representing ground level releases without the effects of buildings have been performed at the River Bend, Three Mile Island and Clinch River power reactor sites (Refs. 8-10). These tests have shown that during stable (E, F, and G) atmospheric conditions, as defined by ΔT criteria in Regulatory Guide 1.23, when the wind speed is light, measured effluent concentrations are usually substantially lower than those predicted by the use of the traditional Pasquill-Gifford prediction curves of lateral and vertical plume spread. These reduced concentrations are due primarily to enhanced horizontal spreading of the plume as it meanders over a large area which occasionally may exceed a 180 degree arc. This meandering of the plume produces σ_y values that are much larger than have been assumed for these conditions.

Since these tracer studies represented only near ground level, point source releases without the effects of release elevation and building influences, and were carried out in terrain exhibiting characteristics unique to each site, they were not considered appropriate for generic application to all nuclear power reactor sites.

To obtain data representative of releases at constructed nuclear power plants, the NRC and NOAA jointly funded atmospheric duffusion tests in the fall of 1975 at the Rancho Seco nuclear facility in California (Ref. 11). Data from these tests, along with consideration of the results already generated by past diffusion tests, were used to determine the combined effects of meander and building wake on values of X/Q. Analyses of these tests, along with consideration of the results already generated by past diffusion tests, provide the meander factors discussed later in this section applicable during light wind, relatively stable atmospheric stability conditions.

For releases through vents or other building penetrations, the meander factor allows credit for the combined effects of plume meander and building wake. As the effects of meander diminish with increasing wind speed and decreasing stability, the effects of building wake become more dominant. For elevated releases, the dispersion assessment remains unchanged because the data collected to date does not confirm the existence of meander at elevations greater than 60m. Because enhanced plume dispersion due to meandering appears to be most prevalent during periods of low wind speed and stable atmospheric conditions, which are the same conditions that give the highest concentrations for ground-level releases, the NRC has incorporated plume meander into the model in an effort to provide more realistic assessments of atmospheric dispersion.

B. Test Data

A quantitative assessment of effects of plume meander at an actual nuclear power plant site was made, utilizing data from the Rancho Seco tests. Atmospheric stability during these tests was determined from the NRC ΔT classification scheme (Ref. 6). No test data were available for the B or C atmospheric stability classes. Samplers were located in arcs with radii of 100, 200, 400, and 800 meters from the reactor containment vessel. Data from all the available tests were utilized in the analysis. More detail on the field program is provided in Reference 11.

In addition to the tests conducted at Rancho Seco, similar tests were jointly funded by NOAA and the NRC and performed at the Experimental Organic Cooled Reactor (EOCR) test reactor building complex at the Idaho National Engineering Laboratory in Idaho in 1975 and 1976 (Ref. 12). Although data from of the EOCR tests were not available to be included in the original assessment of plume meander, they have since become available and have been plotted with the Rancho Seco data (Figures II-1 through II-5). The results of the EOCR tests were very similar to those of Rancho Seco.

The NRC analysis of the results of the Rancho Seco tests focused on the measured values of the horizontal dispersion coefficient, σ_y. Measurements of the vertical dispersion coefficient, σ_z, were not made. The measured values of σ_y from the tests that were used in the NRC analysis were calculated using the second moment method. An important consideration was that atmospheric stability was based on the NRC ΔT classification scheme as per Regulatory Guide 1.23. Use of other classification schemes may not provide similar results in analysis of these data relative to NRC assessments.

C. Development of the Meander Factors

The values of σ_y that were obtained from the Rancho Seco and EOCR studies are shown by atmospheric stability class in Figures II-1 through II-5. Also shown are the Pasquill-Gifford σ_y curves for each stability class and a σ_y curve enhanced by an appropriate multiplier to give a lower envelope to the test results. Because the results of this evaluation were to be used in safety assessments of nuclear power plant design and in siting evaluations for sites located in various topographical and meteorological regimes, a lower envelope of this measured test data was selected as a reasonably conservative approach for estimating increased horizontal dispersion. Selection of the lower envelope curve was subjective. Various whole number multipliers were examined and the curve which most appropriately, considering the objective in determining these meander factors, enveloped the data was selected. This lower envelope multiplier to the Pasquill-Gifford σ_y was then selected as the meander factor applicable to the appropriate atmospheric stability class. As indicated in Figure II-1, no increase in the Pasquill-Gifford σ_y value is applicable for A stability because the σ_y curve is consistent with the lower envelope.

