FNP-0-M-007
February 16, 1981
Revision 2

ALABAMA POWER COMPANY

JOSEPH M. FARLEY NUCLEAR PLANT

FNP-0-M-007

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EMERGENCY DOSE CALCULATIONAL MANUAL
(EDCM)

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Approved:

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Technical Superintendent

Date Approved: 2/18/81

Date of Implementation: 4/1/81

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PREFACE

The automated Class A Dose Calculational Method(DCM) for emergency assessment and dose projection within the plume exposure emergency planning zone (EPZ) will use a segmented plume model. This model will predict plume movement, size and shape by initiating every 15 minutes during effluent release the tracking of a plume segment released from the plant vent stack or other release point as defined by the circumstance of the emergency. Each segment will be tracked by moving its centroid along the mean wind velocity vector. Every fifteen minutes the position of the centroid of each segment, the time of flight, horizontal standard deviation coefficient and vertical standard deviation coefficient will be updated. This will yield position and size of each element. Appropriate corrections for radioactive decay and deposition are applied to these concentrations to obtain accurate dose rates and dose rate predictions at these points. Time of arrival predictions for selected points within the EPZ will be calculated based on current meteorological conditions. The release rate, Ci/sec, will be determined by installed plant monitors and confirmed by a grab sample. Concentration of selected points within the plume will be calculated by applying the appropriate χ/Q equation (considering stability classification, release elevation, building wake effects and real time wind speed) to the release concentration.

The Manual Dose Calculational Method for emergency assessment and dose projection within the plume exposure EPZ will use a continuous point source Gaussian diffusion model. Through use of specific assumptions, the model is simplified to allow purely manual projections and estimates to be made within 15 minutes of the start of an accident and subsequent updates every hour or following any significant change in release rate. This model will predict time averaged plume size, shape and location during effluent release. Time of arrival predictions for selected points within the EPZ will be calculated based on current meteorological conditions. The release rate, Ci/sec, will be determined by installed plant monitors and confirmed by a grab sample. Concentration of selected points within the plume will be calculated by applying the appropriate χ/Q equation (considering stability classification, building wake effects and real time wind speed) to the release concentration.

SECTION I

AUTOMATED CLASS A EMERGENCY

DOSE CALCULATIONAL METHOD

The Automated Emergency Dose Calculational Method described in this section has been developed to meet the requirements of Appendix 2 of NUREG 0654 Rev. 1 for a Class A near real-time, site-specific atmospheric transport and diffusion model.

χ/Q Model

χ/Q (relative concentration) calculations will account for release elevation, building wake effects and existing meteorological conditions. Release locations are: Unit #1 and Unit #2 plant vent stacks, Unit #1 and Unit #2 turbine building vents during primary to secondary leakage, and Unit #1 and Unit #2 steam generator safety and relief valve vents during steam over pressure transients. A single virtual release point (see Figure 8) located on the centerline between Unit 1 and Unit 2 containments is assumed but the distances between the assumed release point and actual release points are not significant (<100m) and do not introduce significant errors at radial distances of interest.

Equations used to estimate χ/Q are based on the general Gaussian plume diffusion equation:

$$\chi(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z\bar{U}} \exp(-0.5(y/\sigma_y)^2)\ \{\exp(-0.5((z-H)/\sigma_z)^2) + \exp(-0.5((z+H)/\sigma_z)^2)\} \quad (1)$$

where,

π = 3.14159

$\chi(x,y,z,H)$ = plume concentration (Ci/m^3)

x = downwind distance from the source (m)

y = crosswind distance from the plume centerline (m)

z = vertical distance from the plume centerline (m)

H = plume centerline height (release height) (m)

$\bar{U}$ = mean wind velocity (m/sec)

σ_y, σ_z = plume dispersion coefficients (m)

Q = release rate (Ci/sec)

When H_e (effective plume height, see BASES) is greater than 2½ times the height of either the Unit #1 or Unit #2 containment building the release will be considered to be an elevated release; the release height (H) will be considered to be equal to H_e and $\bar{U}$ will be obtained at the 46 meter height of the plant meteorological tower. Thus equation (1) will reduce to:

$$\frac{\chi(x,y,z)}{Q} = \frac{Q}{2\pi\ \sigma_y\ \sigma_z\ \bar{U}_{46}} \exp(-0.5\ (y/\sigma_y)^2)\ \{\exp(-0.5((z-H_e)/\sigma_z)^2) + \exp(-0.5((z+H_e)/\sigma_z)^2)\} \quad (2)$$

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where $\bar{U}_{46}$ is the 15 minute average windspeed at 46 meters above plant grade, in m/sec, at the time that the segment leaves the release point and σ_y and σ_z are shown on Figures 1 and 2 (see discussion of σ_y and σ_z calculations under PLUME MODEL). Figure 3 shows plume dispersion based on the Gaussian diffusion model for elevated releases.

For ground level releases, H=z=o and the plume dispersion coefficients must be adjusted for building wake effects. Thus equation (1) is rewritten as:

$$\chi/Q = \frac{1}{\bar{U}_{10}\pi\Sigma_y\Sigma_z} \exp \frac{-y^2}{2\Sigma_y^2} \qquad (3)$$

where

$\bar{U}_{10}$ is the 15 minute average windspeed at 10 meters above plant grade, in m/sec, at the time the segment leaves the release point.

Σ_y horizontal dispersion coefficient corrected for building wake effect = $(\sigma_y^2 + A/2\pi)^{1/2}$

Σ_z = vertical dispersion coefficient corrected for building wake effect = $(\sigma_z^2 + A/2\pi)^{1/2}$

A is the smallest vertical-plane cross-sectional area of the containment building or turbine building, as appropriate according to the downwind sector, in m^2.

The Gaussian diffusion equation with building wake effects has been shown to be conservative (Meteorology and Atomic Energy 1968, pg. 112). The plume tracking methodology proposed, however, reduces this conservatism since the σ_y and σ_z calculations take into account meander caused by changes in the 15 minute average wind directions. The results of this equation are further reduced by radioactive decay and deposition corrections thus minimizing the magnitude of the conservatism. (see discussion of correction factors under DOSE RATE MODEL)

PLUME MODEL

Plume path, dimensions and transit times will be calculated by tracking representative segments released from the source at the start of each 15 minute update interval. At the start of each interval a segment is formed at the assumed release point and at ground elevation or at the effective height (H_e, see BASES) of the release point. At the end of each interval, existing segments are moved to revised locations defined by the following equations:

$$x_{j,k} = x_{j,k-1} + V_{x,k}\,\Delta T \tag{4}$$

$$y_{j,k} = y_{j,k-1} + V_{y,k}\,\Delta T \tag{5}$$

where

$x_{j,k}$ = x coordinate of segment j at end of interval k

$x_{j,k-1}$ = x coordinate of segment j at start of interval k

$V_{x,k}$ = x component of 15 minute average wind velocity prior to the end of interval k

ΔT = time duration of interval k = 15 minutes

$y_{j,k}$ = y coordinate of segment j at end of interval k

$y_{j,k-1}$ = y coordinate of segment j at the start of interval k

$V_{y,k}$ = y component of 15 minute average wind velocity prior to the end of interval k

The last measurable wind direction is used to estimate current wind direction and wind velocity is assumed to be 0.5 meters per second when indicated velocity is less than the minimum starting speed for the vane or anemometer (0.5 meters/sec).

Segments are tracked until they move outside the EPZ. Plume dimensions at the location of each segment are calculated based on the linear distance traveled by each segment, the atmospheric stability classification, and equations which reproduce the correlations shown in Figure 1 (σ_y vs Distance

From Source) and Figure 2 (σ_z vs Distance From Source). The correlations used to calculate σ_y and σ_z will be in the form:

$$\text{Log } \sigma = C_1 + C_2 \text{ Log} x + C_3 (\text{Log } x)^2 \tag{6}$$

When using these correlations the "distance from source" value (x) used for segment j at the end of interval k is defined as:

$$d^y_{j,k} = D^y_{j,k-1} + [(V_{x,k}\Delta T)^2 + (V_{y,k}\,\Delta T)^2]^{1/2} \tag{7}$$

where $D^y_{j,k-1}$ is the virtual distance from the source necessary to obtain the σ_y existing at the start interval k using the σ_y curve for the stability class at the end of interval k, i.e.,

$$D^y_{j,k-1} = C^y_1 + C^y_2 \text{ Log } \sigma_{yj,k-1} + C^y_3 (\log \sigma_{y\,j,k-1})^2 \tag{8}$$

C^y_1, C^y_2 and C^y_3 are polynomial coefficients reproducing the curves shown in Figure 1 in the form Log x = $f(\sigma_y)$

and as

$$d^z_{j,k} = D^z_{j,k-1} + [(V_{x,k}\,\Delta T)^2 + (V_{y,k}\,\Delta T)^2]^{1/2} \tag{9}$$

where $D^z_{j,k-1}$ is the virtual distance from the source necessary to obtain the σ_z existing at the start of interval k using the σ_z curve for the stability class at the end of interval k, i.e.,

$$D^z_{j,k-1} = C^z_1 + C^z_2 \text{ Log } \sigma_{z\,j,k-1} + C^z_3 (\text{Log } \sigma_{z\,j,k-1})^2 \tag{10}$$

C^z_1, C^z_2 and C^z_3 are polynomial coefficients reproducing the curves shown in Figure 2 in the form Log x = $f(\sigma_z)$

Note that unless the stability class changes during interval k,

$$D^{y}_{j,\,k-1} = d^{y}_{j,\,k-1} \text{ and } D^{z}_{j,k-1} = d^{z}_{j,k-1} .$$

If the stability class does not change following segment release, d^y and d^z are both equal to the distance traveled by the parcel. If the stability class does change during interval k, the segment is diffused from its size at the start of interval k using the new stability class without creating a discontinuity in the plume.

Transit times are calculated using plume path, dimensions and average wind velocity. Time of plume arrival at selected points is predicted based on current plume path, dimensions and average wind velocity.

Real time plume tracking will be performed using time intervals of 15 minutes.

Predictions of future plume characteristics will be made using existing plume characteristics, existing meteorological conditions averaged over an interval $\geq$15 minutes and appropriately selected time interval(s).

The plume centerline is defined by line segments connecting the centroid coordinates of each segment to the following segment and, in the case of the last segment released, to the release point. The width of the plume at each segment will be defined as $4.28\sigma_y$ ($4.28\Sigma_y$ for ground level releases) (the width corresponding to 90% of a normal distribution). The outer dimension of the plume will then be defined by tangential lines connecting the arc of each segment (defined by the segment centroid location and a radius of $2.14\sigma_y$ ($2.14\Sigma_y$ for ground level releases)) and the arc of the following segment. If the first segment released is inside the EPZ, the leading edge will be defined by the arc of the first segment. For a constant source term, the peak will be the centroid of the first segment. If the source term increases during the event, the peak is then redefined as the centroid of the first segment released with the increased source term. Thus the peak is the first maximum of a series of discrete points. Receptor points are fixed radially at the site boundary and at 1, 2, 3, 5, 7 and 10 miles. They are variable in azimuth, which is determined by current wind direction and current segment locations. For a current wind direction receptor points are (r, θ) where r is fixed as above and the θ values indicate the azimuth at which each segment will cross the arc defined by r. Prespecified confirmatory points are included for use when the plume path is within 22½° of the point (see Figure 4). Arrival time and dose rate are calculated for the centroid of each segment and the segment representing peak dose rate is indicated. See Figure 5 for a graphical presentation of plume tracking and definition.

The following plume data will be output for real time plume tracking and future plume characteristic results:

1. Plume position
2. Plume dimensions
3. Location of peak relative concentration
4. Arrival time of plume
5. Arrival time of peak relative concentration
6. Magnitude of peak relative concentration
7. The relative concentrations at each segment
8. The arrival times of each segment at the specified arcs.

The output format is shown in Figures 6 and 7.

DOSE RATE MODEL

Once relative concentrations are calculated and the effluent concentration has been determined, via plant monitors or grab sample analysis, dose rates (predictive or assessive) for each segment of the plume will be calculated.

The gamma dose rate from a semi-infinite cloud is:

$$\gamma D = \sum_{i=1}^{N} M_{\gamma i} \, (\chi/Q_{\gamma}) \, Q_{\gamma i} \tag{11}$$

where,

γD = the gamma dose rate (mRad/hr)

N = number of isotopes in release contributing to gamma dose rate

$M_{\gamma i}$ = γ dose factor for the ith isotope (mRad/hr)/(μCi/m^3)

$Q_{\gamma i}$ = the actual effluent release rate of radionuclide i in μCi/sec

(χ/Q_{γ}) = dispersion coefficient in sec/m^3

and similarly the organ dose rate is

$$_{\tau}D = \sum_{i=1}^{N} R_{\tau i} \, (\chi/Q_{\tau}) \, Q_{\tau i} \tag{12}$$

where

$_{\tau}D$ = the cumulative dose rate from gaseous effluents to organ τ

N = number of isotopes in release contributing to the organ dose rate

$R_{\tau i}$ = dose factor for i^{th} isotope

(χ/Q_{τ}) = dispersion coefficient in sec/m^3

$Q_{\tau i}$ = release rate for i^{th} isotope in μCi/sec

Three correction factors are applied to equations (11) and (12); they are:

1. Correction factor for radioactive decay (R) enroute:

$$\left(\frac{Q_{xi}}{Q_{oi}}\right)_R = \exp \quad -\left[(\lambda_i)\ T\right] \tag{13}$$

where:

Q_{oi} = release rate at release source for the i^{th} isotope

Q_{xi} = effective release rate for distance x from release source for the i^{th} isotope.

λ_i = decay constant for i^{th} isotope in cloud

T = Travel time of segment to point where χ/Q is assessed (x)

This correction factor is applied to only those isotopes whose half-life is significantly short relative to the time that a segment would normally remain in the EPZ.

2. Correction factor for deposition (D) enroute:

$$\left(\frac{Q_{xi}}{Q_{oi}}\right)_D = \exp \quad -\left[\left(\frac{2}{\pi}\right)^{1/2} \left(\frac{V_d}{\bar{u}}\right) \int_0^x \frac{\exp -(H_e{}^2/2\sigma_z{}^2)}{\sigma_z}\ dx\right] \tag{14}$$

where

Q_{oi} = release rate at release source for the i^{th} isotope

Q_{xi} = effective release rate for distance x from release source for the i^{th} isotope.

V_d = deposition velocity = 0.01 m/sec

$\bar{u}$ = mean wind speed during plume travel to x, m/sec

H_e = release height, m

σ_z = vertical standard deviation of material in the plume, m

x = linear distance traveled from release point, m

This correction factor is applied only for iodine isotopes since deposition for other isotopes is negligible.

3. Correction factor for air:

$\frac{\rho_o}{\rho}$ = ratio of density of air at STP to density of air at the receptor location. This will be assumed to be 1 at all times.

Thus equation (11) for the gamma dose rate becomes

$$_{\gamma}D = \sum_{i=1}^{N} M_{\gamma i} \; (\chi/Q_{\gamma}) \; (Q_{\gamma i}) \left(\frac{Q_{xi}}{Q_{oi}}\right)_D \left(\frac{Q_{xi}}{Q_{oi}}\right)_R \qquad (15)$$

and similarly the organ dose rate (equation (12)) becomes

$$_{\tau}D = \sum_{i=1}^{N} R_{\tau i} \; (\chi/Q_{\tau}) \; (Q_{\tau i}) \left(\frac{Q_{xi}}{Q_{oi}}\right)_D \left(\frac{Q_{xi}}{Q_{oi}}\right)_R \qquad (16)$$

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PERFORMANCE

The Class A dose calculational method will have two functional modes of operation. The first mode requires little operator input. Data for this mode is taken from stored tables and current monitor inputs. Execution of the code will be initiated by the operator when a high level is exhibited by radiation monitors at the defined release points. Initial estimates and projections will be based on predefined correlations between detector values and source concentration assuming a source isotopic composition corresponding to 1% fuel failure. Using current 15 minute average meteorological data, the plume arrival time at the site boundary and at 1, 2, 3, 5, 7 and 10 mile radius is calculated. The (X/Q)'s are calculated along the plume path at these points. The dose rates at the selected intervals are then calculated.

At the direction of the Emergency Director, samples will be taken initially and at any subsequent time when a change in source isotopic composition is suspected and the correlations used by the release point monitor(s) will be updated to reflect the true source composition.

Output will be hourly or upon demand and will include current plume location and dimensions, current receptor dose rates, predicted arrival time of each segment at each arc boundary and predicted dose rates. The segment representing peak dose rate is indicated.

This same output for an operator entered wind direction can be obtained on demand.

Predictions of future plume shape and dimensions at a specified future time using either current average wind direction or an operator entered wind direction may be obtained on demand.

The second mode of operation allows manual data entry. Manual entry of data is required only in the event that portions of the automatic data aquisition system is inoperable.

All automatic projections are based on the assumption that current meteorological conditions will continue. This assumption should be valid for the projection time interval involved in Class A model requirements.

LIMITATIONS

The Class A DCM is limited in the following manner:

1. The χ/Q predictions are based on theoretical calculations tempered with corrective factors which are in turn based on empirical data. The values obtained represent a time averaged χ/Q. Values at a point within the plume boundary may be significantly higher or lower than the predicted value for short periods of time.

2. All meteorological data is based on statistical averages rather than a continuous mean. Therefore all calculations based on meteorological data are subject to the statistical deviations of finite incremental time periods.

3. The plume path is updated with average data. Therefore the actual path of the plume may be longer than is estimated. The magnitude of this error is minimized by using 15 minute averages. Meander caused by long term wind variation is accounted for by the use of linear distance traveled rather than distance from the source.

SECTION II

MANUAL EMERGENCY DOSE CALCULATIONAL METHOD

The Manual Emergency Dose Calculational Method described in this section has been developed to meet the requirement of NUREG 0654 Rev. 1 item II.I.6, ("Each licensee shall establish the methodology for determining the release rate/projected doses if the instrumentation used for assessment are off-scale or inoperable") as it applies to inoperable hardware used by the automated emergency DCM method. In accordance with the requirements of NUREG 0654, Rev. 1, Appendix 2, Annex 1, item (3)(ii), that portion of it dealing with the transport and diffusion of gaseous effluents has been developed to be consistent with the characteristics of the Class A Model described in Section I. This manual model will be used until the Class A model is implemented (no later than 7/1/82) and in the event the Class A model is inoperable subsequent to its implementation.

χ/Q Model

χ/Q (relative concentration) calculations are based on the general Gaussian plume diffusion equation:

$$\chi(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z \bar{U}} \exp\left(-0.5(y/\sigma_y)^2\right)\{\exp(-0.5((z-H)/\sigma_z)^2) + \exp(-0.5((z+H)/\sigma_z)^2)\} \quad (1)$$

where the terms are defined on page 2.

For manual calculations, all releases are assumed to be ground level releases. This simplifies the equation for χ/Q at the plume centerline to

$$\frac{\chi}{Q} = \frac{\exp -\frac{1}{2}(y/\Sigma_y)^2}{\bar{U}_{10}\pi\Sigma_y\Sigma_z} \quad (17)$$

where the terms are as defined on page 3. Since the ratio of χ/Q at two fixed distances is independent of wind velocity ($\bar{U}_{10}$ and π cancel out) use of this equation is simplified by providing plots of χ/Q for a radial distance corresponding to the site boundary, plots of $\{(\chi/Q)_x/(\chi/Q)_{\text{site boundary}}\}$ versus downwind distance and plots of $1/(2\Sigma_y^2)$ versus downwind distance for each stability class (See Figures 15A-15G and 16A-G). To allow this, the following simplifying assumptions are made:

1. All releases are assumed to originate at the midpoint between the Unit 1 and Unit 2 centerlines. This point is <100m from the farthest actual release point (the turbine building vent stacks) and ~30m from the most probable release point (plant vent stacks) and therefore introduces minimal error at radial distances of interest (see Figure 8).

2. The area term used for calculating building wake effect is set equal to the height of the containment squared ($(40m)^2$) regardless of wind direction. This is a good approximation since the arrangement of building results in a wake effect for the majority of wind directions and the difference between actual area and assumed area will introduce negligible error at radial distances of interest.

3. The site boundary is assumed to be defined by an arc of radius equal to the minimum distance to the boundary.

4. Σ_z is limited to $\leq$ 1000m to account for possible limited mixing heights.

PLUME MODEL

Plume location is determined by use of an overlay oriented with the centerline in the average downwind direction. One overlay is provided for each stability class. Plume width lines corresponding to 10%, 1%, 0.1%, 0.01% and 0.001% of the centerline χ/Q at the site boundary are provided so that plume dimensions may be defined based on dose rate at the site boundary. Examples are provided in Figures 9A through 9G.

In the event that the stability class changes, the overlay is changed to that corresponding to the new stability class.

Development and use of these overlays are based on the same simplifying assumptions as listed for the χ/Q Model.

Plume arrival time is obtained by use of a plot of travel time versus wind speed for each radial distance of interest (site boundary and each mile arc at which dose rate exceeds 1 mRem/hr up to the 10 mile arc). Plume position and arrival time calculations will be based on the time at which the release started or the time at which the source term exhibited a major change. Plume travel is assumed to be in a single straight line defined by the assumed source location and the last 15 minute average wind direction.

DOSE RATE MODEL

Gamma dose rate and iodine dose rate at the site boundary are calculated by multiplying the estimated/projected χ/Q value (sec/m^3) times the effluent concentration (μCi/ml) times the effluent flow rate (cfm) times a dose conversion factor defined by

$$_{\gamma}D = \frac{1}{(34.33)(60)} \sum_{i=1}^{N} M_{\gamma i} \, Q'_{\gamma i} \qquad (18)$$

where $_{\gamma}D$ = the gamma dose rate conversion factor

$M_{\gamma i}$ = γ dose factor for isotope i

$Q'_{\gamma i}$ = the relative abundance of isotope i

$= Q_{\gamma i} / \sum_{i=1}^{N} Q_{\gamma i}$

where $Q_{\gamma i}$ = the curies of isotope i in the effluent

$\frac{1}{(34.33)(60)}$ = units conversion factor $\frac{(m^3 - min)}{(ft^3 - sec)}$

and

$$_{\tau}D = \frac{1}{(34.33)(60)} \sum_{i=1}^{M} R_i \, Q'_{\tau i} \qquad (19)$$

where $_{\tau}D$ = thyroid dose rate conversion factor

R_i = thyroid dose factor for iodine isotope i based on infant breathing rate.

$Q'_{\tau i}$ = the relative abundance of iodine isotope i

$= Q_{\tau i} / \sum_{i=1}^{N} Q_{\gamma i}$ for use with gross effluent concentration

$= Q_{\tau i} / \sum_{i=1}^{N} Q_{\tau i}$ for use with Iodine effluent concentration

where $Q_{\tau i}$ = the curies of iodine isotope i in the effluent

Dose rates at other ... ions (x, y) can be calculated as:

$$\text{Dose Rate} = \begin{bmatrix} \text{site boundary} \\ \text{dose rate} \end{bmatrix} \begin{bmatrix} \frac{(\chi/Q)_x}{(\chi/Q)_{\text{site boundary}}} \end{bmatrix} \begin{bmatrix} \exp\left(-\left(\frac{1}{2\Sigma_y^2} \right)_x (y^2) \right) \end{bmatrix} \qquad (20)$$

where $\{(\chi/Q)_x / (\chi/Q)_{\text{site boundary}}\}$ and $(1/[2\Sigma_y^2])_x$ are obtained from Figures 16A-G.

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To allow rapid initial dose assessment and prediction, the release is initially assumed to consist of a fixed set of isotopes whose relative abundance is determined by the time since reactor shutdown (see BASES). The dose conversion factors for γ dose and thyroid dose are provided graphically as a function of time since shutdown.

Figure 13 shows dose conversion factors for converting gross effluent concentration of filtered and unfiltered effluent to iodine and γ dose rates. Figure 14 shows dose conversion factors for converting effluent concentrations in terms of noble gas only or iodine only to γ and iodine dose rates, respectively.

Dose conversion factors are revised as necessary following sampling and analysis.

To allow timely manual dose rate projections, isotope decay and deposition during plume travel are neglected. This is done by setting their respective factors equal to one.

PERFORMANCE

At the onset of an emergency condition as indicated by high readings on effluent monitors if the Class A computer model is not operable the Manual DCM will be performed as follows:

1. Atmospheric stability class is determined from the lapse rate ($\Delta T/\Delta z$) shown by the plant meteorological instrumentation or, if that instrumentation is inoperable, by use of Turner's Algorithm (see BASES), wind speed and % cloud cover and ceiling height obtained from the Dothan Airport. Wind direction and wind speed are read from plant instrumentation or, if plant instrumentation is inoperable, they are obtained from the Dothan Airport.

2. Release concentration ($\mu Ci/ml$) is determined using installed instrumentation or, if such equipment is offscale or inoperable, by use of portable monitors as described in FNP-0-RCP-25.

3. Release flow rate (cfm) is determined based on the release source:

    a. For stack release - 75,000 cfm per Aux Bldg exhaust fan plus (in the event of a fuel handling accident if RE-025 trips) 4000 cfm.

    b. For steam jet air ejector/Turbine Building release - 1050 cfm.

    c. For steam generator (S/G) atmospheric reliefs and safeties - determined graphically based on S/G pressure.

4. χ/Q (sec/m^3) is obtained for the site boundary using a plot of χ/Q versus wind speed for the existing stability class.

5. Site boundary dose rate is estimated using the χ/Q, release concentration, effluent flow rate and estimated dose factors (see DOSE MODEL).

6. If the site boundary dose rate is $\geq$ 1 mRem/hr:

    a. The dose rate is multiplied by estimated repair time to predict estimated integrated dose at the plume centerline for the site boundary.

    b. The plume dimension overlay corresponding to the existing stability class is placed over the 10 mile EPZ map and the centerline oriented in the downwind direction. The isodose lines on the overlay are used in conjunction with the dose rate and integrated dose calculated for the site boundary to evaluate predicted dose rates and integrated dose within the 10 mile EPZ.

c. Arrival times at the site boundary and at mile arcs out to 10 miles or to a dose rate of $\leq$ 1 mRem/hr are predicted using a plot of Travel Time versus Wind Speed and time elapsed since the release began.

7. Steps 1-6 are repeated as necessary every hour, following any significant change in release rate or if sample results indicate a significant change in dose factors, until the release is terminated. If average direction changes, the overlay plume boundary is marked to indicate exposed area and the plume centerline is then reoriented to the new downwind direction.

8. As a long term action field measurement results are utilized to verify prediction accuracy. Equation 20 is used to calculate estimated dose rates for the field measurement location. Plume centerline dose rates are calculated from field measurement results as:

$$(\text{Dose Rate})_x = \frac{(\text{Dose Rate})_{x,y}}{\exp\left[-\left(\frac{1}{2\Sigma_y^2}\right)_x (y^2)\right]}$$

where $(\text{Dose Rate})_x$ = centerline dose rate at downwind distance x

$(\text{Dose Rate})_{x,y}$ = dose rate at measurement point at downwind distance x and off-centerline distance y

$1/[2\Sigma_y^2]_x$ = value taken from figures 16A through G for distance x

y = off-center distance, m

LIMITATIONS

The Manual Emergency DCM is limited in the following manner

1. The χ/Q predictions are based on theoretical calculations. The values obtained represent the time averaged χ/Q. Values at a point within the plume boundary may be significantly higher or lower than the predicted value for short periods of time.

2. All meteorological data is based on statistical averages rather than a continuous mean. Therefore all calculations based on meteorological data are subject to the statistical deviations of finite incremental time periods.

3. The plume path is updated with average data. Therefore the actual path of the plume may be longer than is estimated. Such an occurrance may result in the predicted χ/Q value and average dose rate being higher than the time average values observed in the plume.

4. All releases are assumed to be at ground elevation. Plant Vent Stack releases during periods of very low wind velocity may actually be elevated or mixed-mode releases (See Figures 10A through 10G). Under these conditions the dose rates may be over predicted. This fact should be considered when recommending protective actions and when evaluating field monitoring data.

5. The predicted χ/Q, dose rate and integrated dose values in the outer portions of the 10 mile EPZ will be high during stability classes A and B when actual effective mixing height is greater than ~1250 m.

SECTION III

BASES FOR CLASS A DCM AND MANUAL EMERGENCY DCM

BASES

The equations in this document represent meteorological conditions surrounding the Farley Plant site which has no unusual geophysical constraints affecting the wind and weather. There are no mountains, canyons, troughs or large bodies of water within the emergency planning zone (EPZ). The terrain is smoothly varying, intermittently forrested and cleared for farming. Thus the meteorological parameters measured at the site meteorological tower are representative of EPZ parameters.

The following site specific factors have been determined.

1. The turbine building steam jet air ejector vents and the main steam relief valve vents are considered ground level release points at all times. The plant vent stacks may be either elevated or ground level. For ground level releases equations (3) and (17) contain wake effects, considering the cross-sectional area A of surrounding structures. Reference: Stuart, G.E., et al., "Rancho Seco Building Wake Effects on Atmospheric Diffusion," NOAA Technical Memorandum ERL ARL-69, Air Resources Laboratory, Idaho Falls, Idaho, November 1977, and Slade, D.H., "Meterology and Atomic Energy - 1968," p. 112.

2. Since the height of each plant vent stack is only slightly more than the surrounding buildings the release mode is always considered ground level in the Manual DCM Model and the automated Class A Model assumes elevated releases to occur only when H_e is more than 2½ times the height of the reactor building (40 meters). This occurs only during periods of low wind velocity (See Figures 10A through 10G).

3. All plume diffusion equations for ground level releases use wind speed and direction data taken at 10 meters above terrain elevation. The 10 meter level is considered representative of the depth through which the plume is mixed with building wake effects.

4. The stability class for the various calculations will be derived from $\Delta T/\Delta z$ in accordance with Table 1 of Reg. Guide 1.23 except for the case where plant meteorological data is not available in which case wind speed, wind direction, % cloud cover and ceiling height will be obtained through the local weather service and the stability class will be determined using the Turner Algorithm described below (Reference: Turner Bruce D., "A

Diffusion Model for Urban Areas," Journal of Applied Meteorology, Vol. 3, pg. 90 & 91, Feb. 1964). This is a compensatory action in accordance with NUREG 0654. Following installation of a backup meteorological tower, wind speed, wind direction, σ_θ and σ_ϕ will be obtained from the backup instrumentation. This manual will be revised to provide correlations between σ_θ and σ_ϕ and atmospheric stability class.

The Turner Algorithm for atmospheric stability determines stability class (A thru G) using wind speed and net radiation index based on % cloud cover, time of day, ceiling height and solar altitude angle.

The net radiation index used with wind speed to obtain Turner's stability class is determined by the following procedure:

A) If the total cloud cover is 10/10 and the ceiling height is less than 7,000 feet, use net radiation index equal to 0 (whether day or night).

B) For nighttime (night is defined as the period from one hour before sunset to one hour after sunrise):

   (1) If total cloud cover is ≤4/10, use net radiation index equal to -2.

   (2) If total cloud cover is >4/10, use net radiation index equal to -1.

C) For daytime:

   (1) Determine the insolation class number (see next paragraph).

   (2) If total cloud cover is ≤5/10, use the net radiation index in Figure 11 corresponding to the insolation class number.

   (3) If cloud cover is >5/10, modify the insolation class number by following these six steps:

      a.) If ceiling height is <7,000 ft., subtract 2.

      b.) If ceiling height is ≥7,000 ft. but <16,000 ft., subtract 1.

c.) If total cloud cover equals 10/10, subtract 1. (This will only apply to ceiling heights $\geq$7,000 ft. since cases with 10/10 coverage below 7,000 ft. are considered in item 1 above).

d.) If insolation class number has not been modified by steps (1), (2), or (3) above, assume modified class number equal to insolation class number.

e.) If modified isolation class number is less than 1, let it equal 1.

f.) Use the net radiation index in Figure 11 corresponding to the modified class number.

The solar altitude angle for FNP is estimated using the equation

$$\alpha = \arcsin \left(\sin \delta \sin \phi + \cos \left(\left(\frac{H-12}{12}\right)\pi\right) \cos \delta \cos \phi\right) \quad (21)$$

where ϕ = station latitude ($\cong$ 31.2°)

H = hour of day (24 hour clock) and

$$\delta = \arctan \left\{-\tan (23.5°) \cos\left(\frac{2\pi(N+10)}{365}\right)\right\} \quad (22)$$

where N = number of days from the beginning of the year

Insolation class number is then assigned as:

Solar Altitude Angle	Insolation	Insolation Class Number
$60° < \alpha$	Strong	4
$35° < \alpha \leq 60°$	Moderate	3
$15° < \alpha \leq 35°$	Slight	2
$\alpha \leq 15°$	Weak	1

For use with the Manual DCM, a plot has been developed from equation (20): insolation class number based on time of day and month of the year (Figure 12).

5. Dose conversion factors are obtained by assuming that the source is composed of the most significant isotope contributors that can escape from failed fuel in the reactor core following normal power operation and then become airborne.* The initial concentration of each isotope in containment following a loss of coolant accident is calculated as:

$$C = \frac{(NI)(EF)(FF)}{V} \tag{23}$$

where NI = core inventory
EF = escape fraction
FF = failed fuel fraction
V = containment volume

Relative concentrations $(C_i / \sum_{i=1}^{N} C_i)$ of the most significant dose contributors are calculated. The relative concentrations of iodine isotopes are reduced by 95% in anticipation of ESF charcoal filter I_2 removal prior to release and the resulting new relative concentrations calculated.

For FNP, the following relative concentrations are assumed for a LOCA immediately following normal operation.

Isotope	Relative Concentrations <u>Without</u> Filtering	Relative Concentrations <u>with</u> Filtering
Kr-85	**1.19E-3	1.67E-3
Kr-85m	5.14E-2	7.22E-2
Kr-87	1.00E-1	1.40E-1
Kr-88	1.21E-1	1.70E-1
I-131	3.59E-2	2.53E-3
I-132	5.14E-2	3.61E-3
I-133	7.00E-2	4.91E-3
I-134	7.94E-2	5.57E-3
I-135	6.54E-2	4.59E-3
Xe-133	3.51E-1	4.93E-1
Xe-135	7.25E-2	1.02E-1

**1.19E-3 = 1.19×10^{-3}

The relative concentrations are recalculated for various times following shutdown to account for half life differences. The resulting relative concentrations versus time are used to calculate Whole Body and Thyroid dose conversion factors as a function of time since shutdown.

*Reference: Radiation Analysis Design Manual, Westinghouse 312 Plant, Section 5.

6. σ_y will be derived from the equations producing the graphs in Fig. 1, Lateral diffusion, σ_y vs. downwind distance from source for Pasquill's turbulence types. Reference: Slade, D.H., "Meteorology and Atmoic Energy - 1968," p. 102.

7. σ_z will be derived from the equations producing the graphs in Figure 2, Vertical diffusion, σ_z vs. downwind distance from source for Pasquill's turbulence types. Reference: Slade, D.H., "Meteorology and Atomic Energy - 1968," p. 103.

The effective plume height, H_e, (used in the automated Class A model only) is defined as follows:

$$H_e = h_s + h_{pr} - h_g - c \text{ where} \tag{24}$$

h_s is the physical height of the release point (height of stack above the base) in meters,

h_{pr} is the height of the plume rise, based on Briggs Jet equation, in meters,

h_g is the maximum height of terrain (relative to plant grade) between the release point and the receptor in meters,

c is the correction for low relative exit velocity, from Regulatory Guide 1.111. If ω_o is $\geq 1.5\ \bar{U}_e$, then c = o. Otherwise c is calculated as:

$$c = 3(1.5 - \omega_o/\bar{U}_e)d \text{ where} \tag{25}$$

d is the effective stack diameter = 1.8 meters,

$\bar{U}_e$ is the average windspeed determined during the time period Δt at the 46 meter meteorology tower elevation in m/sec,

ω_o is the vertical effluent velocity in m/sec.

The Briggs Jet equation is defined as follows:

$$h_{pr} = 1.44\ d \left(\frac{\omega_o}{\bar{U}_e}\right)^{2/3} \left(\frac{x}{d}\right)^{1/2} \tag{26}$$

subject to the limits

$$h_{pr} \leq 3.0 \left(\frac{\omega_o}{\bar{U}_e}\right) d \tag{27}$$

$$h_{pr} \leq 1.5 \left(\frac{F_m}{\bar{U}_e}\right)^{1/3} \left(S\right)^{-1/6} \tag{28}$$

where:

d = effective plant stack diameter = 1.8 m

x = linear distance traveled by segment centroid

$$F_m = \left(\frac{\rho_o}{\rho}\right) \left(\omega_o\right)^2 \left(\frac{d}{2}\right)^2 \tag{29}$$

$\frac{\rho_o}{\rho}$ = ratio of ambient air density to effluent air density, 1

S = stability parameter (sec^{-2})

$$= \left(\frac{9.81 m/sec^2}{T}\right) \left(\frac{\Delta T}{\Delta z} + 9.8 \times 10^{-3}\ {}^0K/m\right) \tag{30}$$

T = ambient air temperature, ^0K

ΔT = differential temperature between upper and lower elevations, ^0K

Δz = vertical displacement between upper and lower temperature sensors (m). This distance is normally 51m but will be 20.5 m during sensor calibration

In the event that $\Delta T/\Delta z$ is not available from plant instrumentation it is approximated based on the stability class determined from alternate stability indicators.

9.81 m/sec^2 = acceleration due to gravity near the surface of the earth.

$9.8 \times 10^{-3}\ {}^0K/m$ = adiabatic lapse rate.

V_d, the deposition velocity used in equation (14) is set equal to 0.01.

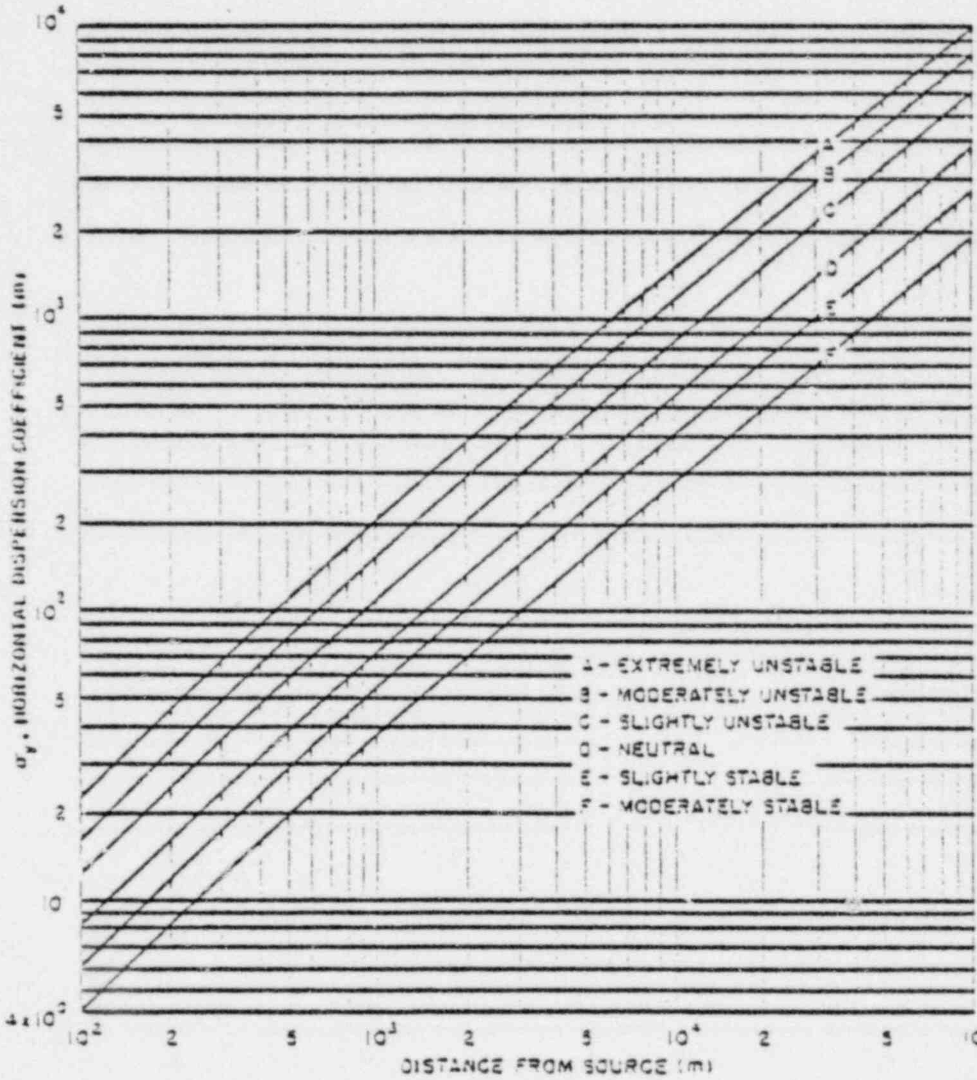


Fig. 1 - Lateral diffusion, σ_y, vs. downwind distance from source for Pasquill's turbulence types.

$$\sigma_y(G) = \frac{2}{3}\sigma_y(F)$$

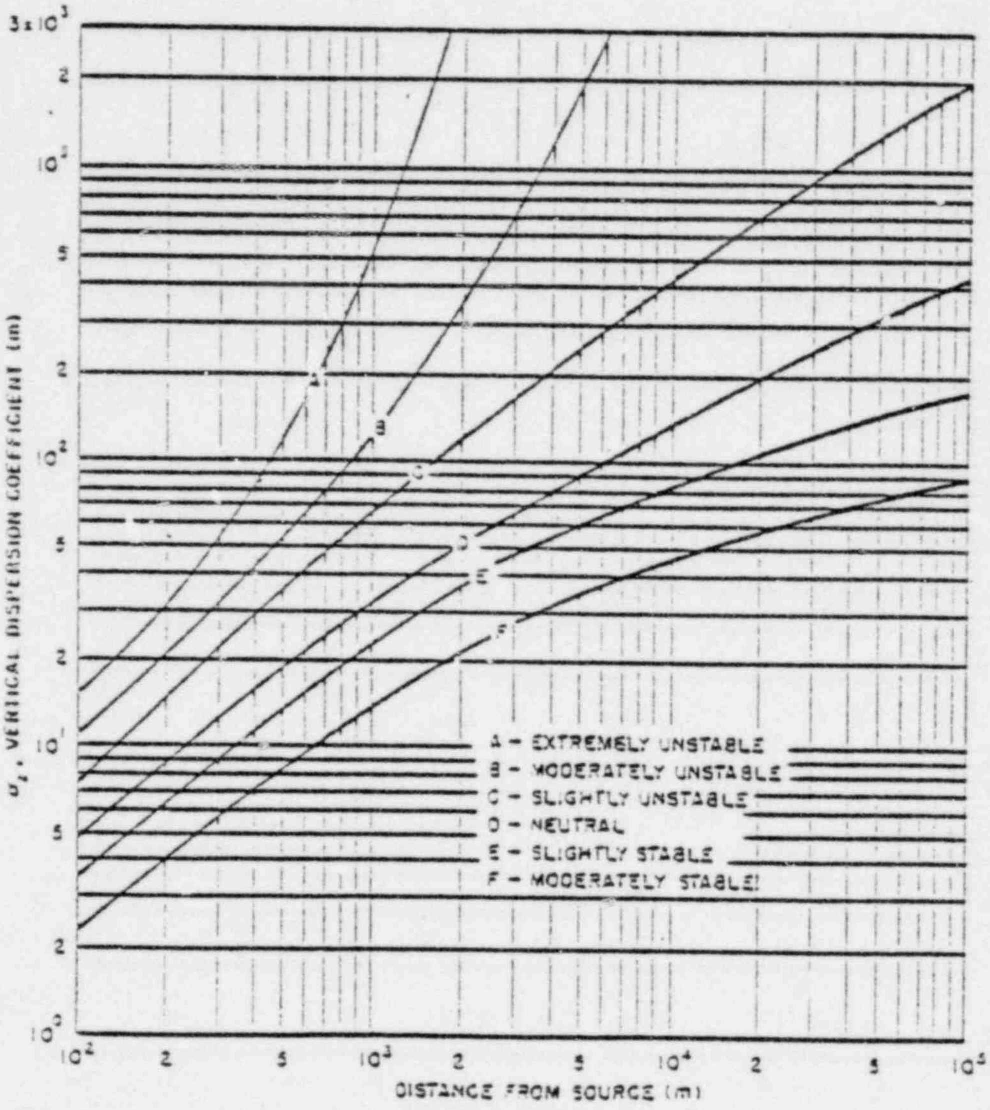


Fig. 2—Vertical diffusion, σ_z, vs. downwind distance from source for Pasquill's turbulence types.