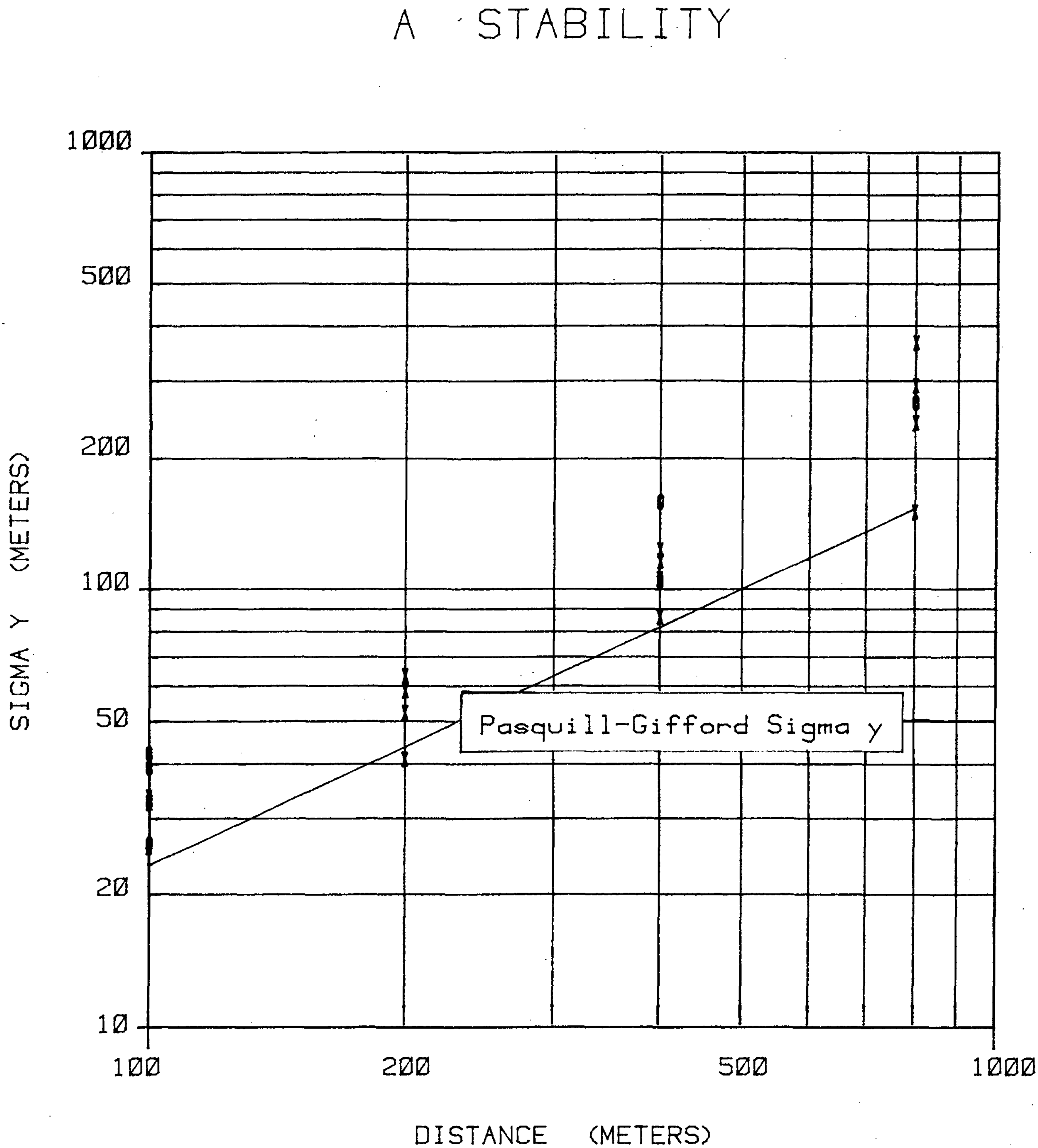

FIGURE II-1. Measured Values of Sigma y for Rancho Seco (X) and EOCR (Ø) for Stability Class A.

D STABILITY

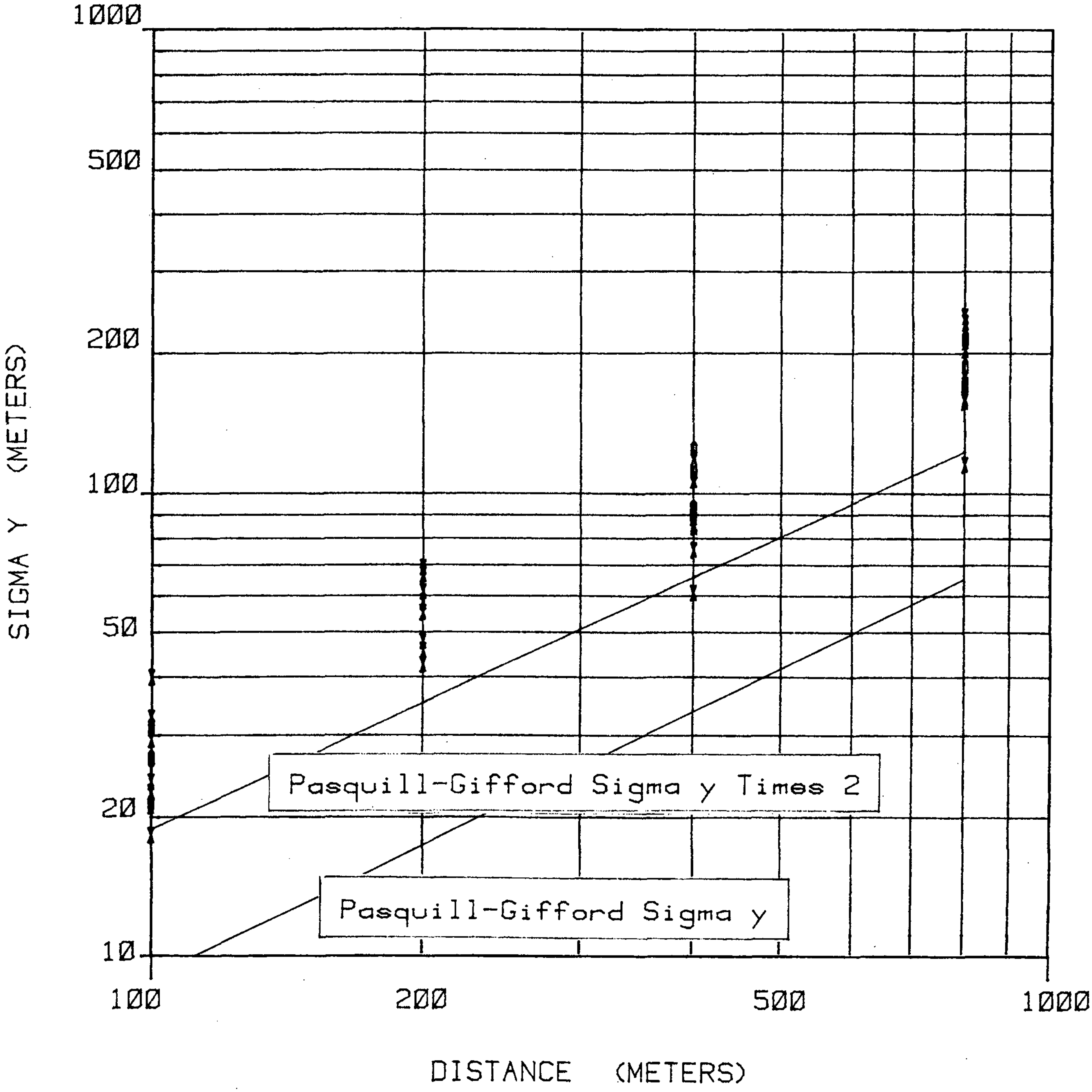

FIGURE II-2. Measured Values of Sigma y for Rancho Seco (X) and EOCR (Ø) for Stability Class D.

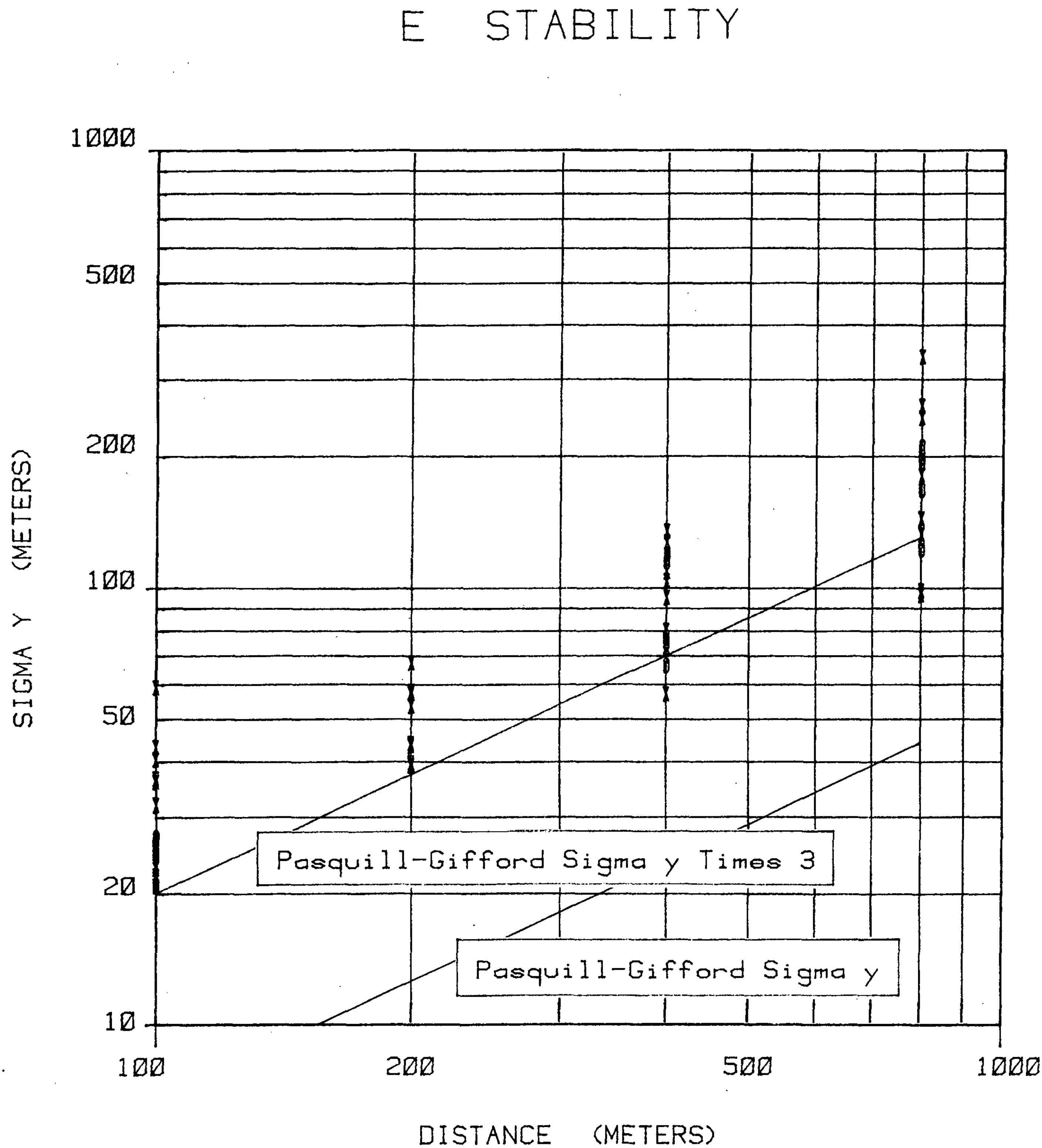

FIGURE II-3. Measured Values of Sigma y for Rancho Seco (X) and EOCR (Ø) for Stability Class E.

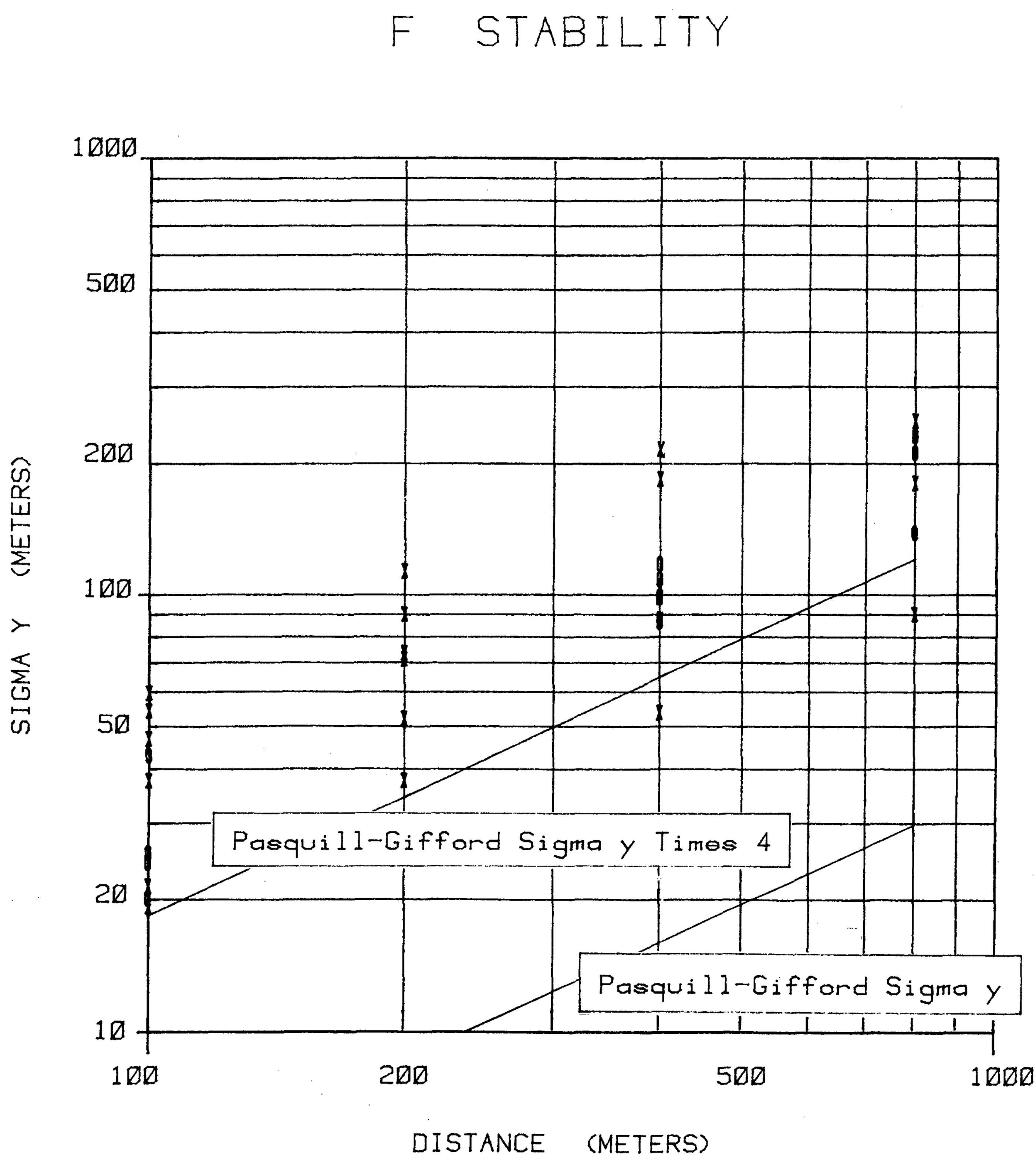

FIGURE II-4. Measured Values of Sigma y for Rancho Seco (X) and EOCR (Ø) for Stability Class F.