$$\sigma_z(G) = \frac{3}{5}\sigma_z(F)$$

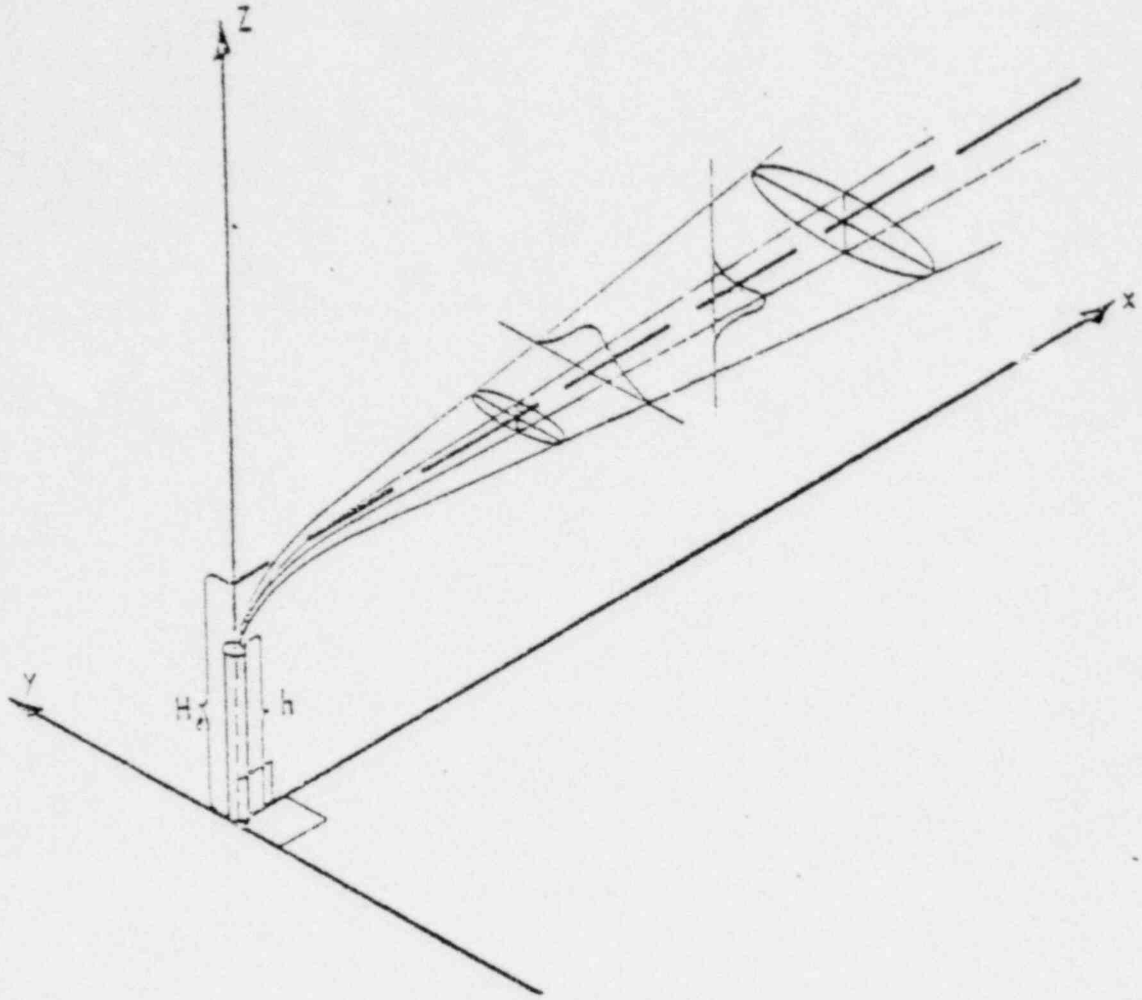
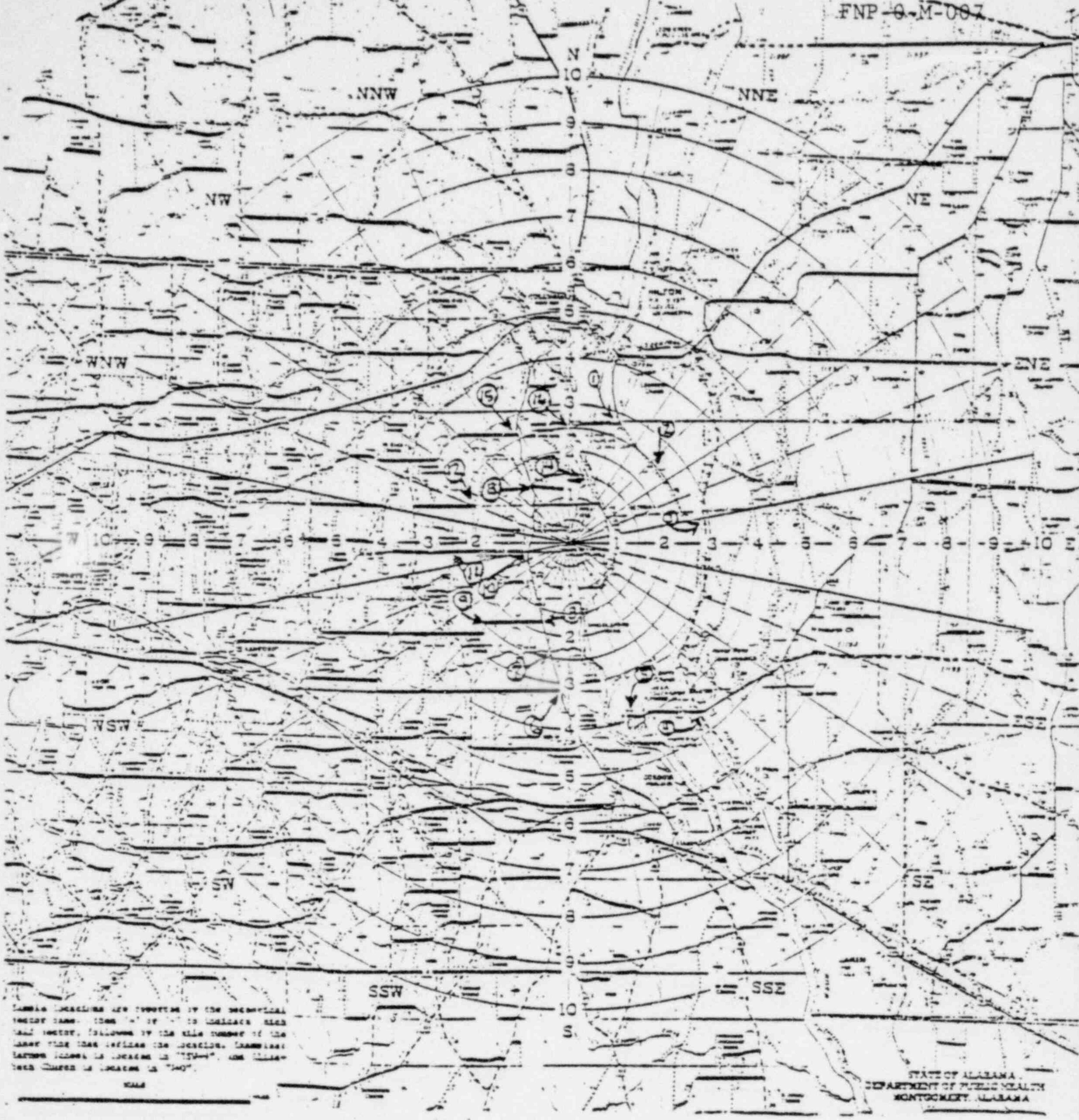


Figure 3 Coordinate system showing aussian distributions in the horizontal and vertical.



PREDESIGNATED MONITORING POINTS

POOR ORIGINAL

Point No.	Location	Description	Point No.	Location	Description
1	NNE-4	Road intersection	9	SW-4	Bend in road
2	NE-2	Bridge	10	WSW-1	APCO gate at AL95
3	E-4	Road intersection at GA370	11	W-4	Road intersection
4	SE-4	Intersection of GA273 & GA370	12	WNW-2	Road intersection
5	SSE-4	Grace Southern	13	NNW-1	Road intersection at AL95
6	S-3	Smith Branch at AL95	14	NNE-1	Bend in road
7	S-2	Cedar Creek at AL95	15	NNW-4	Road intersection at AL95
8	SSW-4	Road intersection at AL95	16	N-4	Andrews Dam

Figure 4

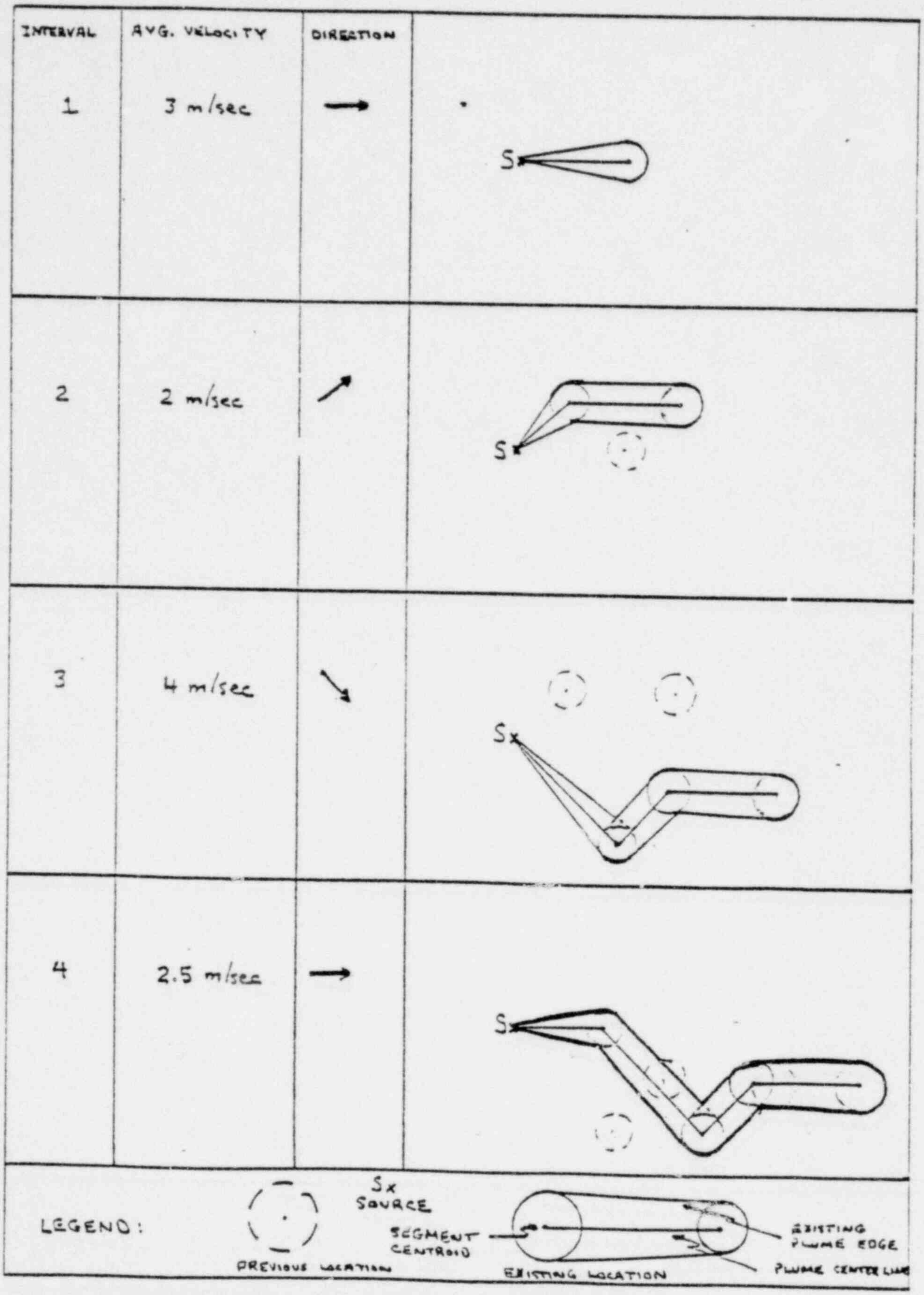


FIGURE 5 MODELING OF REAL TIME PLUME GROWTH

DATE XX/XX/XX

Last Average Wind Direction (degrees from N) XXX.X
Wind Direction used for projection XXX.X

SEGMENT NUMBER	LOCATION R(miles)	LOCATION θ (degrees from N)	ARRIVAL TIME (Central Time)	CENTERLINE DOSE RATE (mRem/hr)	CRITICAL ORGAN DOSE RATE (mRem/hr)	$\frac{\chi}{Q}$
XX	XX.XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
XX	XX.XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX
	XX	XXX.X	XXXX	X.XE±XX	X.XE±XX	X.XE±XX

radial location at last update

radius of arcs not yet crossed

azmuth location at last update

projected azmuth location where arc will be crossed

time of last update

projected arrival time at (R,θ)

γdose rate at last update

projected γ dose rate at time of crossing

critical organ dose rate at last update

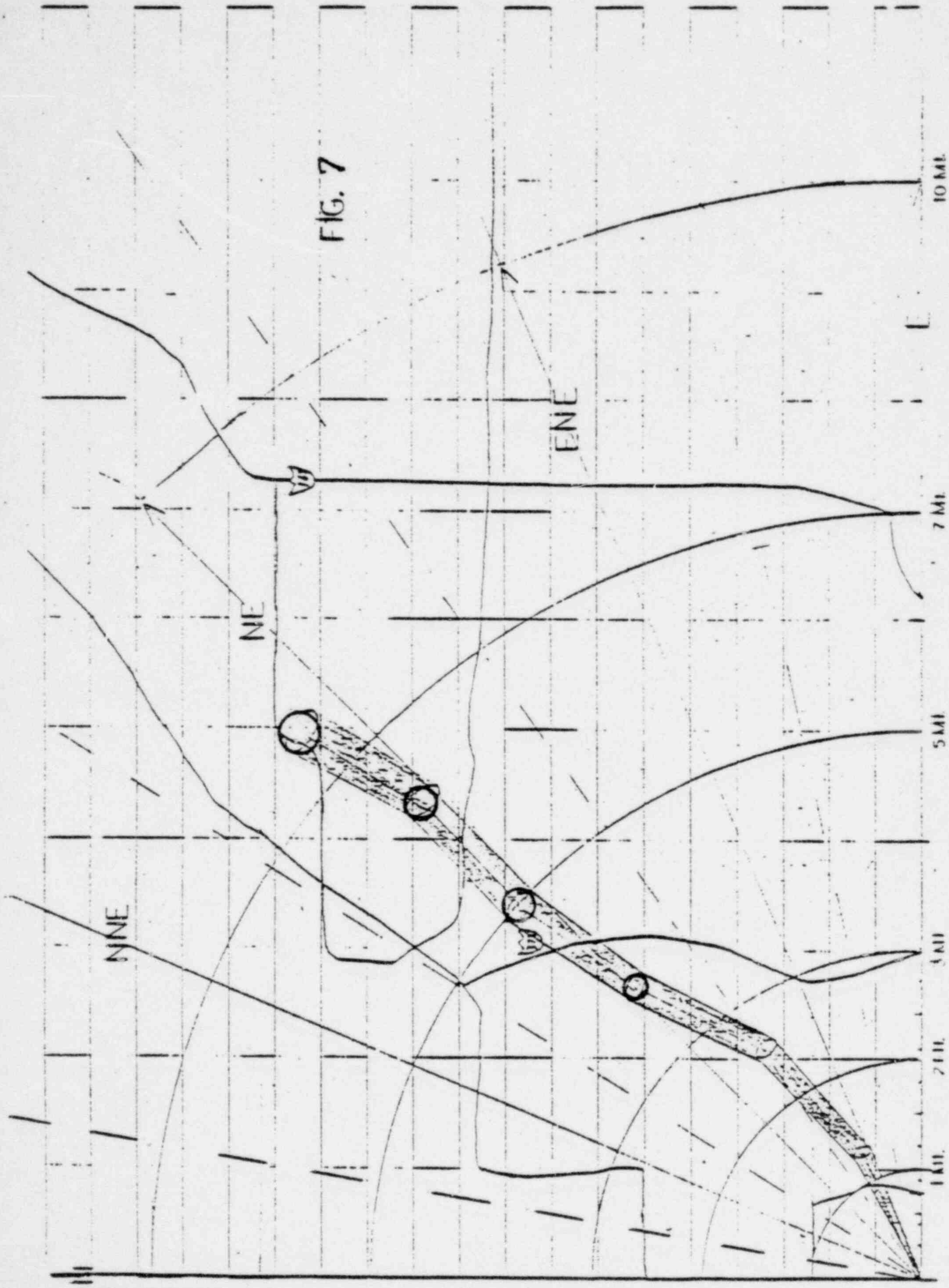
projected critical organ dose rate at time of crossing

relative concentration at last update

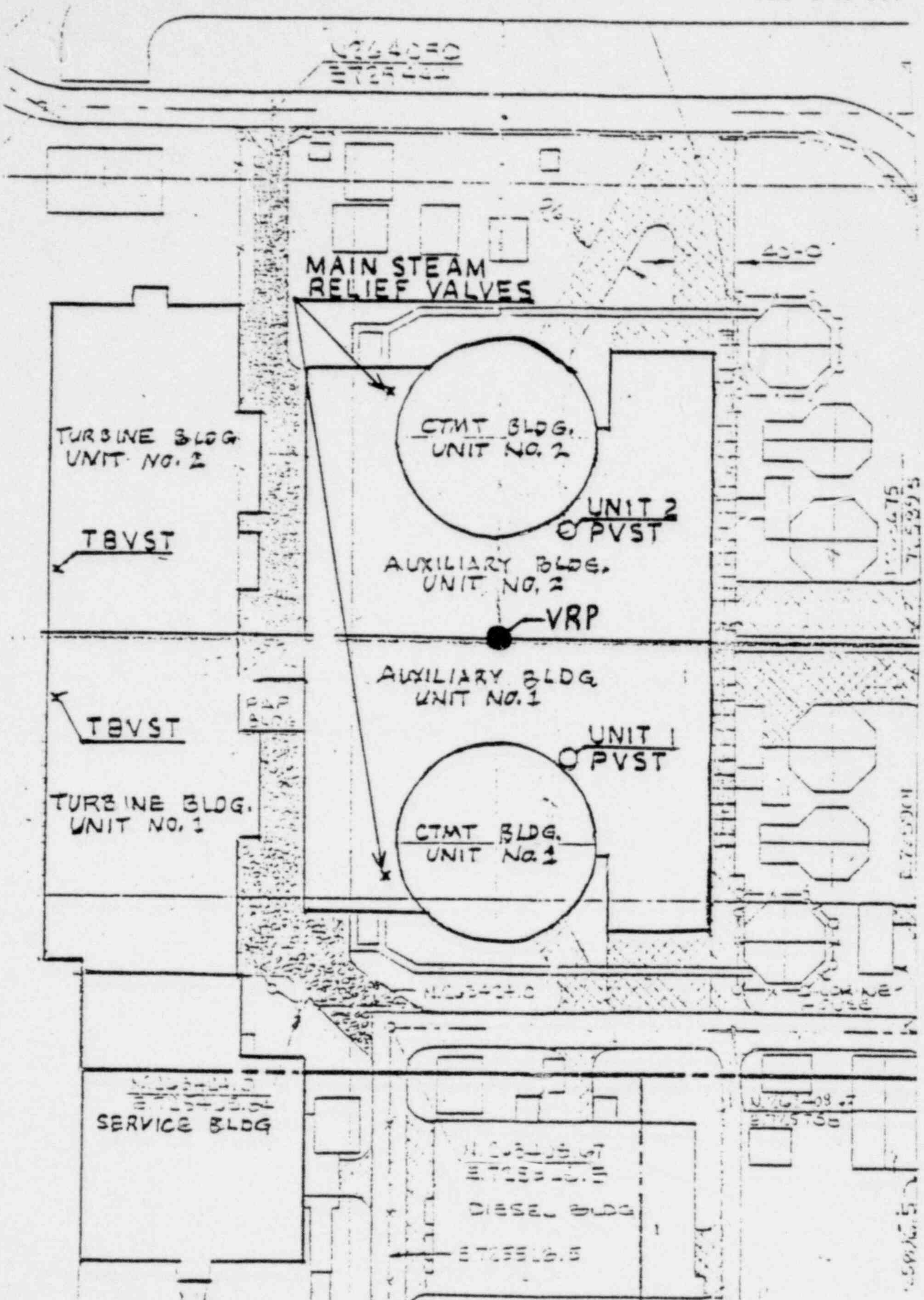
projected relative concentration at time of crossing

(Etc. for each segment being tracked inside the EPZ)

FIGURE 6 TABULAR OUTPUT FORMAT



EXAMPLE OF PLUME PLOT UNDER NEUTRAL CONDITIONS WIND SPEED ≈ 5 MILES PER HR.