G STABILITY

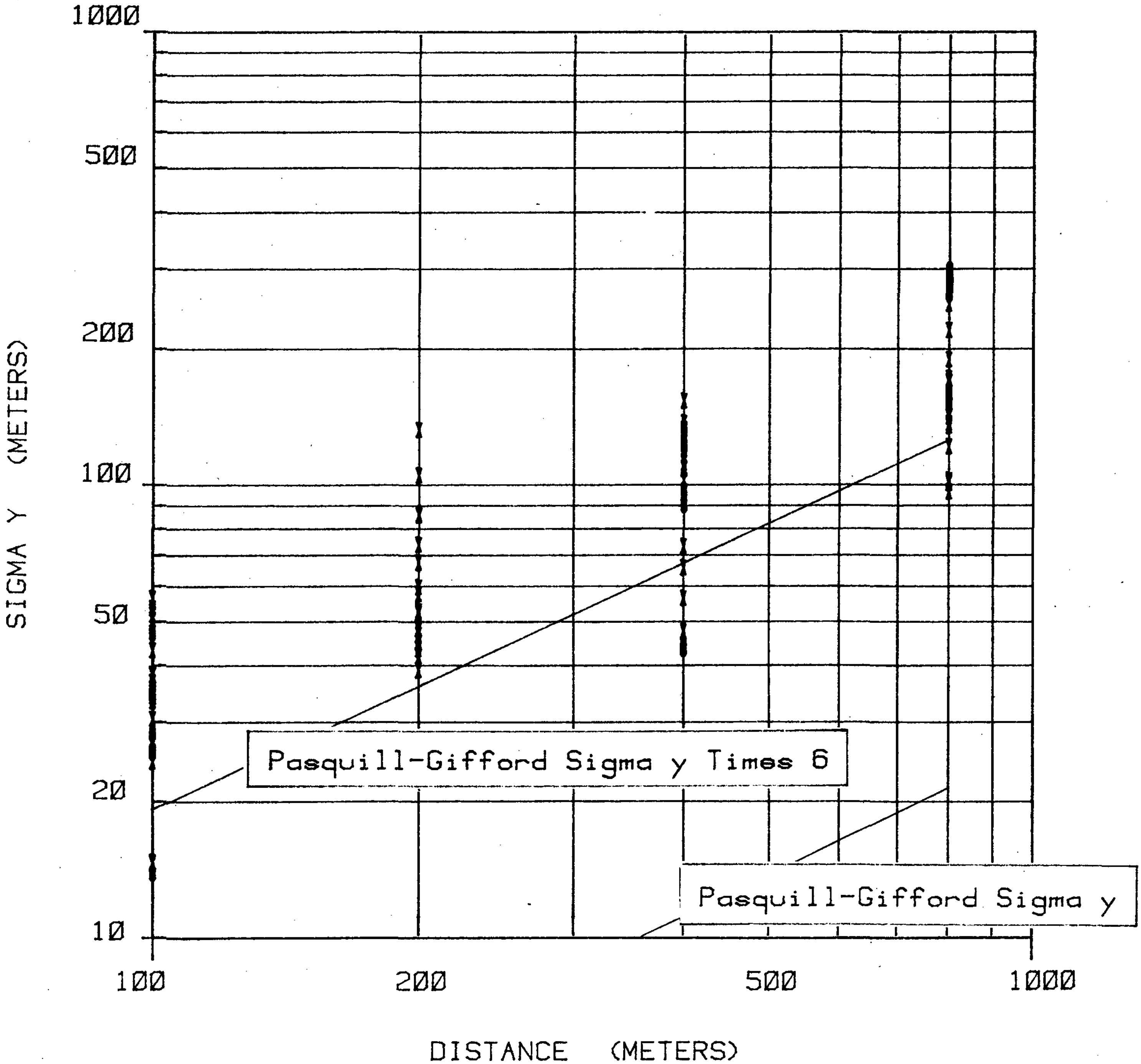

FIGURE II-5. Measured Values of Sigma y for Rancho Seco (X) and EOCR (Ø) for Stability Class G.

The NRC analysis of the Rancho Seco data was accomplished specifically for Regulatory Guide 1.145 and application to the design and siting of nuclear power plants. Application of the meander factors developed by the NRC to other assessments should not be accomplished without a thorough examination of all test data provided in References 11 and 12.

At this point two limiting criteria were imposed on the application of the meander factors. Since the Rancho Seco measurements were limited to a distance of 800m from the release point, it was not deemed appropriate to apply any values for distances beyond this. Therefore, credit for additional plume spread from meander would only be applied to a downwind distance of 800m from the release point. Beyond 800m, additional credit would not be allowed. However, any credit received up to 800m would be retained. To account for this, the following equations were adopted.

$$\Sigma_y = M\sigma_y \text{ for distances less than or equal to 800 m}$$
$$\Sigma_y = [(M-1)\sigma_{y800m}] + \sigma_y \text{ for distances greater than 800 m}$$

where:

Σ_y is lateral plume spread with meander and building wake effects, meters,

σ_y is lateral, plume spread based on Pasquill-Gifford, meters,

σ_{y800m} is σ_y at a distance of 800m, meters, and

M is the meander factor, dimensionless.

Analysis of the Rancho Seco and other tests indicated that meander is most prevalent during D, E, F, and G stability conditions accompanied by low wind speeds. A wind speed of 2.0 meters/second was selected as a limit below which full meander credit could be received and a speed of 6.0 meters/second was selected as a limit above which no additional credit could be received. Between these two values the meander factor varies logarithmically from full credit at 2.0 meters/second to no credit at 6.0 meters/second. The selection of these wind speeds was based on the many different atmospheric dispersion studies performed over the past several decades (e.g., Prairie Grass (Ref. 13), Green Glow (Ref. 14), and others mentioned previously). A graph of the meander factors developed from this analysis versus wind speed can be found in Figure II-6.

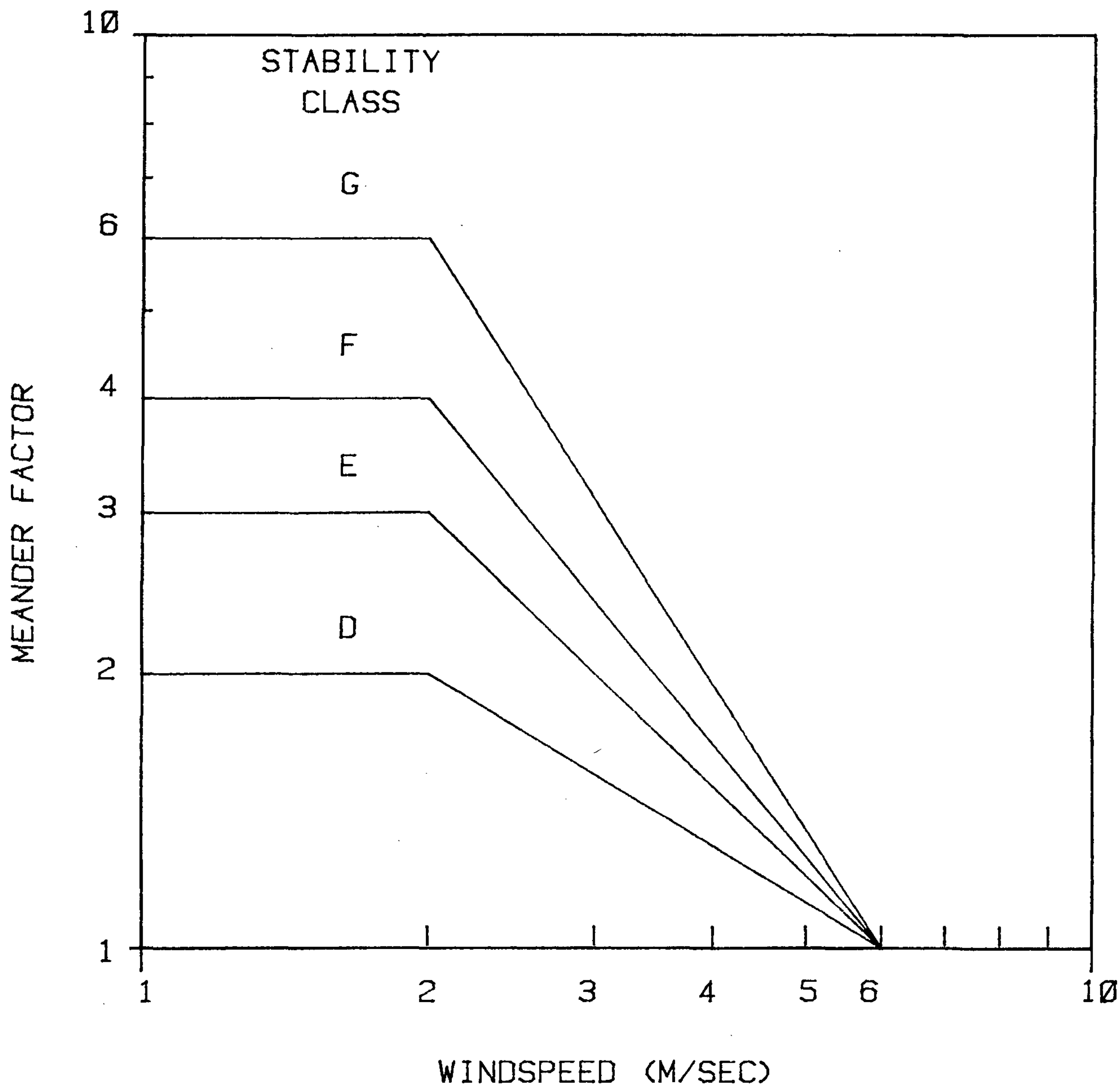

FIGURE II-6. Meander Factors for Correction of Pasquill-Gifford Sigma y Values by Atmospheric Stability Class.

III. BASIS AND USE OF THE EQUATIONS FOR GROUND-LEVEL RELEASES

Regulatory Guide 1.145 incorporated the use of three principal equations for calculating ground-level relative concentrations at the plume center line. These equations, referred to in the guide as Equations 1, 2 and 3, are as follows:

$$X/Q = \frac{1}{u_{10}(\pi \sigma_y \sigma_z + A/2)} \qquad (1)$$

$$X/Q = \frac{1}{u_{10}\, 3\pi\, \sigma_y \sigma_z} \qquad (2)$$

$$X/Q = \frac{1}{u_{10}\, \pi\, \Sigma_y \sigma_z} \qquad (3)$$

where

X/Q is relative concentration, sec/m^3,

π is 3.14159,

u_{10} is windspeed at 10 meters above plant grade, m/sec,

σ_y is lateral plume spread, a function of atmospheric stability and distance, meters,

σ_z is vertical plume spread, a function of atmospheric stability and distance, meters,

Σ_y is lateral plume spread with meander and building wake effects, (see Section II.C), meters, and,

A is the smallest vertical-plane cross-sectional area of the reactor building, square meters.

The bases for Equations 1 and 2 can be found in Meteorology and Atomic Energy-1968, (Ref. 7) and Regulatory Guides 1.3 and 1.4 (Refs. 2 and 3). The factor A/2 in Equation 1 and the factor 3 in Equation 2 are included to give additional credit for turbulent mixing in the wake of buildings and structures. The A/2 term in Equation 1 is better known as the cA term with c being conservatively assigned a value of 0.5. The factor of 3 in Equation 2 is used as upper limit to the amount of credit that can be obtained from the building wake effect. This is the basis for choosing the higher value between Equations 1 and 2. Credit is given for building wake effects based on Equation 1 until it reaches the upper limit determined by Equation 2, then the value from Equation 2 is used.

Equation 3 was formulated based on inclusion of the meander factor which included credit for building influences. (See Section II.) By comparing the higher value derived from Equations 1 and 2 with the value from Equation 3 and picking the lower of the two values, additional credit may be received for enhanced plume spreading under low wind speed and stable atmospheric conditions as well as for building wake effects. For further information, Appendix A of Regulatory Guide 1.145 contains several examples of the selective use of Equations 1, 2 and 3 under various wind speed and stability conditions.

The dispersion equations in the guide for elevated releases are essentially the same as discussed in Meteorology and Atomic Energy and Regulatory Guide 1.3. Since these equations or their use does not entail significant changes from past practice (except for the direction dependent applications), they are not discussed here. For further information, refer to Regulatory Guide 1.145.

IV. PARAMETRIC STUDY RESULTS

A. Purpose

As discussed in the Introduction of this report, the parametric study was accomplished in order to examine the effects of the Regulatory Guide 1.145 accident analysis dispersion methodology relative to the direction-independent methodology. The Regulatory Guide 1.145 methodology utilizes the critical sector relative concentration (X/Q) approach in which the effects of the directional dependence of boundary distances, wind direction frequencies, and frequencies of atmospheric stability conditions are considered. The guide also incorporates credit for horizontal diffusion by considering the effects of plume meander. The critical sector refers to the selection of X/Q values for the determination of compliance with the dose guidelines contained in 10CFR Part 100. Regulatory Guide 1.145 should be referred to for additional guidance. Because this approach is a marked departure from the direction-independent method, the effects of each of the three features of the model (i.e., direction-dependent consideration, a variable exclusion distance as a function of direction, and meander), as well as the complete Regulatory Guide 1.145 approach, were examined in the parametric study. The basis for all the analyses in the parametric study was to determine the effect on the direction-independent 5 percent X/Q value used for accident consequence assessments. This approach puts the effect of the Regulatory Guide 1.145 methodology in perspective relative to the direction-independent method.

B. Data Used

Data that were used for the parametric study were the most recently available meteorological data from 18* nuclear power plant sites which were representative of the meteorological and topographical regimes encountered during the various licensing activities. All sites utilized had meteorological programs

*Initially, 18 sites were examined in detail while three additional sites were evaluated later. The three additional sites were not studied to the extent of the original 18; most figures and tables provided in this NUREG are discussed or based on 18 sites.

consistent with the 1972 version of Regulatory Guide 1.23 Onsite Meteorological Programs. The data were obtained in the form of joint frequencies of wind direction, wind speed, and atmospheric stability as provided on the plant docket with the NRC. Atmospheric stability was based on vertical temperature differential (ΔT) and wind speed and wind direction were collected at a nominal height of 10 meters. Values of relative concentrations (X/Q) calculated for the study are all for ground-level releases since this represents the vast majority of licensing assessments. Table IV-1 provides the meteorological/topographical regime of each site examined. The reference numbers on this table will be utilized throughout this section. Boundary distances utilized in various aspects of the study were actual distances for a given site.

C. Study Results

1. Effect of Sector Dependency

Atmospheric diffusion conditions are directionally dependent for a particular location, with some wind direction flows associated with poor diffusion and others with relatively good diffusion. The differences in atmospheric diffusion as a function of wind direction can be especially prominent at sites on the shores of large bodies of water (e.g., lakes and oceans) and in deep river valleys. Knowledge of these directionally-dependent conditions plus consideration of variable Exclusion Area Boundary (EAB) or Low Population Zone (LPZ) distances results in a more realistic evaluation. The Regulatory Guide 1.145 methodology considers the directional variability of diffusion conditions and boundary distances by dividing the boundaries into 16 22.5-degree sectors. Although wind direction data are recorded in 22.5-degree sectors, the direction-independent methodology did not consider this information. Additionally, the direction-independent methodology utilized circular boundaries with a radius equal to the minimum distance of the actual boundary, as opposed to the actual boundary distances. The first part of the parametric study was to examine the effect of the Regulatory Guide 1.145 methodology relative to the direction-independent approach by examining the relationship of the two methods for sector dependency.