POOR ORIGINAL

VIRTUAL RELEASE POINT (VRP)

FIGURE8

Rev. 1

Relative Dose Rate Plume Boundary For stability class A

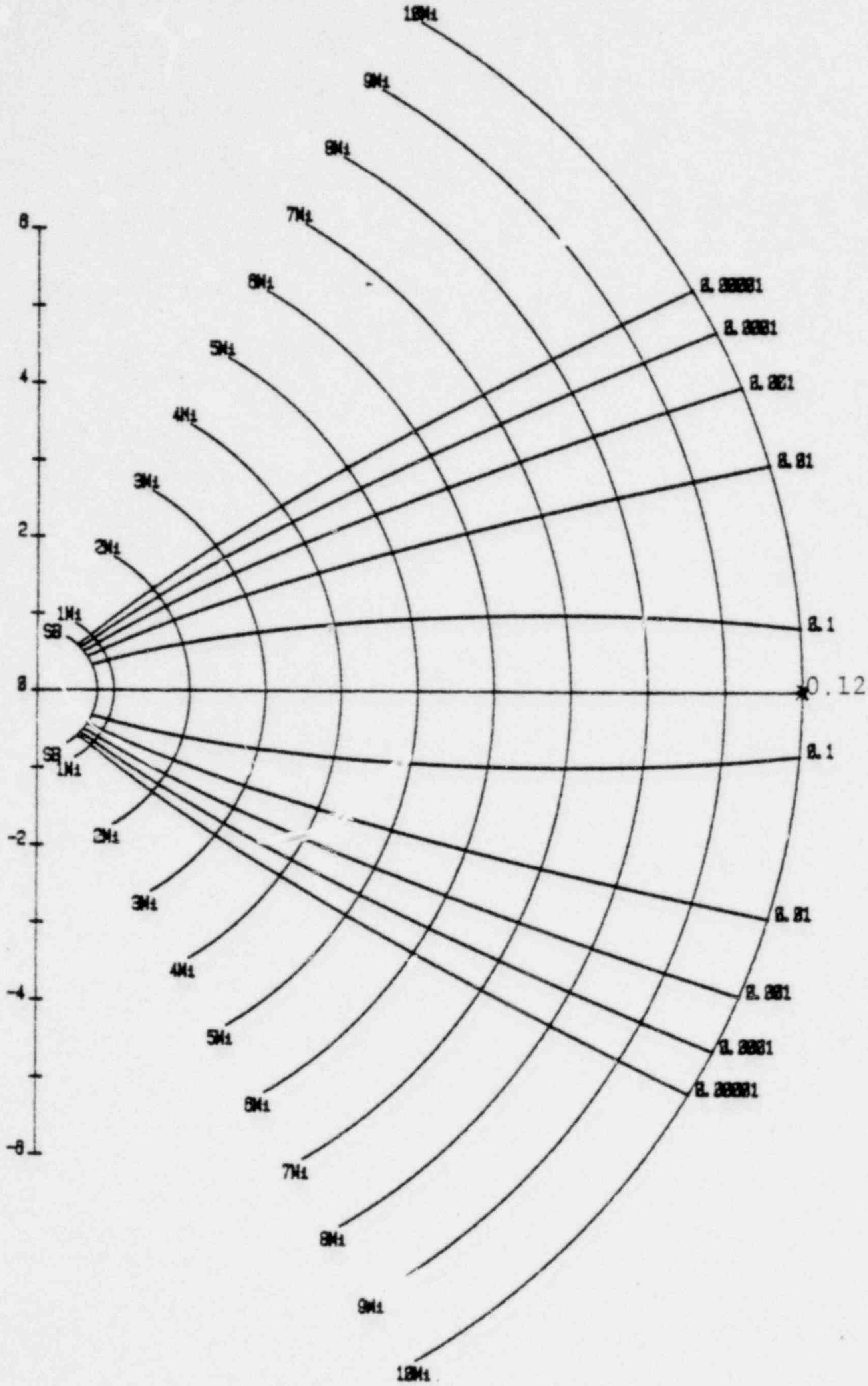
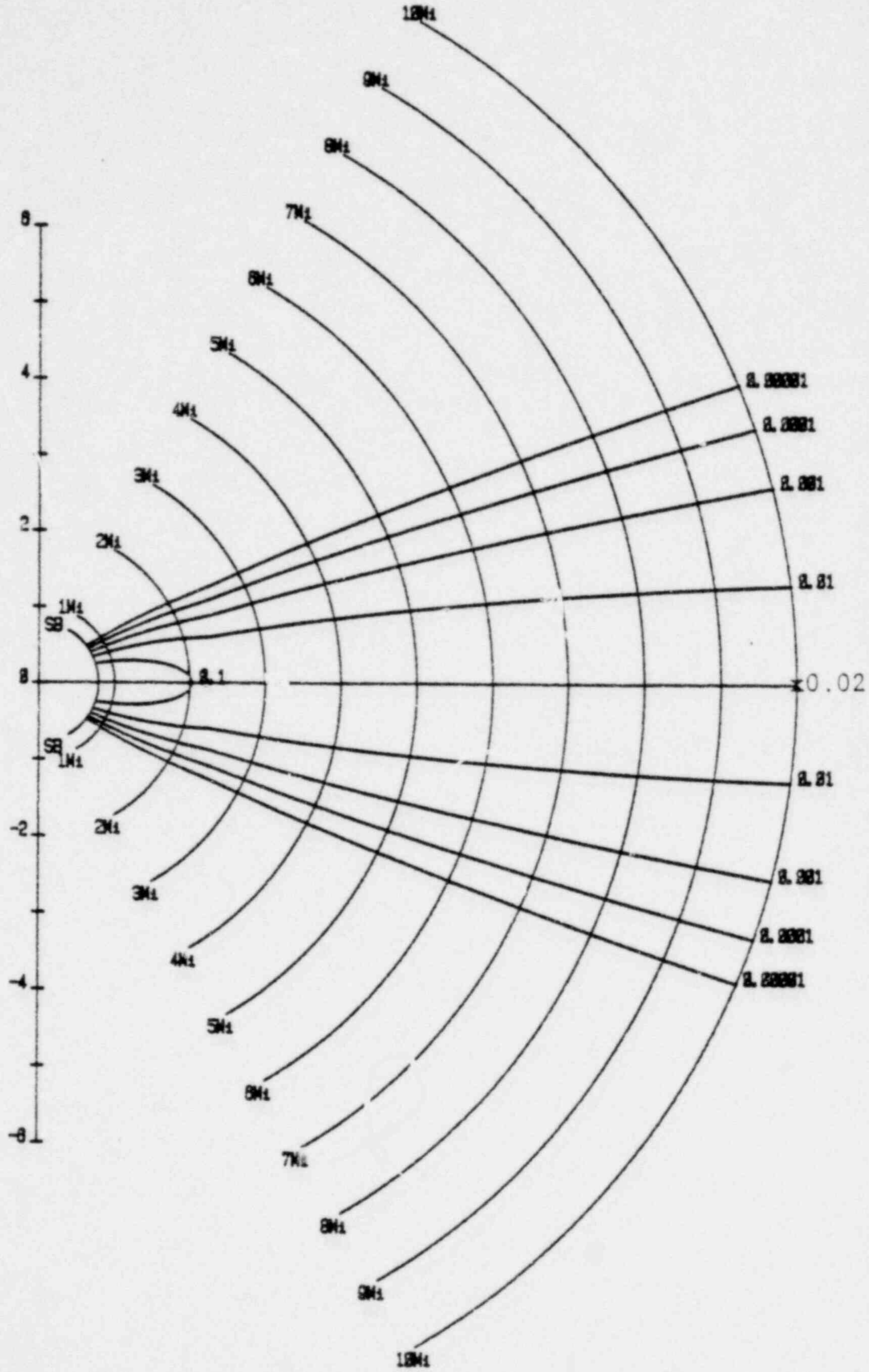
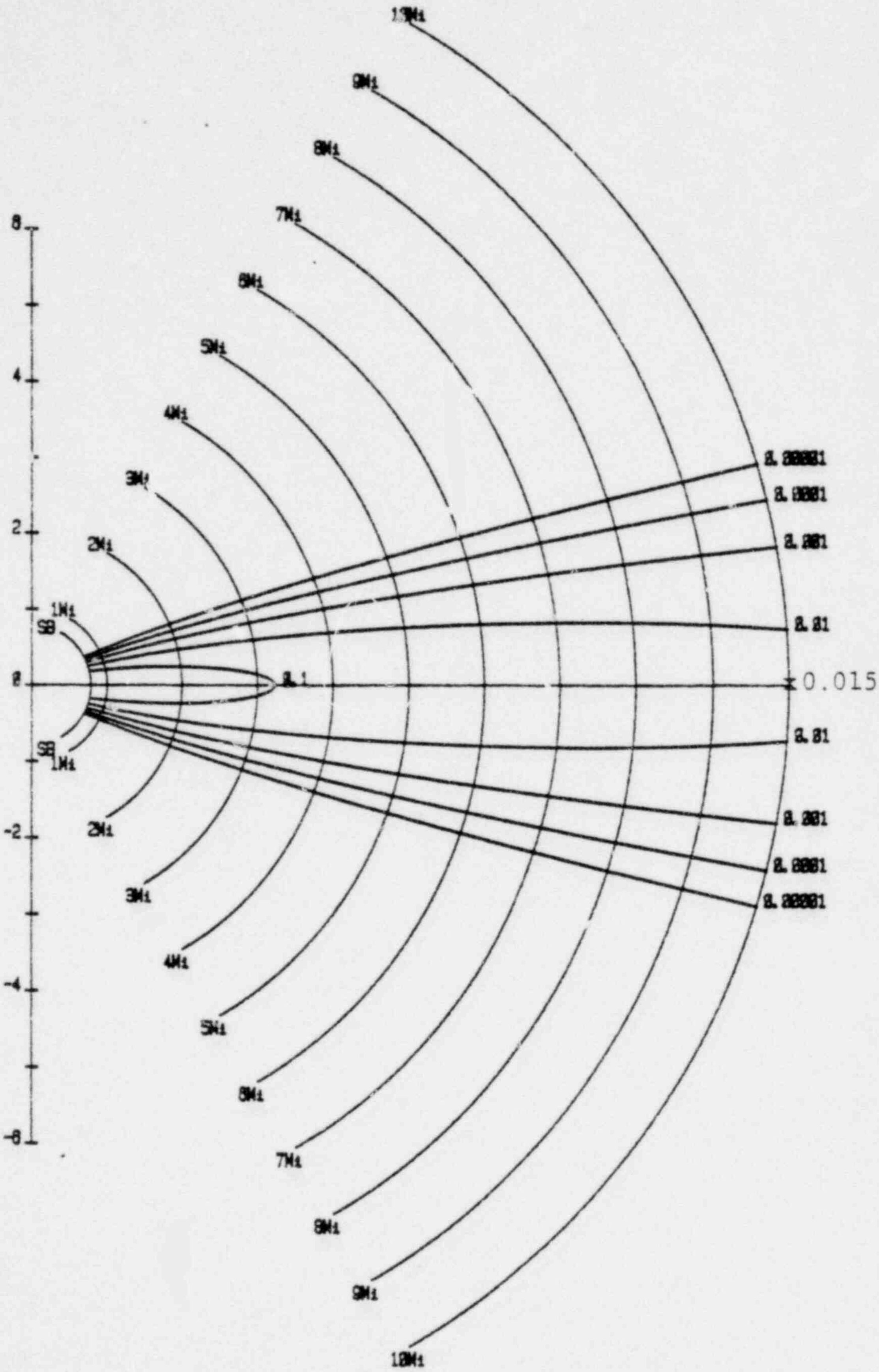


FIG. 9B Relative Dose Rate Plume Boundary
For stability class B



Relative Dose Rate Plume Boundary
For stability class C



Relative Dose Rate Plume Boundary For stability class D

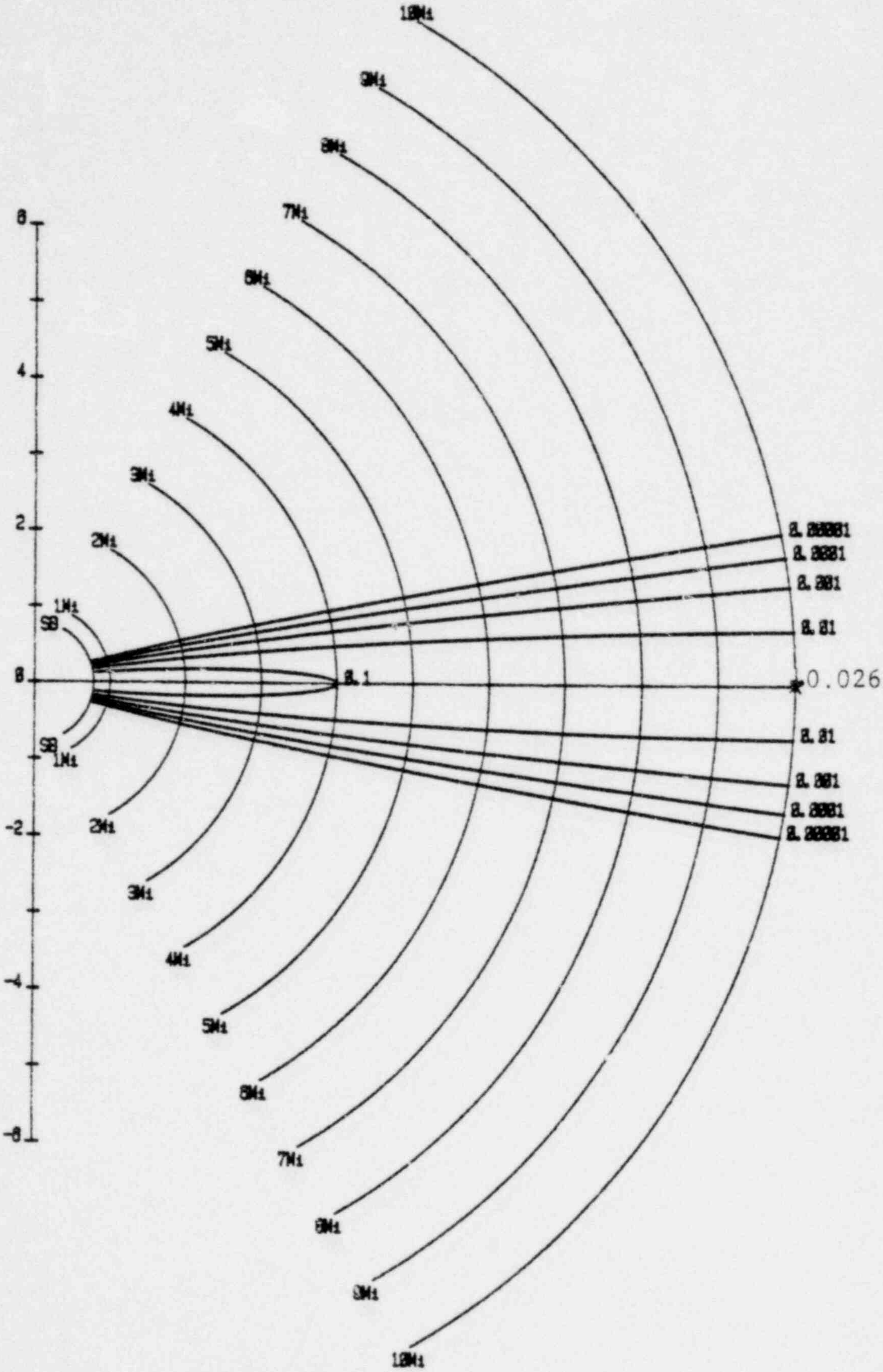
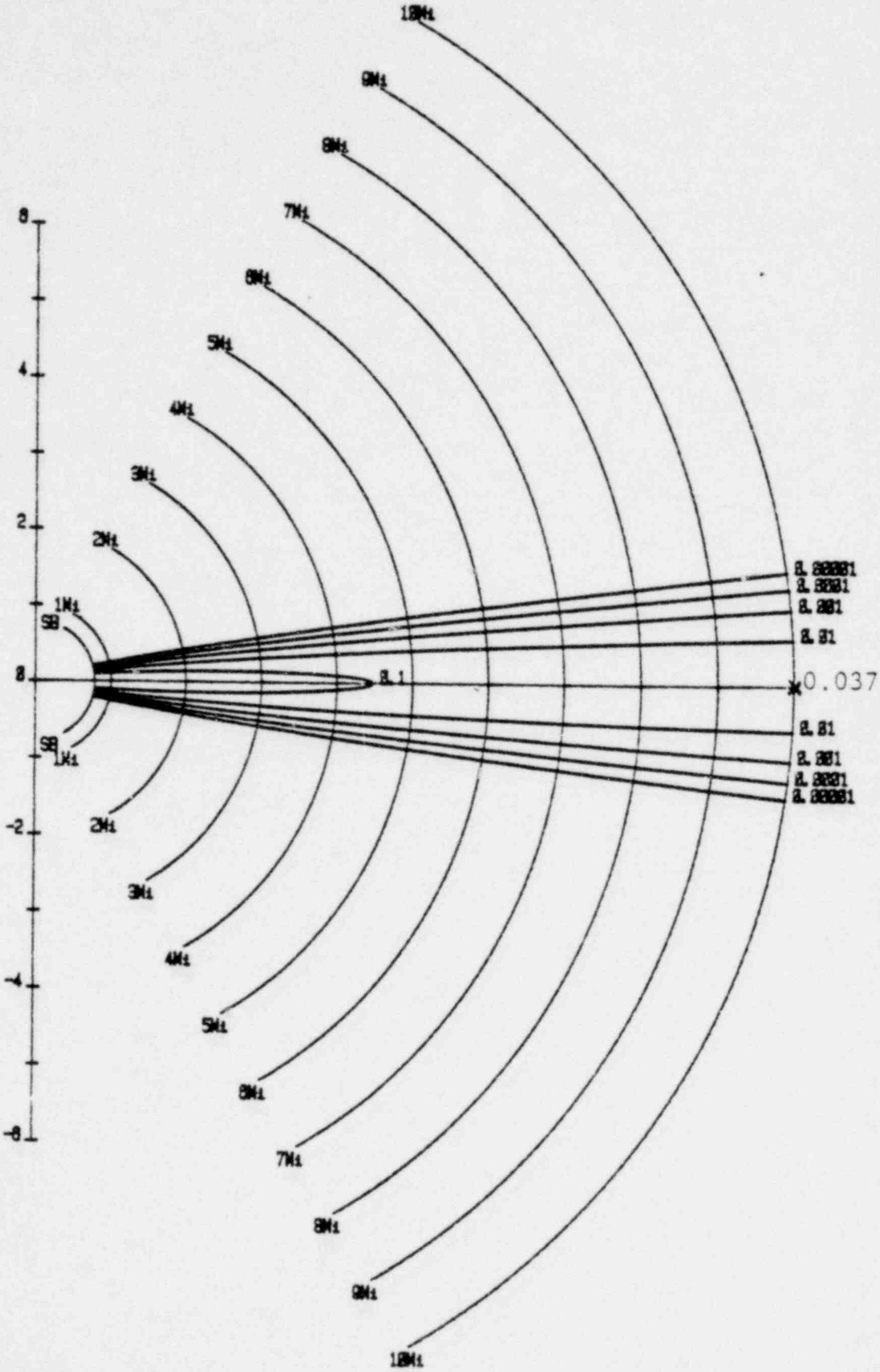