TABLE IV-1
Parametric Study Site Characterization

Site	Site Characteristics
1	Midwest (Flat)
2	Southeast (Valley)
3	Southeast (Rolling Hills)
4	Midwest (Flat)
5	East-Central (Valley)
6	South (Coastal)
7	Midwest (Valley)
8	Midwest (Flat)
9	East (Valley)
10	Southeast (Rolling Hills)
11	Southeast (Rolling Hills)
12	Southeast (Rolling Hills)
13	Southeast (Rolling Hills)
14	Northeast (Valley)
15	Southeast (Coastal)
16	Midwest (Coastal)
17	Northeast (Coastal)
18	Southeast (Coastal)
19	Midwest (Coastal)
20	East (Valley)
21	East (Valley)

If atmospheric dispersion conditions (represented by stability and wind speed pairings) and boundary distances are identical in each of 16 22.5-degree wind direction sectors, and if the wind direction frequencies are identical in each of the 16 directions (i.e., 100%/16 or 6.25%), then the calculated direction-independent 5 percent X/Q value (see Section I.B) would be equalled or exceeded about 27 hours in each sector (i.e., 5% x 8760 hours per year/16). Since atmospheric dispersion conditions and wind direction frequencies can vary considerably from sector to sector, the direction-independent 5 percent X/Q value is equalled or exceeded a different number of hours in each sector. The total number of hours for all sectors is still 438 (5% x 8760 hours per year). The likelihood that the direction-independent 5 percent X/Q value would be equalled or exceeded in a specified sector would be less than 5 percent, and usually much less than 5 percent of the total time, averaging 27 hours in each sector (approximately 0.31%).

Table IV-2 shows the distribution of the number of hours per year that X/Q values exceed the direction-independent 5 percent X/Q value in each of 16 sectors for the 18 sites, considering only the variation of diffusion conditions by direction (i.e., a circular boundary). Meander is not included. For example, an analysis of 18 of the sites (Table IV-2) shows that the maximum number of hours per year the direction-independent 5 percent X/Q value was exceeded in a specific direction was 158 hours (158/8760, 1.8% of the total time) at Site 6. The minimum number of hours per year the direction-independent 5 percent X/Q value was exceeded in a specific direction was zero hours also at Site 6. This is indicative of a very high frequency of winds in those sectors with the maximum number of hours and a corresponding low frequency in those sectors with the minimum number of hours. The greater the number of hours the 5 percent value is exceeded, the more frequently it occurs, and consequently, the poorer the diffusion conditions are. Note that the average per sector for each site is about 27 hours and the average around the site is nearly 5% x 8760, or 438 hours.

Table IV-2. Number of Hours the 5 Percent X/Q Value is Equalled or Exceeded in Each Sector Considering a Constant Boundary and No Meander.

	Site																		
Direction	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Average
N	44	31	15	48	19	135	22	41	25	21	18	8	15	17	16	72	31	15	
NNE	39	26	12	3	16	39	10	26	27	28	28	15	12	19	30	23	63	12	
NE	37	25	12	4	27	20	24	38	30	28	36	31	17	15	23	19	77	18	
ENE	32	34	3	40	32	10	14	26	28	41	25	71	20	10	42	21	47	30	
E	31	39	4	28	16	3	14	27	32	16	34	113	29	20	36	18	37	46	
ESE	24	73	5	22	10	0	20	22	25	21	30	88	21	39	44	16	11	43	
SE	27	30	7	23	14	0	12	20	14	31	36	28	28	54	43	15	9	58	
SSE	34	23	13	18	18	0	21	20	26	28	26	13	19	57	39	12	25	92	
S	45	13	17	21	29	0	22	31	24	31	28	11	35	68	21	12	19	43	
SSW	24	15	29	22	40	0	15	23	17	40	25	8	29	79	12	9	13	24	
SW	15	19	101	38	75	1	26	44	17	39	23	7	50	57	17	10	11	10	
WSW	12	13	141	33	71	1	17	21	25	35	20	9	55	11	8	17	8	14	
W	16	15	34	33	43	2	26	21	30	23	29	6	56	3	27	45	12	7	
WNW	20	32	17	34	27	14	50	24	37	22	25	7	27	1	22	59	14	11	
NW	23	22	11	32	17	71	86	31	39	18	22	6	15	4	27	53	20	5	
NNW	28	40	14	28	16	158	49	31	28	21	20	8	14	5	26	54	20	7	
Total	451	450	435	427	470	454	428	446	424	443	425	429	442	459	433	455	417	435	440
Average	28	28	27	27	29	28	27	28	27	28	26	27	28	29	27	28	26	27	27.5

Consideration of a variable EAB or LPZ as a function of direction will always result in equal or lower calculated X/Q values for ground-level releases compared to the direction-independent methodology. This is because circular boundaries were chosen as the minimum boundary distance and any increase in distance to account for the actual boundary will result in lower values since, for ground-level releases, X/Q decreases with distance. To examine this effect, the number of hours the direction-independent 5 percent value is equalled or exceeded by sector with a variable boundary was calculated. This is shown in Table IV-3. For this and other evaluations in the parametric study involving variable boundaries, over-water boundaries at coastal sites were assigned a distance equal to the shortest overland boundary distance, and actual site boundary distances were used to define the EAB boundary over land. Table IV-3 shows that the decrease in the number of hours the direction-independent 5th percentile value is equalled or exceeded (indicative of a larger number of lower X/Q values in the distribution) can be significant for some sectors at some sites. The maximum overall decrease was 281 hours at Site 3. No change occured at Site 14 because the actual boundary was defined as circular. On the average, the decrease was 127 hours around the site and 7.5 hours for a sector.

This portion of the study, then, shows the variability of diffusion conditions by sector (Table IV-2), with some wind directions being associated with poorer diffusion conditions and the expected changes due to the inclusion of a variable boundary (Table IV-3). Both results are reflected in the X/Q value.

2. Effect of Meander

Atmospheric diffusion tests have shown that short-term X/Q values may be reduced substantially due to lateral plume meander. The NRC analysis of these tests has resulted in the development of conservative reduction factors for X/Q values to describe the effect of meander (See Section II). Consideration of meander alone resulted in a decrease in the selected X/Q value by about a factor of two, varying between about 1.5 and 2.5 for the 18 sites. Table IV-4 gives the number of hours that the direction-independent 5 percent X/Q value

Table IV-3. Number of Hours The 5 Percent X/Q Value is Equalled or Exceeded in Each Sector Considering The Actual Exclusion Area Boundaries and No Meander.