FIG. 9E **Relative Dose Rate Plume Boundary For stability class E** FNP-0-M-007



Relative Dose Rate Plume Boundary For stability class F

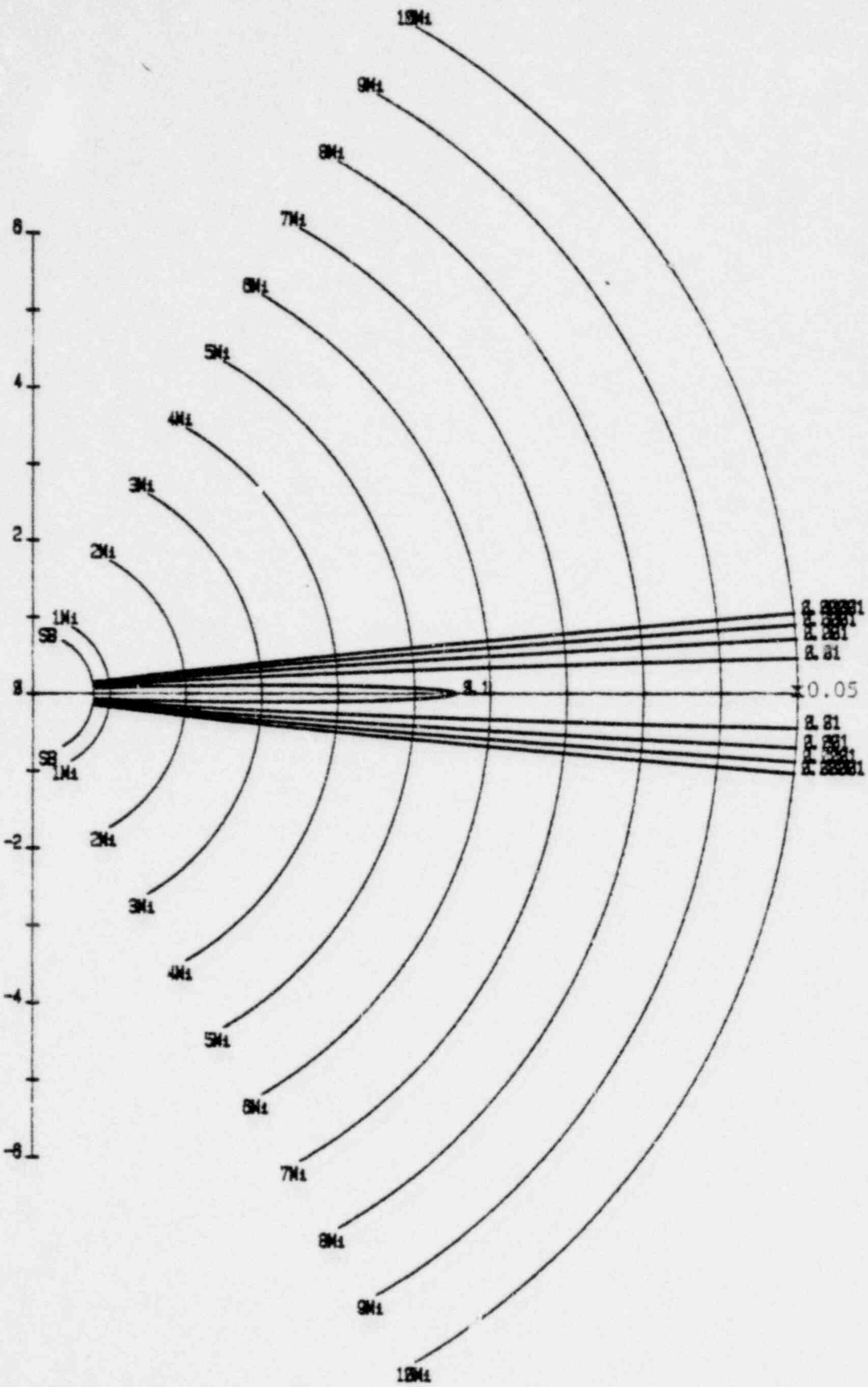


FIG. 9G Relative Dose Rate Plume Boundary
For stability class G

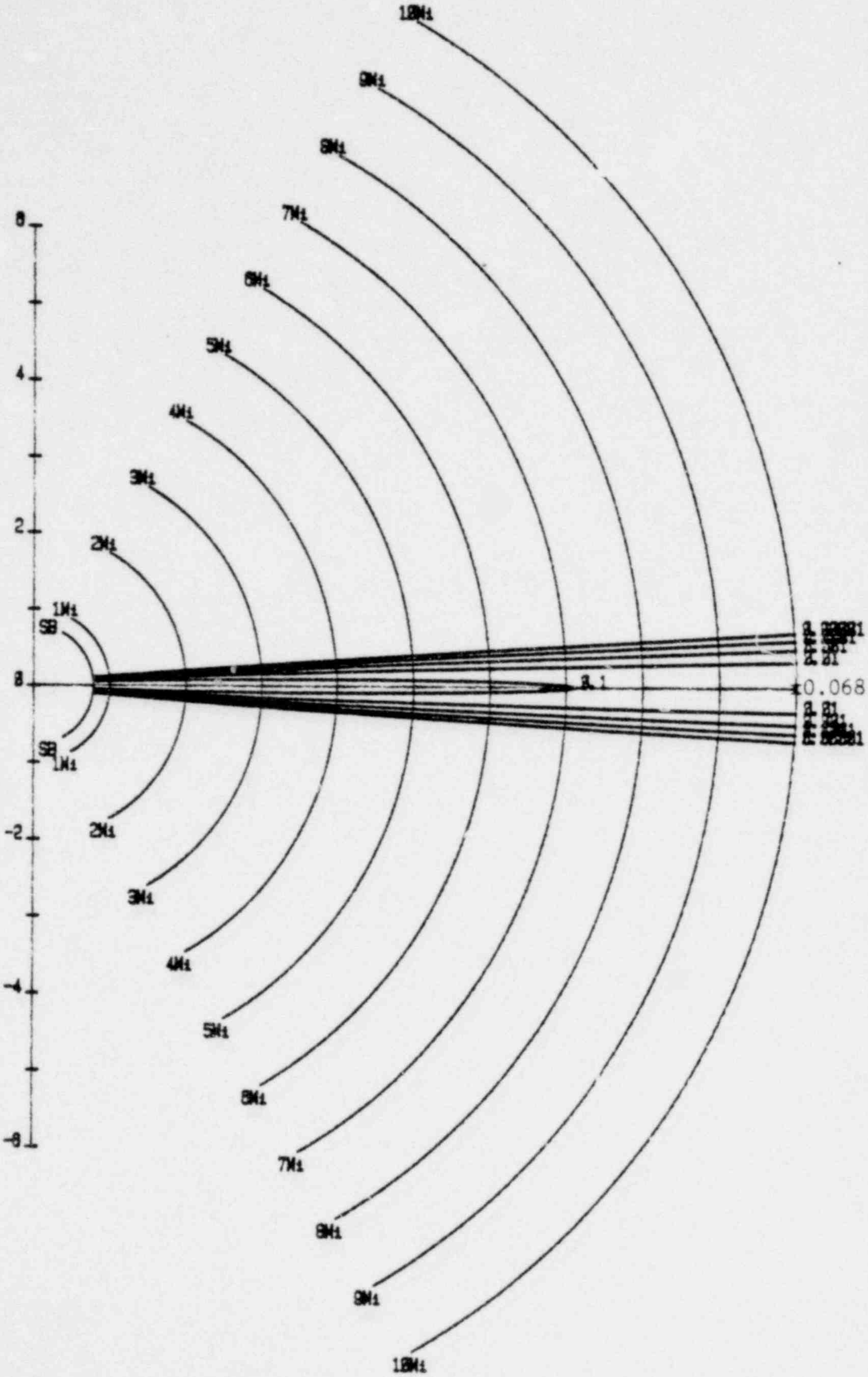


Fig. 10A Equivalent Release Height versus Wind Speed
For Class A

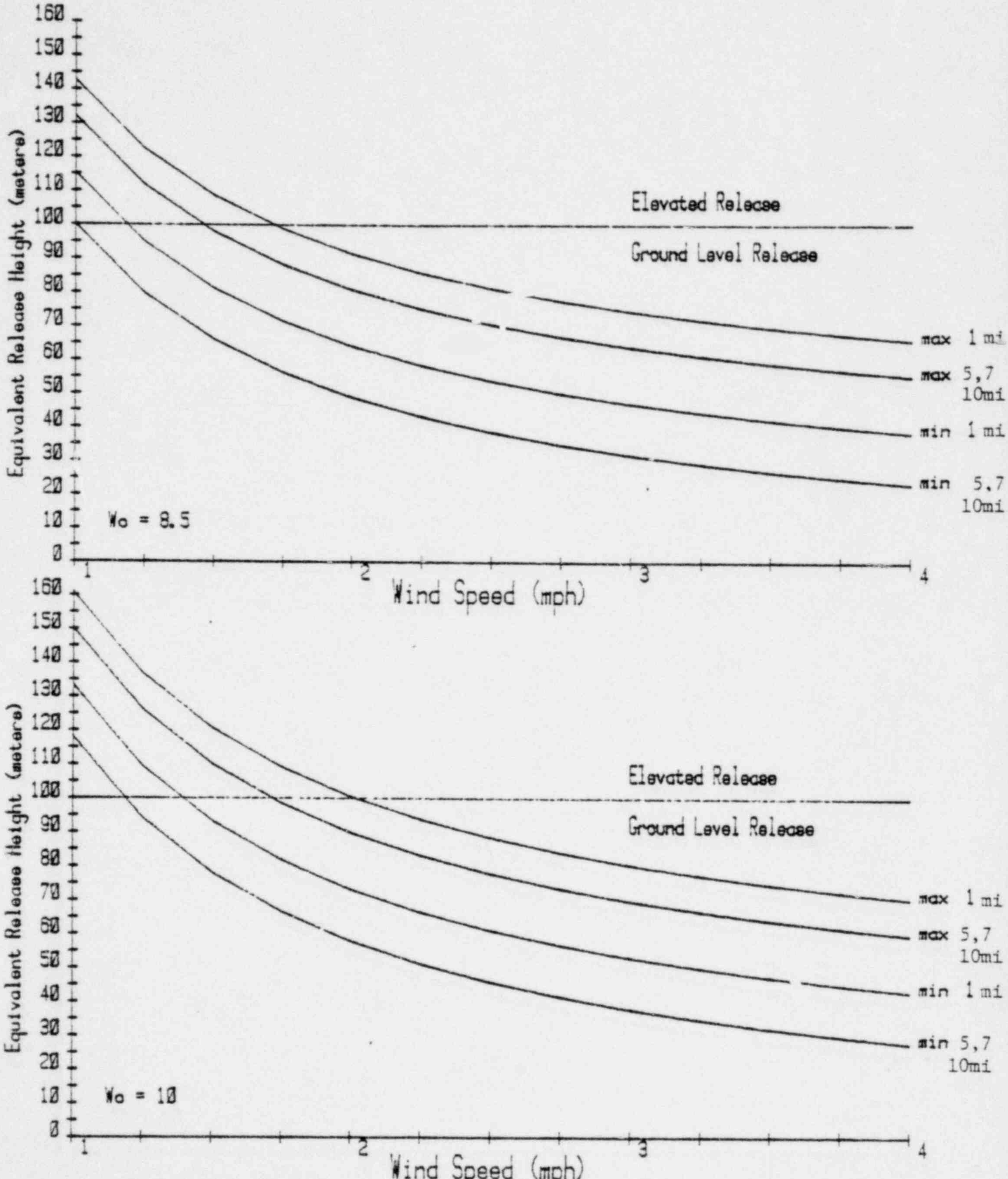


Fig. 10B Equivalent Release Height versus Wind Speed
For Class B

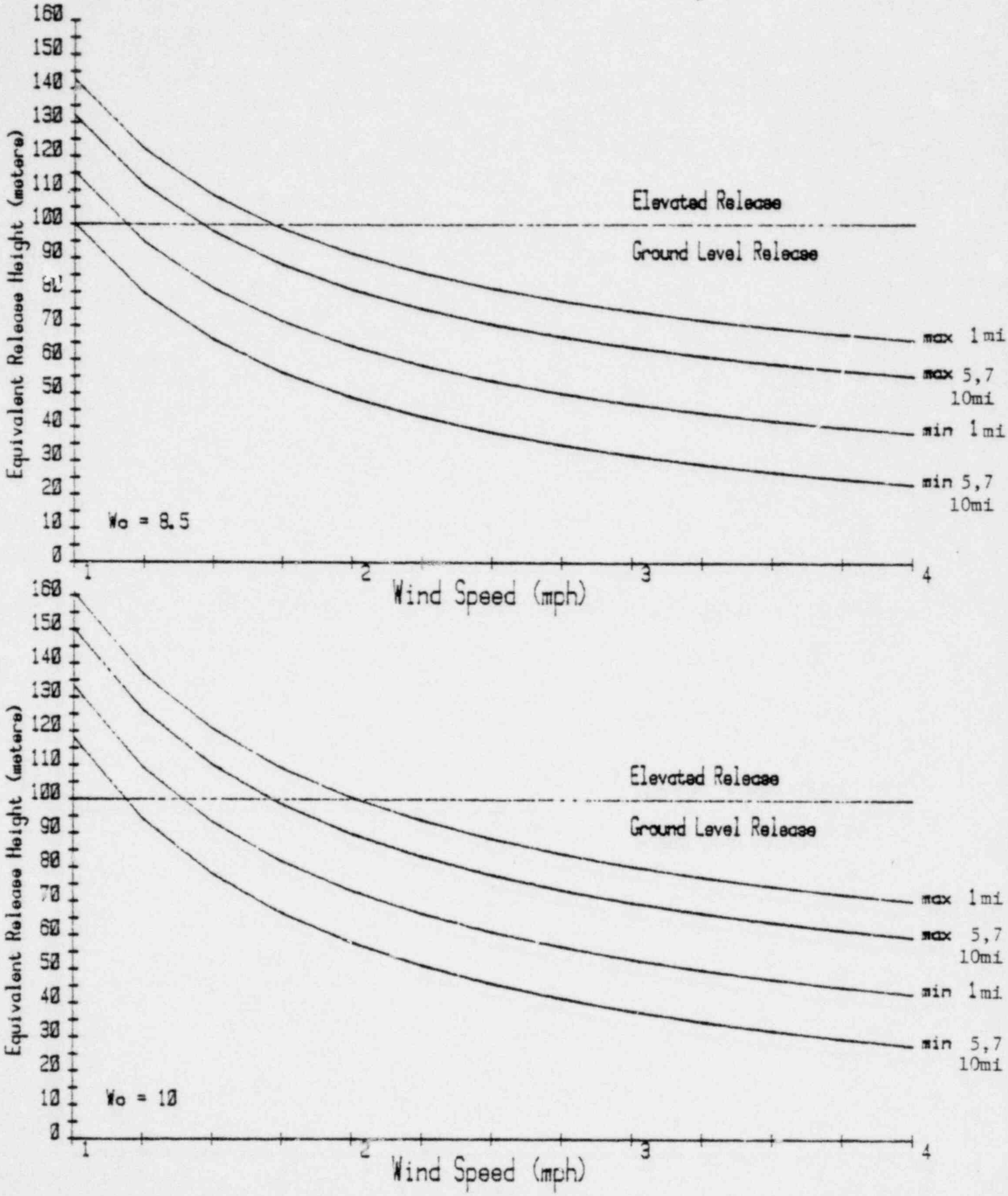


Fig. 10C Equivalent Release Height versus Wind Speed
For Class C

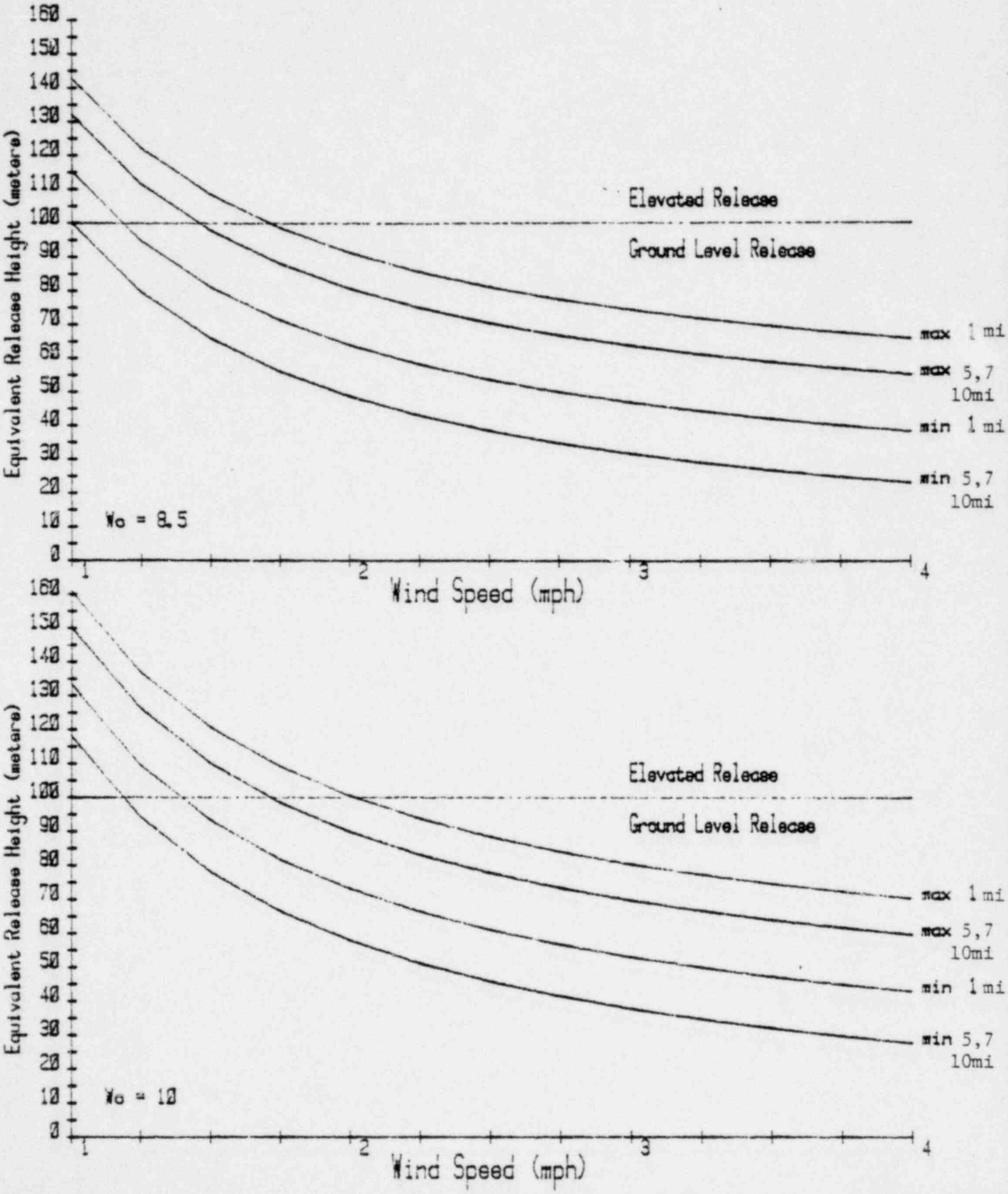


Fig. 10D Equivalent Release Height versus Wind Speed
For Class D

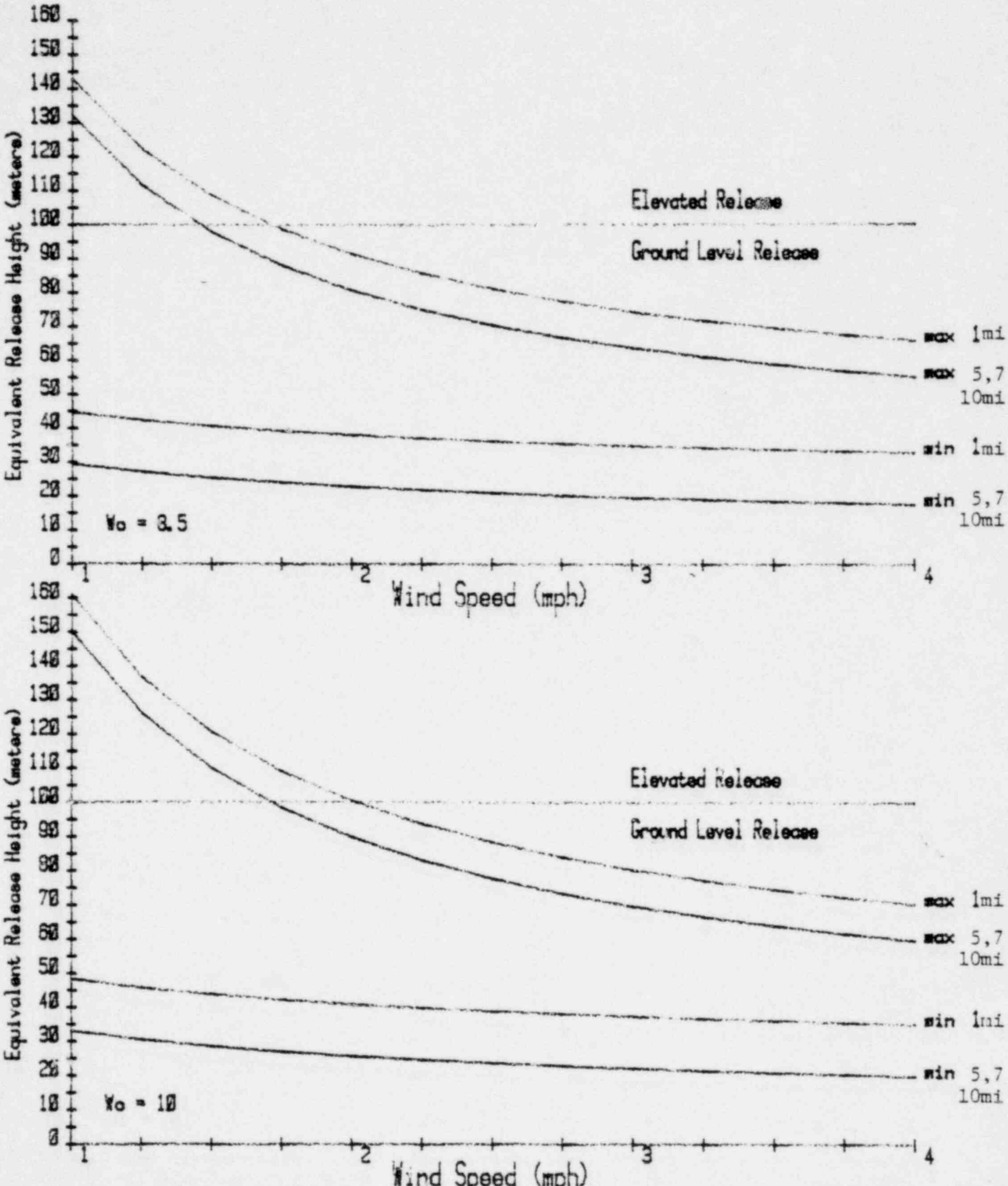
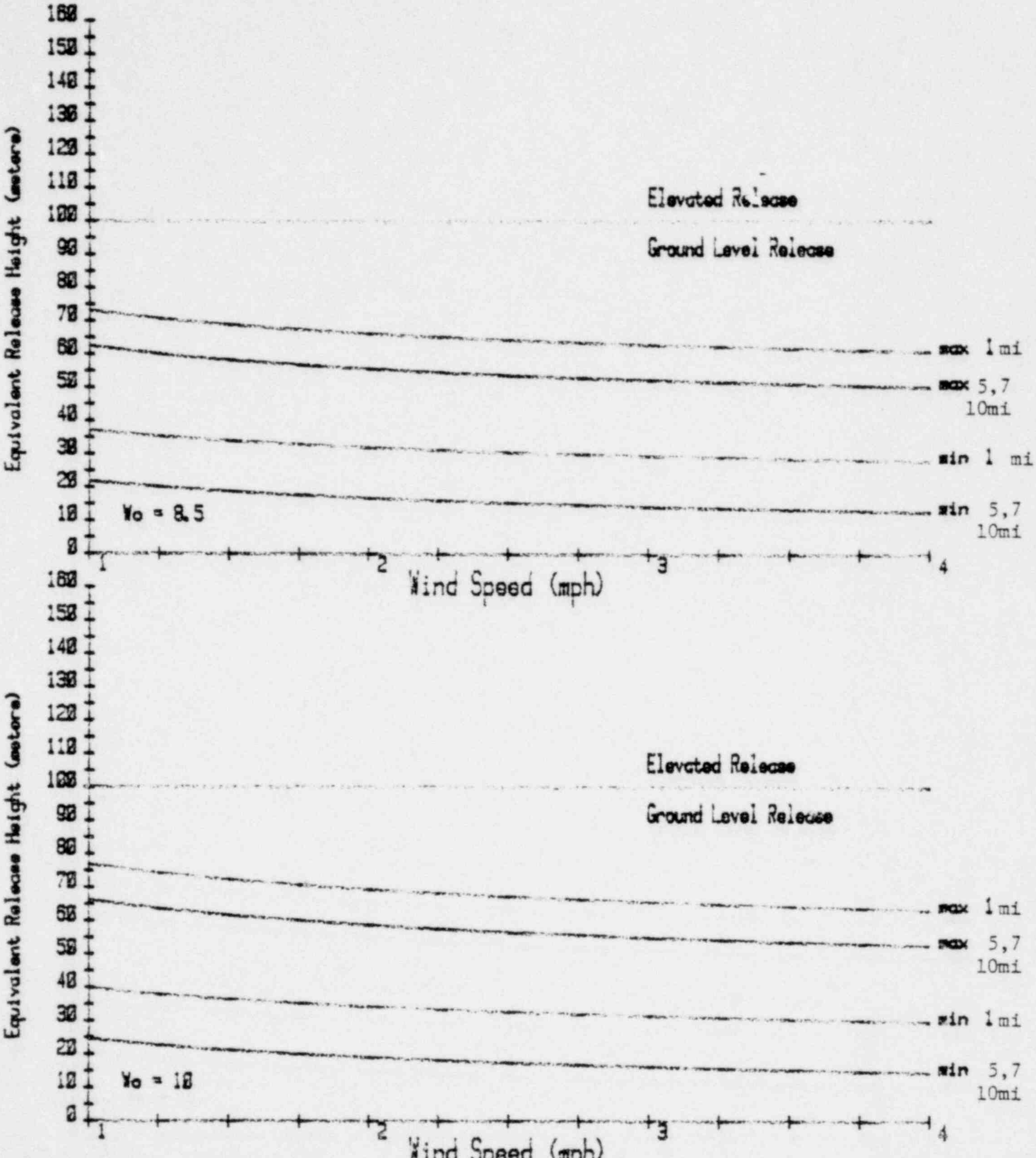