	Site																		
Direction	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
N	44	21	15	28	4	135	1	9	15	19	17	6	14	17	15	72	31	15	
NNE	34	21	13	0	5	39	0	10	26	24	21	6	11	19	30	23	63	12	
NE	35	27	10	0	9	20	1	17	27	17	23	17	10	15	23	14	77	11	
ENE	30	34	1	40	9	10	14	8	28	24	22	69	12	10	42	10	47	30	
E	24	38	2	25	6	3	14	9	33	10	33	113	16	20	36	3	37	46	
ESE	21	73	2	20	4	0	17	10	24	24	22	85	5	39	44	4	11	43	
SE	19	7	3	19	8	0	3	14	18	13	25	20	11	54	42	5	6	58	
SSE	29	4	9	15	12	0	7	18	14	10	22	6	6	57	36	10	21	92	
S	41	3	11	17	25	0	9	28	9	11	24	5	13	68	20	7	14	43	
SSW	21	5	3	18	36	0	3	21	8	11	22	4	2	79	12	9	10	17	
SW	6	8	8	14	75	1	9	24	15	14	22	3	6	57	17	10	8	8	
WSW	6	5	34	13	60	1	14	16	4	24	30	5	31	11	8	17	6	12	
W	9	6	18	1	17	0	26	9	7	15	28	3	36	3	26	45	6	6	
WMW	15	12	8	19	10	1	35	9	8	14	24	4	15	1	22	59	11	11	
NW	20	15	4	11	3	6	43	10	6	18	21	4	7	4	26	53	13	6	
NNW	29	27	13	20	4	59	3	4	23	20	19	6	14	5	25	54	20	7	Average
Total	383	306	154	260	287	275	199	216	265	268	375	356	209	459	424	395	381	417	313
Average	24	19	10	16	18	17	12	14	17	17	23	22	13	29	27	25	24	26	20.0

Table IV-4. Number of Hours the 5 Percent X/Q Value is Equalled or Exceeded in Each Sector Considering a Constant Site Boundary and Meander Included.

Direction	Site 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Average
N	16	9	5	16	6	11	9	0	11	4	8	1	2	2	7	12	21	4	
NNE	13	8	5	0	5	2	4	0	14	10	12	2	2	2	16	0	19	4	
NE	14	7	4	0	8	2	12	1	12	10	5	4	3	1	14	8	16	6	
ENE	15	10	1	10	7	2	7	0	14	12	13	8	4	2	19	8	7	13	
E	13	10	1	9	4	0	7	1	11	5	17	12	5	1	16	6	11	21	
ESE	9	21	5	7	2	0	10	0	12	7	16	10	4	5	24	7	5	20	
SE	11	9	2	7	4	0	5	1	9	10	16	4	5	4	23	5	13	27	
SSE	12	7	6	6	4	0	10	0	11	8	11	2	3	7	17	5	13	42	
S	16	4	8	5	9	0	28	1	12	9	10	2	6	5	10	4	12	19	
SSW	8	4	13	5	8	0	7	1	6	12	10	1	5	6	5	6	9	10	
SW	4	6	41	3	16	0	13	4	7	11	8	1	9	6	8	6	8	5	
WSW	4	4	56	8	16	0	8	3	9	10	7	1	8	0	4	8	6	6	
W	5	5	14	4	12	0	13	2	13	6	11	1	8	0	13	15	8	3	
WNW	6	10	7	8	8	0	23	2	11	5	10	1	4	0	11	13	12	5	
NW	8	7	4	3	3	5	46	1	14	5	8	1	3	0	13	12	14	2	
NNW	10	11	6	9	5	15	21	1	9	6	7	1	2	0	12	10	21	2	
Total	164	132	177	100	117	37	223	18	175	130	169	52	73	41	212	125	195	189	129
Average	10	8	11	6	7	2	14	1	11	8	11	3	5	3	13	8	12	12	8.0

is exceeded at each of the 18 sites due to meander alone (i.e., a circular boundary). Consideration of meander significantly decreases the calculated X/Q value. The number of hours the direction-independent 5 percent value was equalled or exceeded decreased from the comparable analysis in Table IV-2 by an average for all sites of 311 hours or 19.5 hours per sector. It is also apparent that the magnitude of the effect of meander is site and direction dependent.

3. Selection of the Sector Probability Level

To consider the variability of atmospheric dispersion conditions and wind direction frequencies among 16 sectors from site to site in a consistent manner, the X/Q value exceeded for a specified fraction of the time in each sector should be considered. Since the direction-independent approach utilizes a constant probability (5 percent) that is equalled or exceeded around the entire site, this can be used as a point of departure for selecting a constant level of probability for considering X/Q values in each of the 16 directional sectors. This would result in the determination of 16 X/Q values (one in each sector) which are exceeded no more than some percentage of the total time in each sector. The highest of these 16 X/Q values can then be selected for determining compliance with 10 CFR Part 100. This procedure ensures that all sites are evaluated on a consistent probabilistic basis.

Because the variable boundary distance concept, like the directional concept, is a conceptual change from the direction-independent methodology, both these changes will have to be considered in the selection of a "percentage of the total time" that will be used to determine the controlling X/Q value in each sector. However, since meander is credit to be given to better represent the physical characteristics of dispersion and not a conceptual change, it is not used for this determination.

To obtain a controlling sector percentile value consistent with the direction-independent 5 percent value for the site, the number of hours the 5 percent X/Q value is exceeded in each of the 16 sectors for 18 of the sites, including variable site boundaries (Table IV-3) was examined. From these data the sector at each site that the direction-independent 5 percent X/Q value was exceeded the greatest number of hours was chosen as the worst sector and plotted in Figure IV-1. Figure IV-1 shows that, on the average (geometric mean), the direction-independent 5 percent X/Q is equalled or exceeded approximately 0.6 percent (about 53 hours) of the total time in the worst sector. Because there is a large spread in the data, it was determined that the 0.5 percentile level (about 44 hours) in the Regulatory Guide 1.145 methodology would be reasonably consistent with the 5 percent value in the direction-independent approach while not implying more refinement in the selection process than what existed. This means the 0.5 percent X/Q value is selected from each of the 16 sectors, and the highest of these (i.e., the critical sector) is used to determine compliance with 10 CFR Part 100.

However, in unusual siting situations it is possible that a X/Q value determined by the Regulatory Guide 1.145 methodology may not be sufficiently conservative. To avoid this, a 5 percent overall site (based on total observations) X/Q value is also calculated considering variable site boundaries and meander. If this X/Q value is greater than the 0.5 percent sector X/Q value, than it is used to represent the diffusion conditions at the site.

4. Overall Impact of the Regulatory Guide 1.145 Methodology

Table IV-5 shows a comparison of X/Q values selected using the direction-independent approach and the complete Regulatory Guide 1.145 methodologies (i.e., with direction dependency, variable boundaries, and meander). For the Regulatory Guide 1.145 approach, the highest X/Q value for all directions, based on the 0.5 percent value, is presented in this table. The Regulatory Guide 1.145 approach produced X/Q values which were about 70% of those produced by the direction-independent approach. For the 21 sites, the magnitude of the decrease ranged from of a factor of 1.1 to a factor of 2.2 with an average decrease of 1.4. At only one site, did the selected X/Q value increase (by about a factor of 1.3).

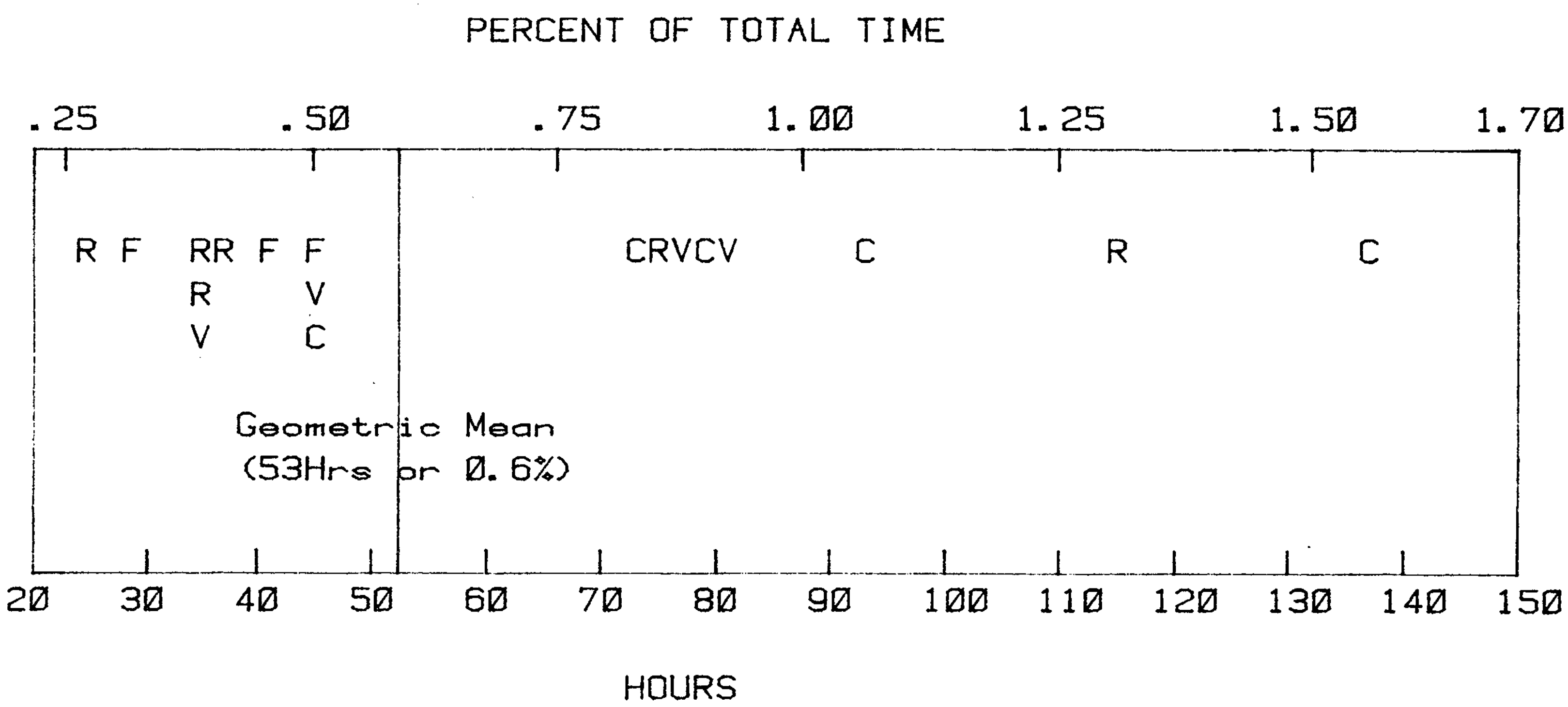

FIGURE IV-1. Number of Hours the 5 Percent Relative Concentration is Exceeded in the Worst Sector Using the R.G.1.145 Methodology With a Variable Site Boundary and No Meander. Data are Plotted as Site Types.

Key	Site Type
C	Coastal
F	Flat
R	Rolling
V	Valley

Table IV-5
Comparison Between the Past and Regulatory Guide 1.145 Methodology

Exclusion Area Boundary

Site	Past Model (5% X/Q)	Regulatory Guide 1.145 Model Critical Sector X/Q	Ratio (Past/R.G. 1.145)
1	4.2 -4*	2.9 -4	1.4
2	1.6 -3	1.4 -3	1.1
3	4.3 -3	2.2 -3	1.9
4	2.6 -4	1.6 -4	1.6
5	1.5 -3	1.2 -3	1.2
6	1.4 -3	1.2 -3	1.2
7	6.2 -3	5.2 -3	1.2
8	1.8 -4	1.3 -4	1.4
9	1.1 -3	6.5 -4	1.7
10	1.2 -3	5.7 -4	2.1
11	2.2 -4	1.8 -4	1.2
12	1.4 -3	1.1 -3	1.3
13	1.4 -3	6.4 -4	2.2
14	9.9 -4	7.1 -4	1.4
15	1.7 -4	1.6 -4	1.1
16	4.2 -4	3.4 -4	1.2
17	9.6 -4	8.7 -4	1.1
18	6.6 -4	8.8 -4	0.7
19	9.6 -4	7.9 -4	1.2
20	8.2 -4	6.1 -4	1.3
21	1.9 -3	1.7 -3	1.1
Average			1.4

*X/Q = 4.2 x 10-4 sec/m3

Table IV-6 presents a comparison of the percent of the time the direction-independent approach and the Regulatory Guide 1.145 approach X/Q values are exceeded at the actual EAB. Note that the X/Q value selected by the Regulatory Guide 1.145 approach for each site is actually exceeded between 0.4 percent and 3.4 percent of the time around the entire site, averaging about 1.8 percent for all 18 sites. For comparison, the direction-independent 5 percent X/Q, calculated at an assumed circular exclusion area boundary, is actually exceeded less than 5 percent of the time around the actual EAB, averaging about 3.6 percent for the 18 sites examined.

5. Conclusions

The Regulatory Guide 1.145 approach permits consideration of the actual variations of atmospheric dispersion conditions and wind frequencies as a function of direction from the plant, as well as allowing for more complete utilization of site shape. This methodology also incorporates the results of recent atmospheric diffusion tests to better define dispersion during low wind speed conditions. The approach is a significant improvement in the evaluation of atmospheric dispersion characteristics at reactor sites. The methodology also allows for a more consistent evaluation from site to site by ensuring that the X/Q value used for evaluating plant design will be equalled or exceeded no more than 0.5 percent of the time (44 hours/year) at any point around the exclusion area boundary for any reactor site.

Table IV-6
Percent of the Time the X/Q Calculated by the Indicated Methodology is Exceeded Over the Actual Exclusion Area Boundary

Site	Past Approach (5% X/Q)	Regulatory Guide 1.145 (0.5% maximum sector)
1	4.4	2.7
2	3.5	1.3
3	1.7	1.7
4	3.0	2.1
5	3.3	1.2
6	3.1	0.4
7	2.3	1.2
8	3.3	1.0
9	3.0	2.4
10	3.0	3.4
11	4.2	2.6
12	4.0	0.9
13	2.4	2.0
14	5.0*	1.8
15	4.8	2.6
16	4.5	1.9
17	4.4	2.2
18	4.8	1.4
Average	3.6	1.8

*Circular Boundary

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16. ABSTRACT *(200 words or less)*

Regulatory Guide 1.145, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants, presents several substantial changes in the previous methodology of atmospheric dispersion analyses described in Regulatory Guides 1.3 and 1.4. This new methodology discussed in Regulatory Guide 1.145 includes, 1) the reduction in estimated ground-level concentrations due to plume meandering during the occurrence of stable atmospheric stability conditions and light wind speeds, and 2) the recognition that atmospheric dispersion conditions are directionally dependent. As a result of these developments, the NRC Meteorology Staff conducted a parametric study to examine the consequences of these changes on previous and future licensing activities. This parametric study was instrumental in the determination of appropriate probability levels for the risk assessment methodology discussed in the guide. The technical basis for the new methodology and the results of the parametric study are documented in this NUREG. This documentation includes the relationship of the new approach to the previous methodology.

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