Fig. 10E Equivalent Release Height versus Wind Speed
For Class E



Gen. Rev. 1

Fig. 10F Equivalent Release Height versus Wind Speed
For Class F

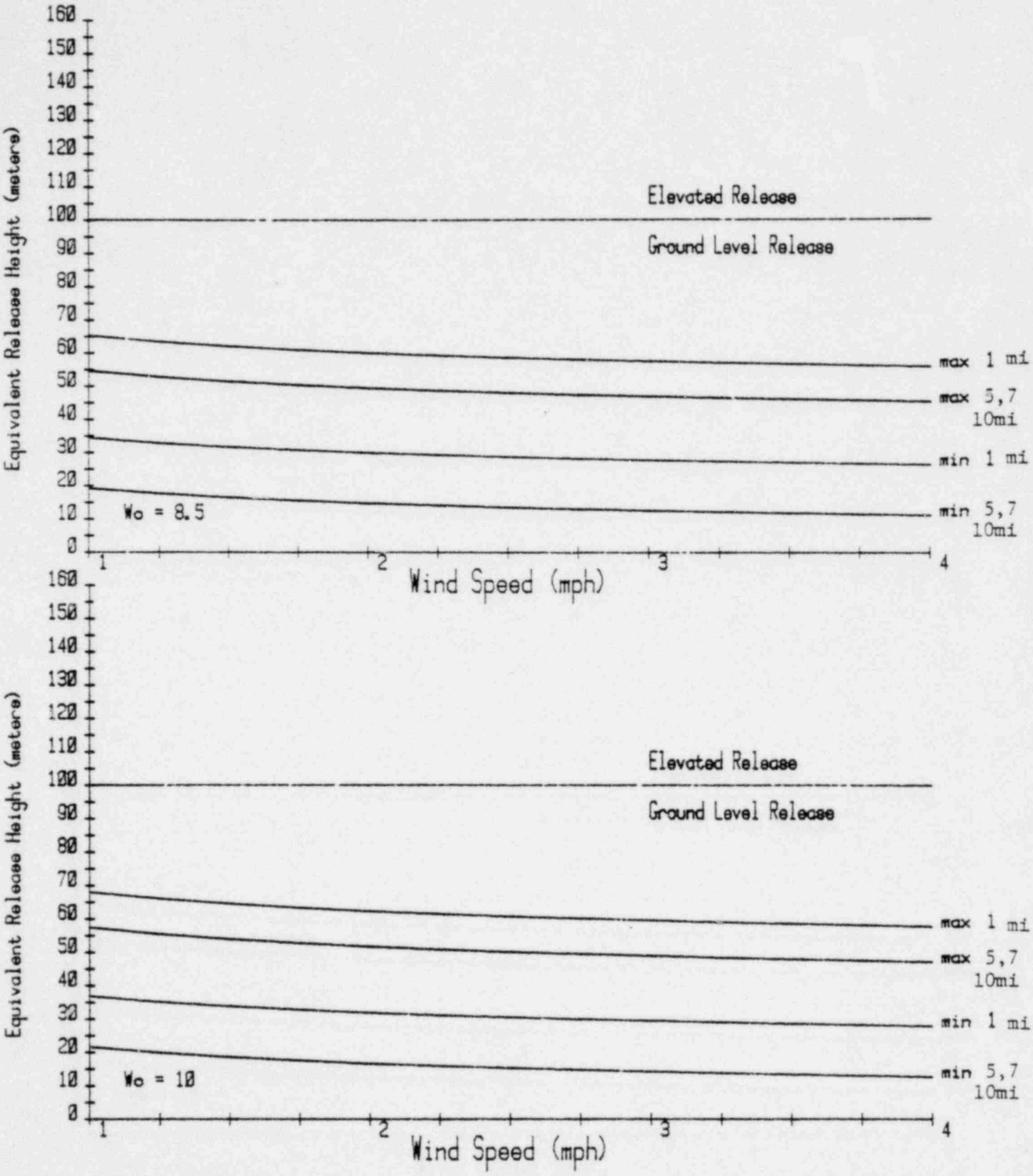
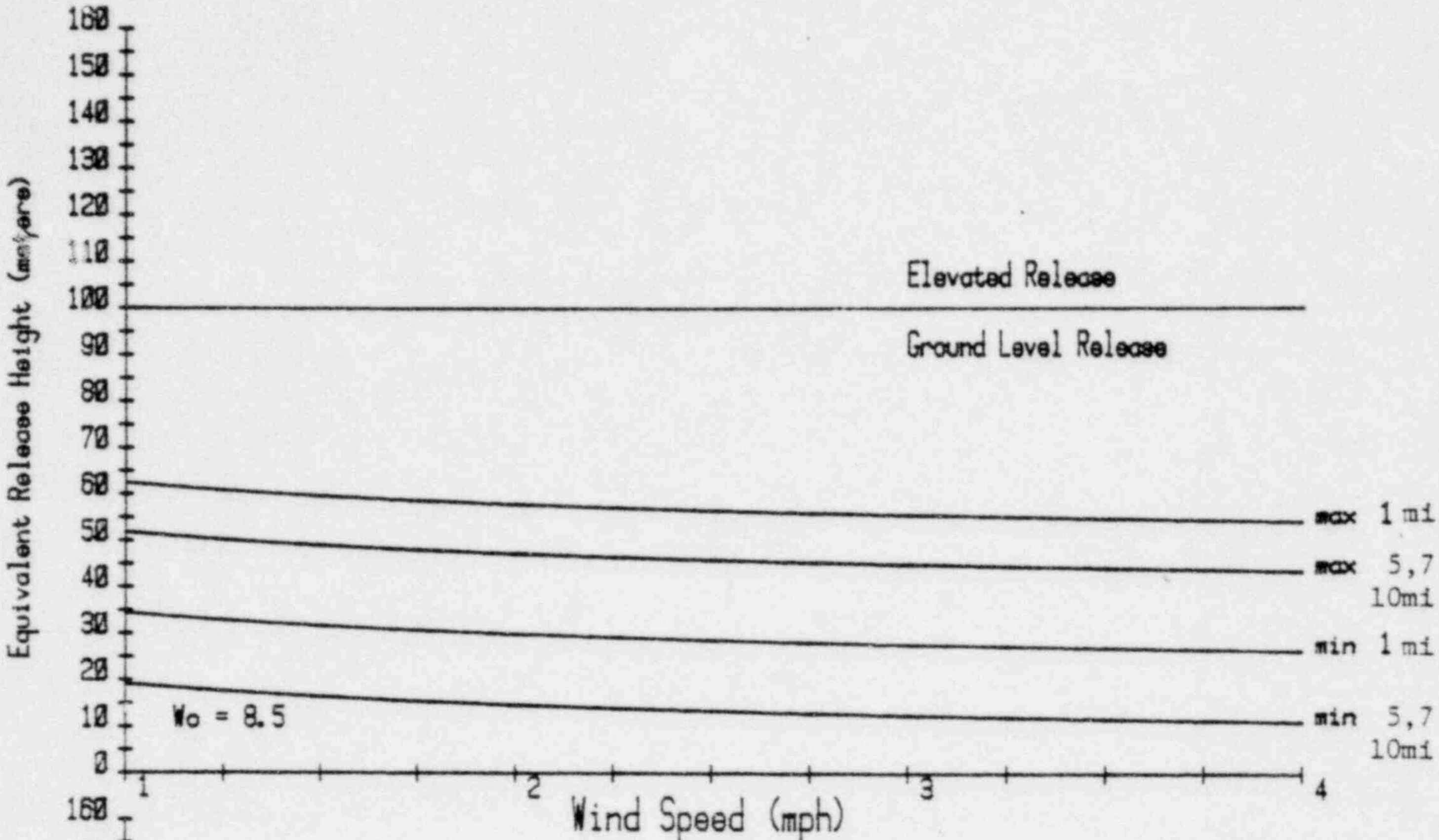


Fig. 10G Equivalent Release Height versus Wind Speed
For Class G



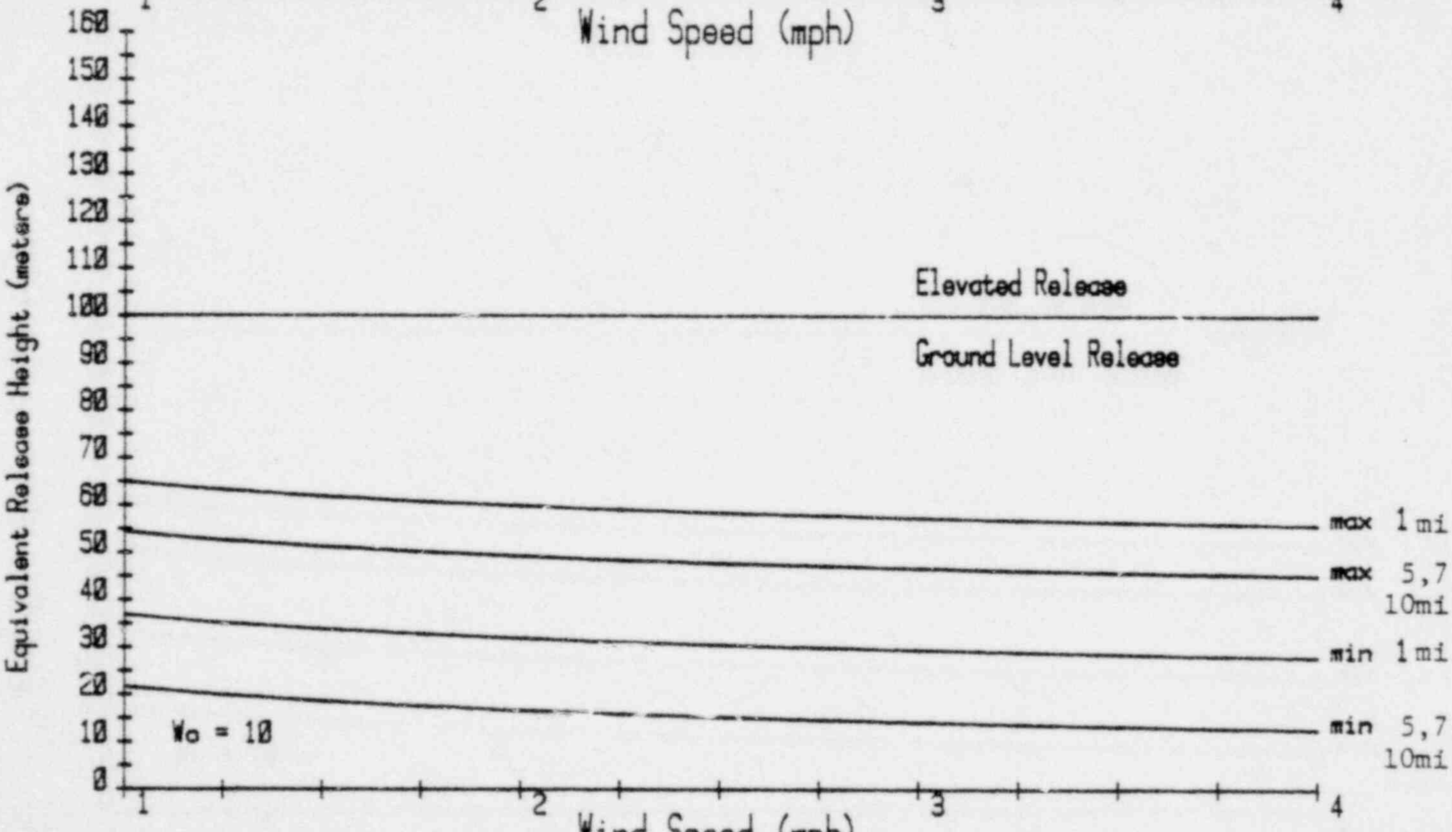


FIGURE 11

Turner Stability Class as a Function of Net Radiation Index and Wind Speed

Wind Speed (mph)	Wind Speed (knots)	NET RADIATION INDEX 4	3	2	1	0	-1	-2
0 - 1.6	0-1	A	A	B	C	D	F	G
1.7 - 3.9	2-3	A	B	B	C	D	F	G
4.0 - 6.2	4-5	A	B	C	D	D	E	F
6.3 - 7.4	6	B	B	C	D	D	E	F
7.5 - 8.5	7	B	B	C	D	D	D	E
8.6 - 10.8	8-9	B	C	C	D	D	D	E
10.9- 12.0	10-11	C	C	D	D	D	D	E
12.1- 13.1	12	C	C	D	D	D	D	D
13.2	12	C	D	D	D	D	D	D

Figure 12: Insolation Class Number For Farley Nuclear Plant Using Turner's Algorithm

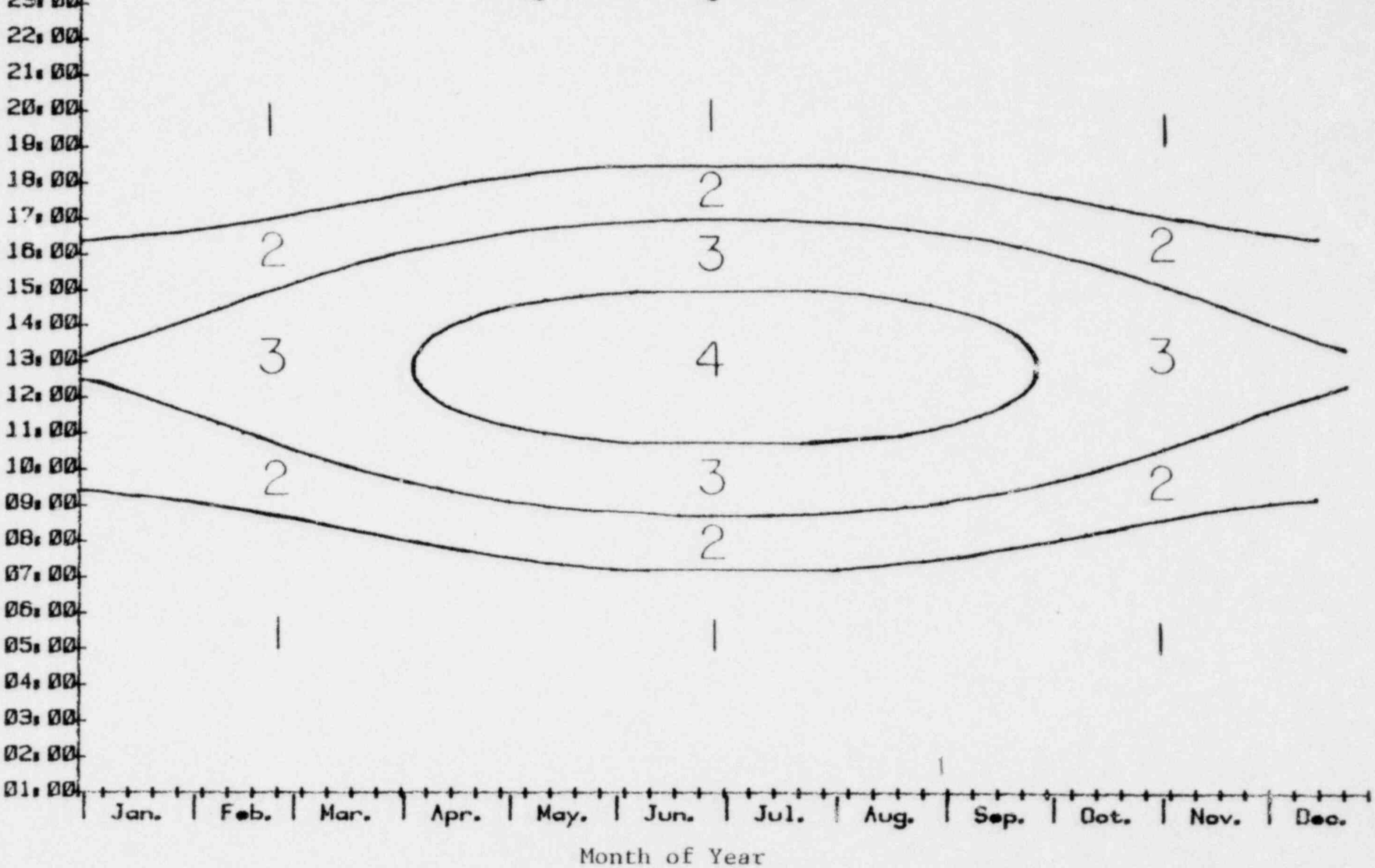


Fig 13A Dose Factors versus Time
Gross Effluent Activity
For Filtered Iodines

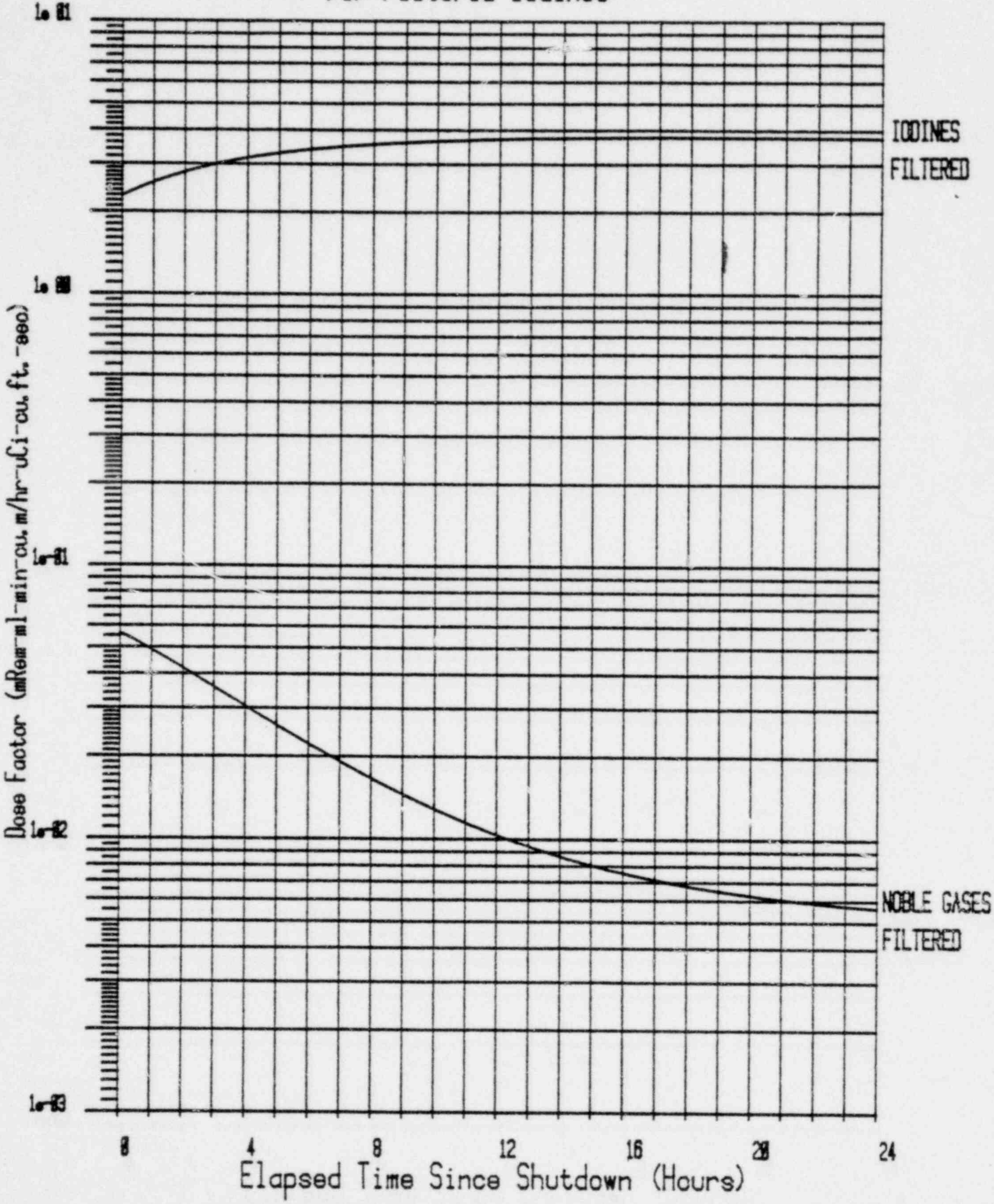


Fig 13B Dose Factors versus Time
Gross Effluent Activity
For Unfiltered Iodines

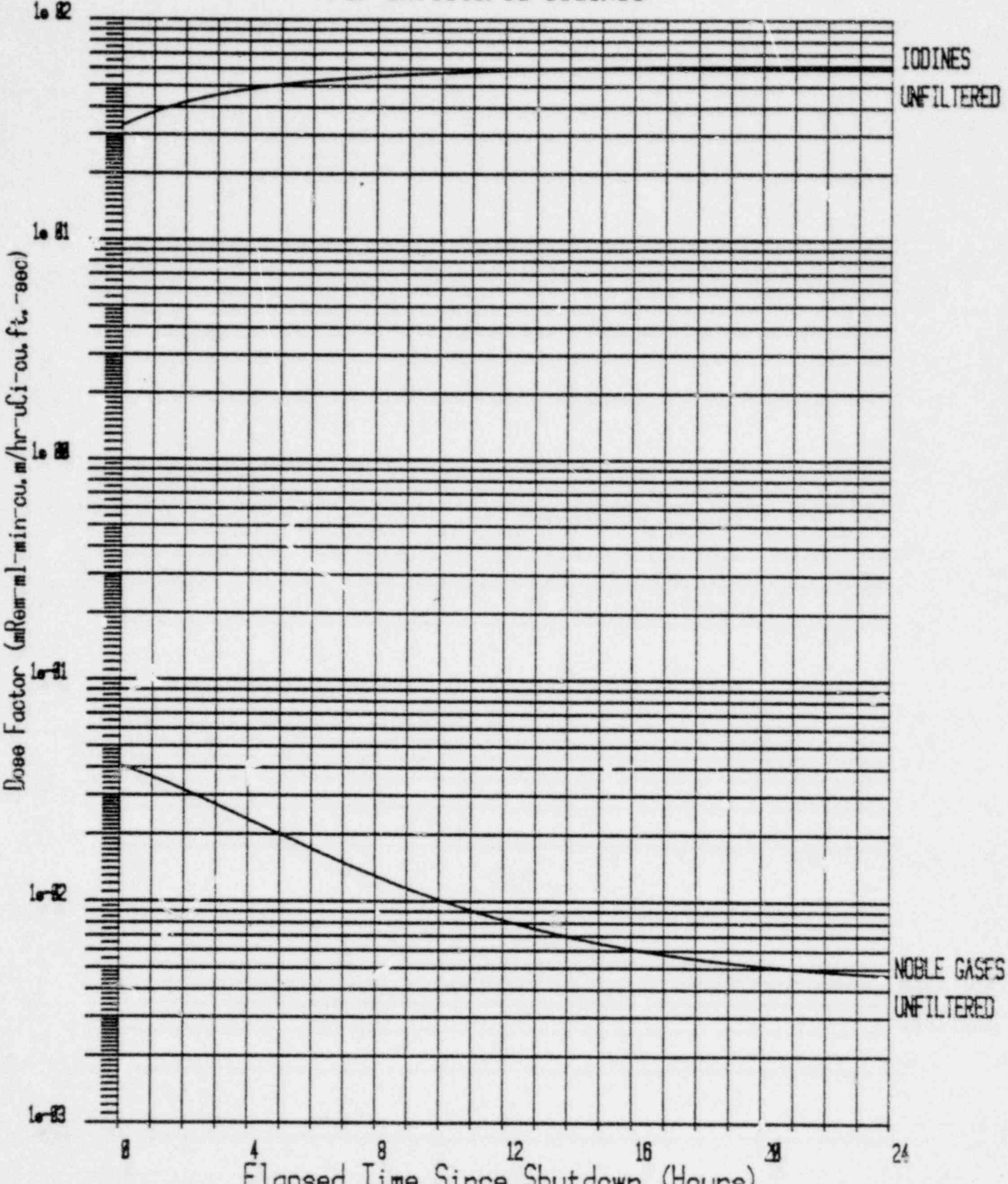


Fig 14A Dose Factors versus Time
Specific Effluent Activity
Noble Gases

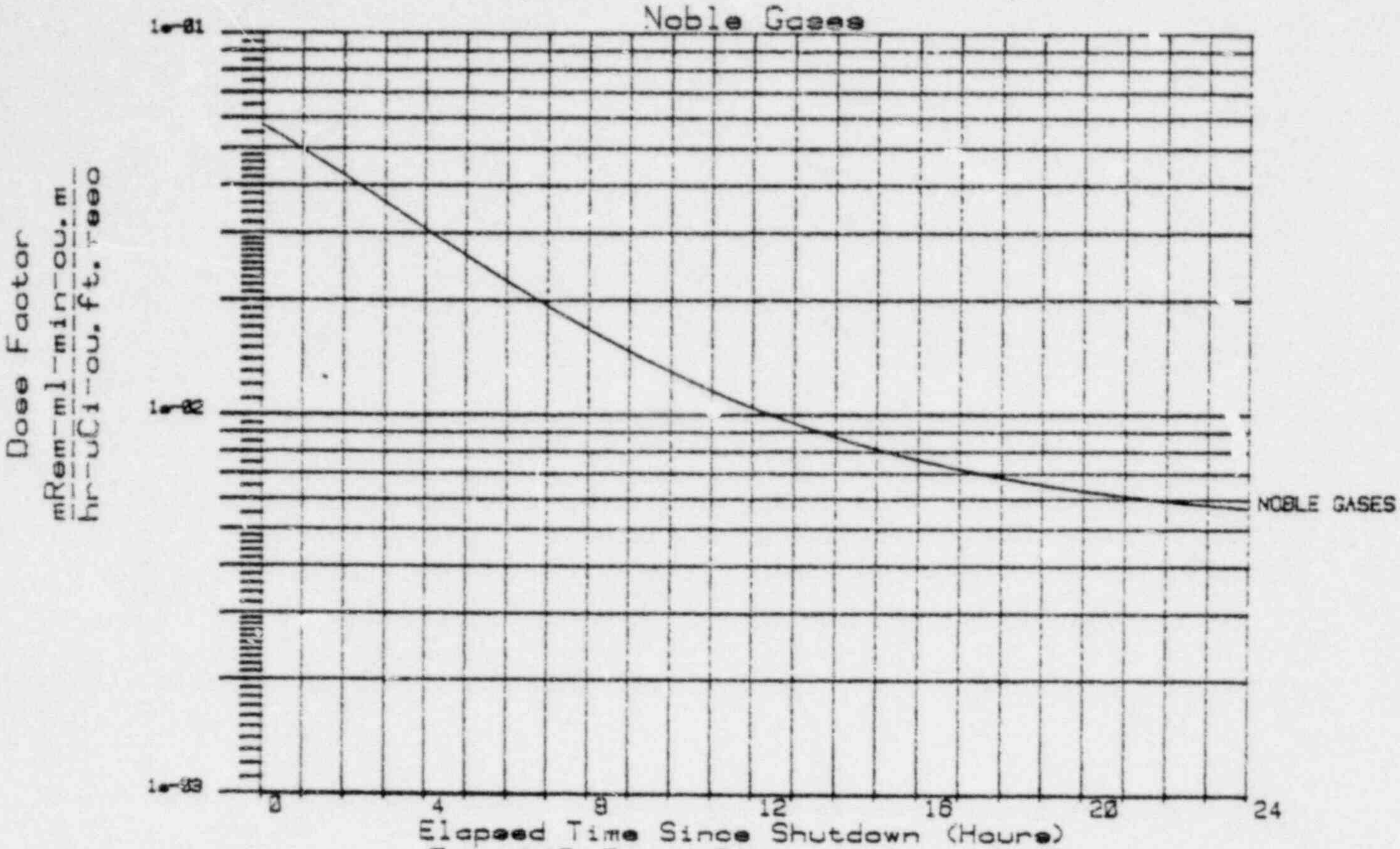


Fig 14B Dose Factors versus Time
Specific Effluent Activity
Iodines

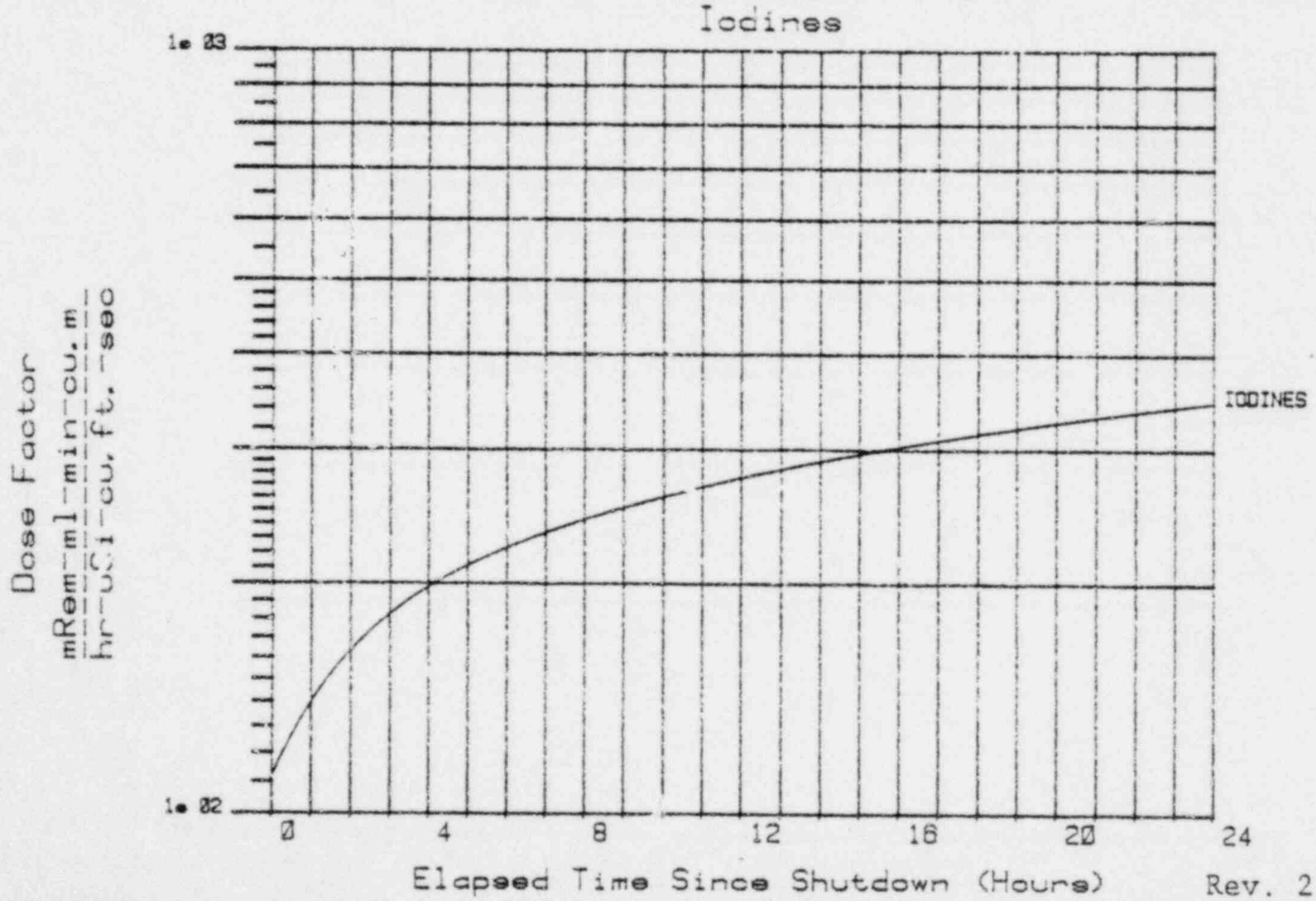


Fig. 15A Site Boundary χ/Q vs Wind Speed
FOR STABILITY CLASS A

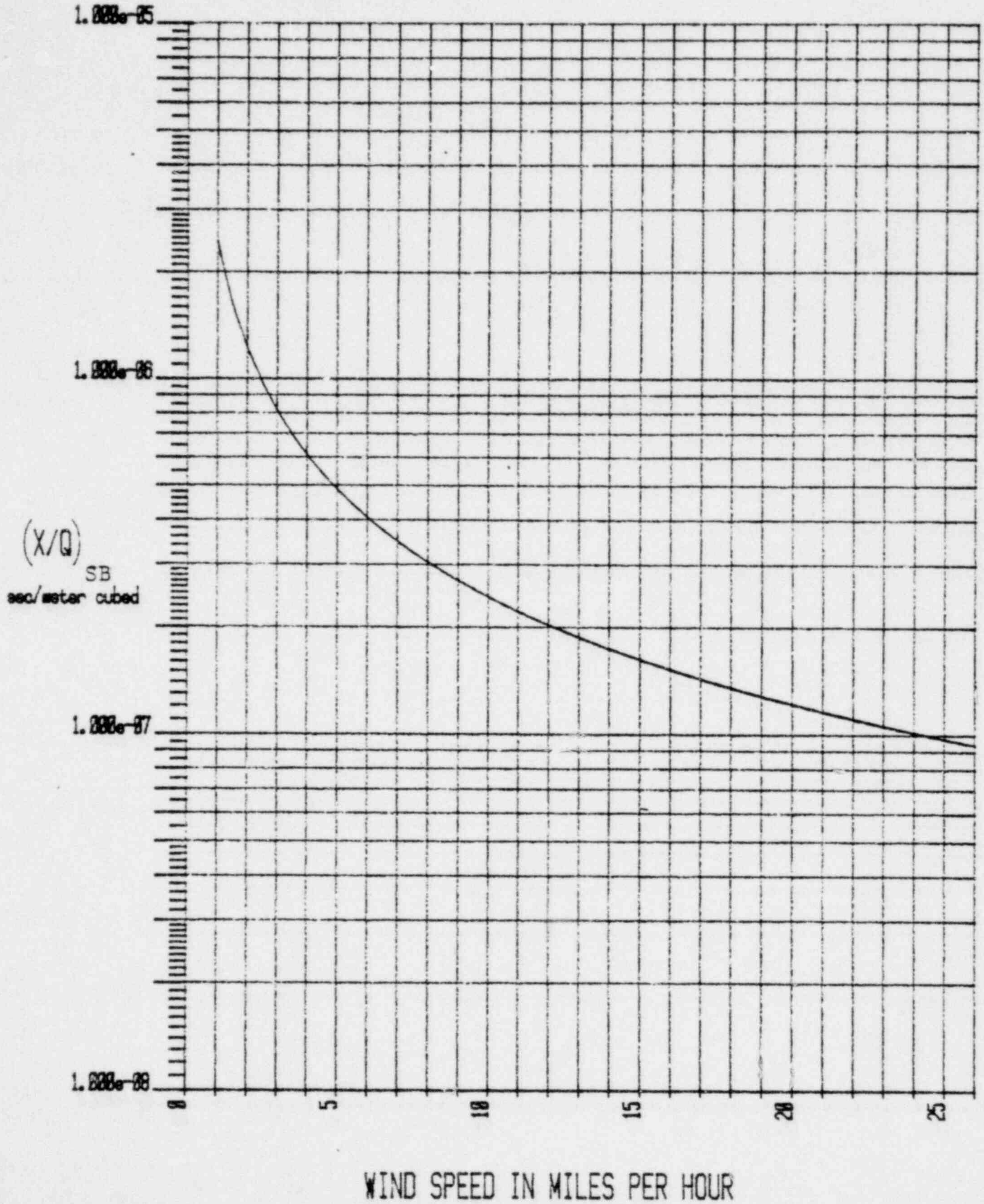


Fig. 15B Site Boundary χ/Q vs Wind Speed FOR STABILITY CLASS B

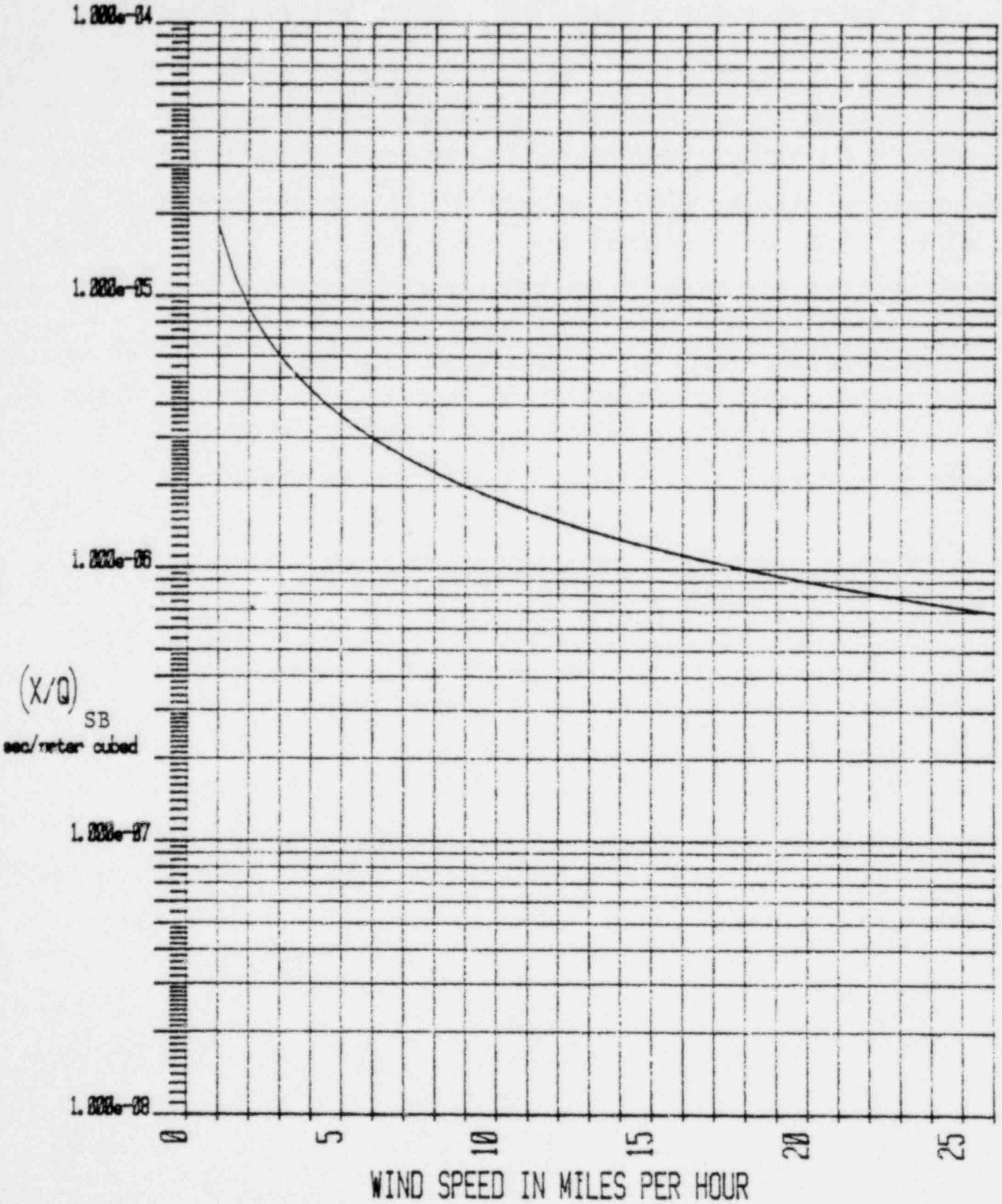


Fig. 15C Site Boundary χ/Q vs Wind Speed FOR STABILITY CLASS C

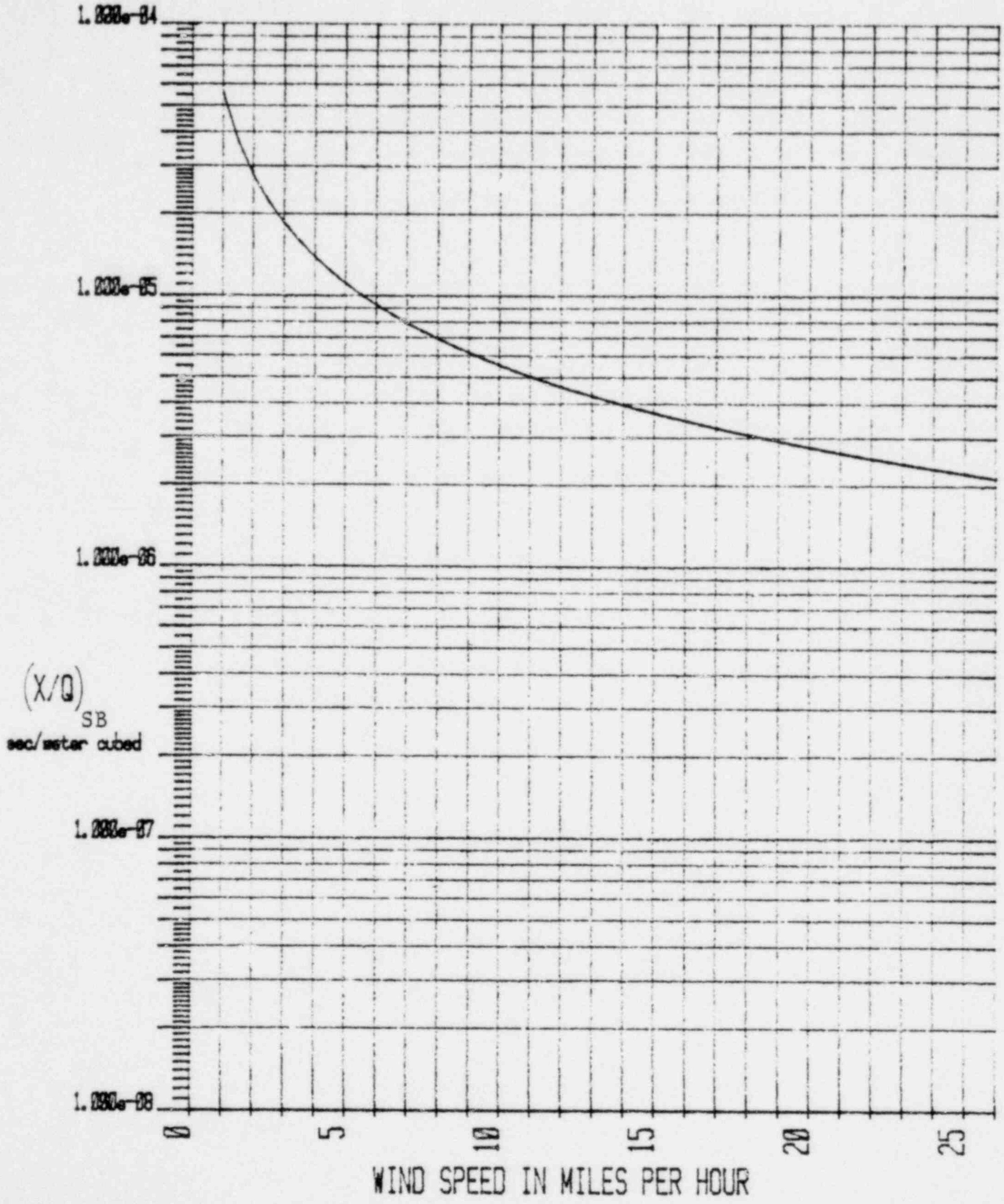


Fig. 15D Site Boundary χ/Q vs Wind Speed
FOR STABILITY CLASS D

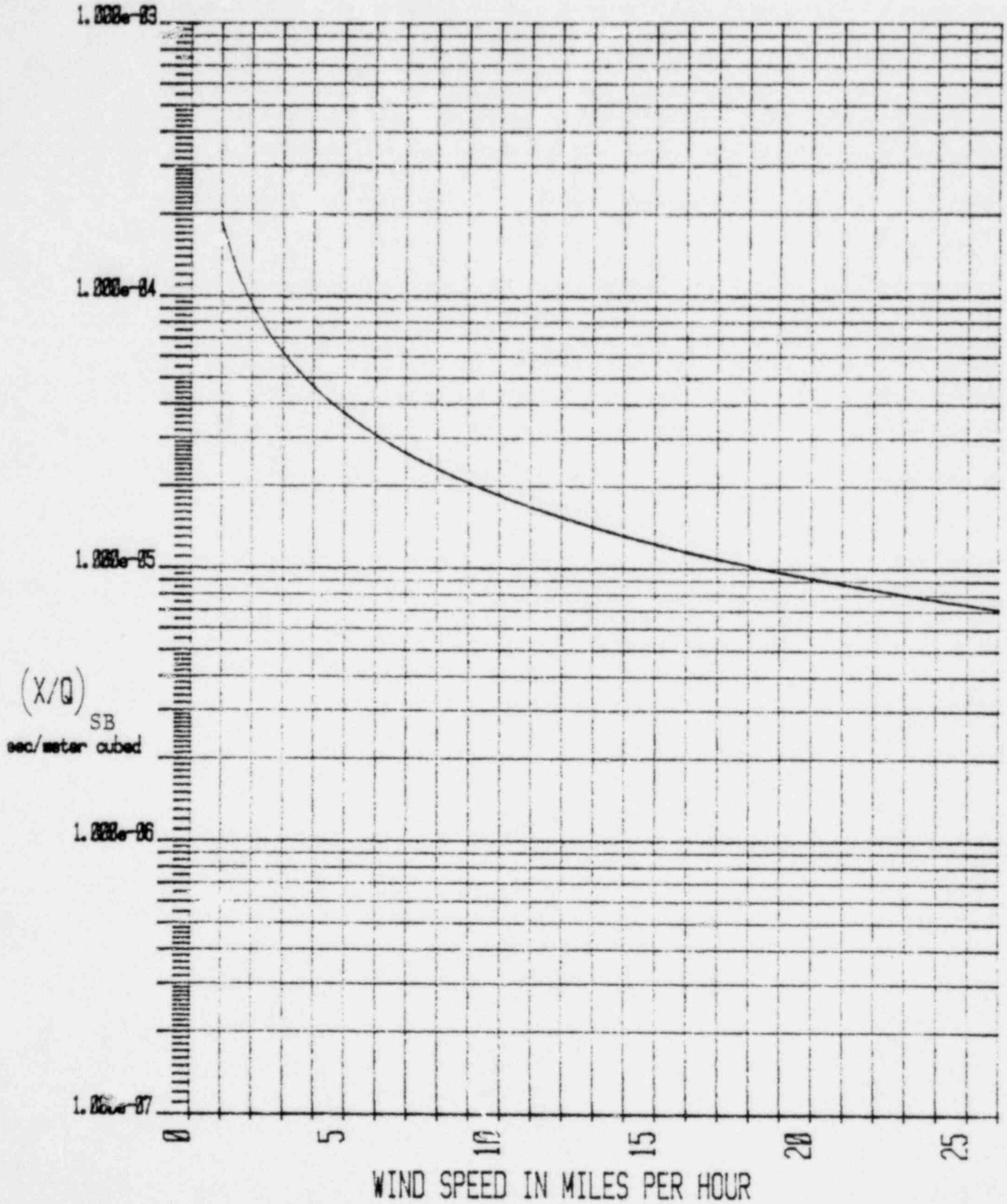


Fig. 15E Site Boundary χ/Q vs Wind Speed
FOR STABILITY CLASS E

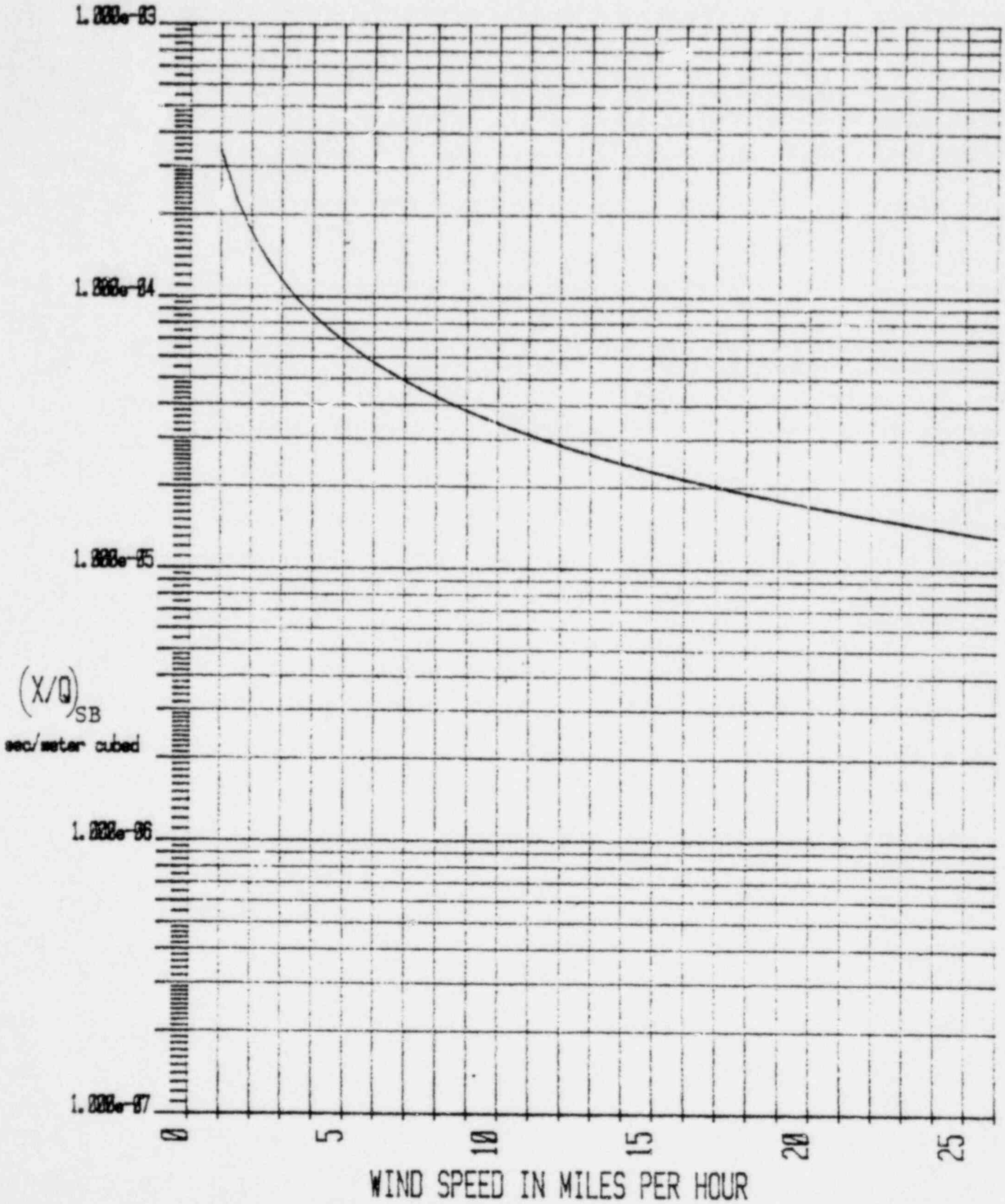


Fig. 15F Site Boundary χ/Q vs Wind Speed
FOR STABILITY CLASS F

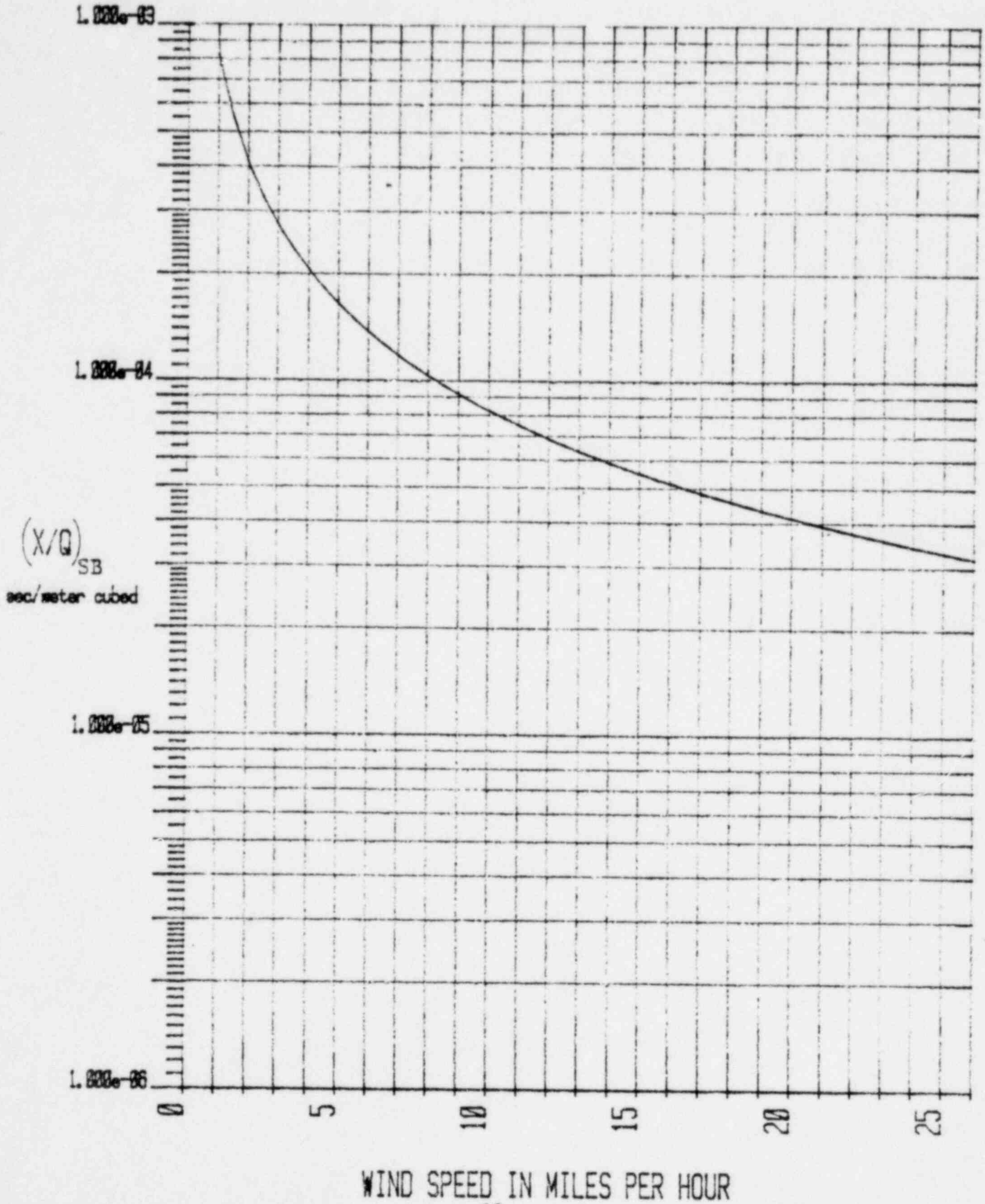


Fig. 15G Site Boundary χ/Q vs Wind Speed

FOR STABILITY CLASS G

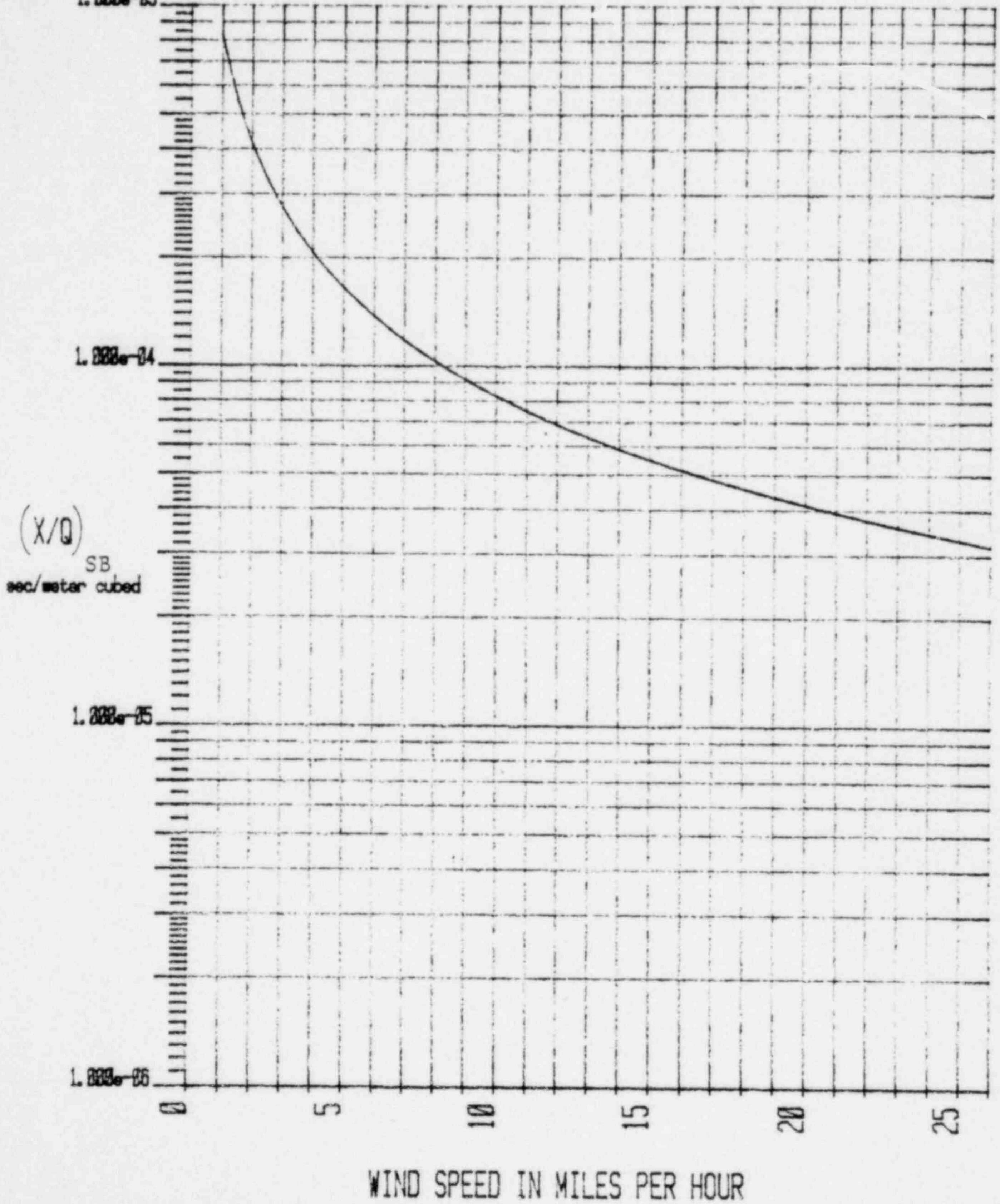


FIG. 16A $(\chi/Q)_x$ / $(\chi/Q)_{SB}$ versus DISTANCE
FOR STABILITY CLASS A

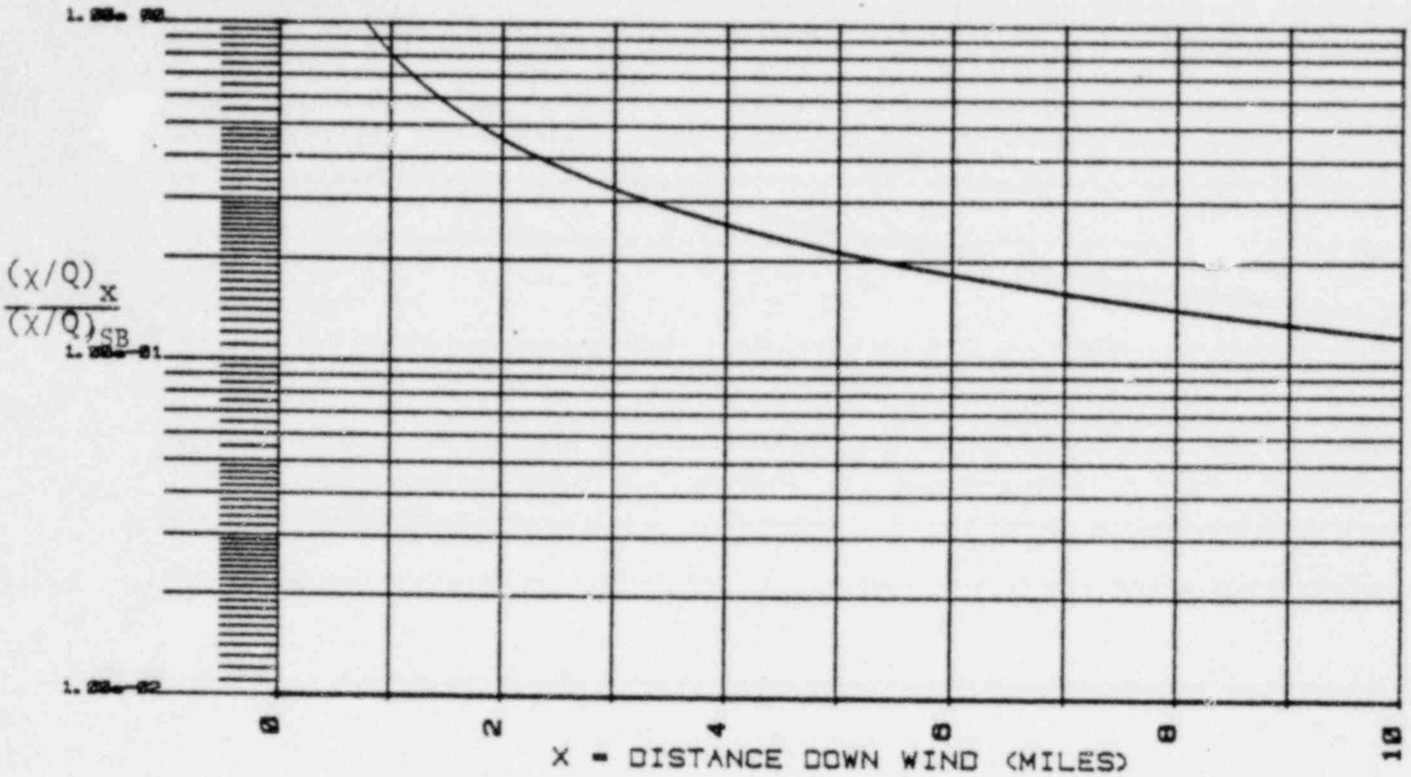


Fig. 16A $1/(2(\Sigma_y)^2)$ vs DISTANCE
FOR STABILITY CLASS A

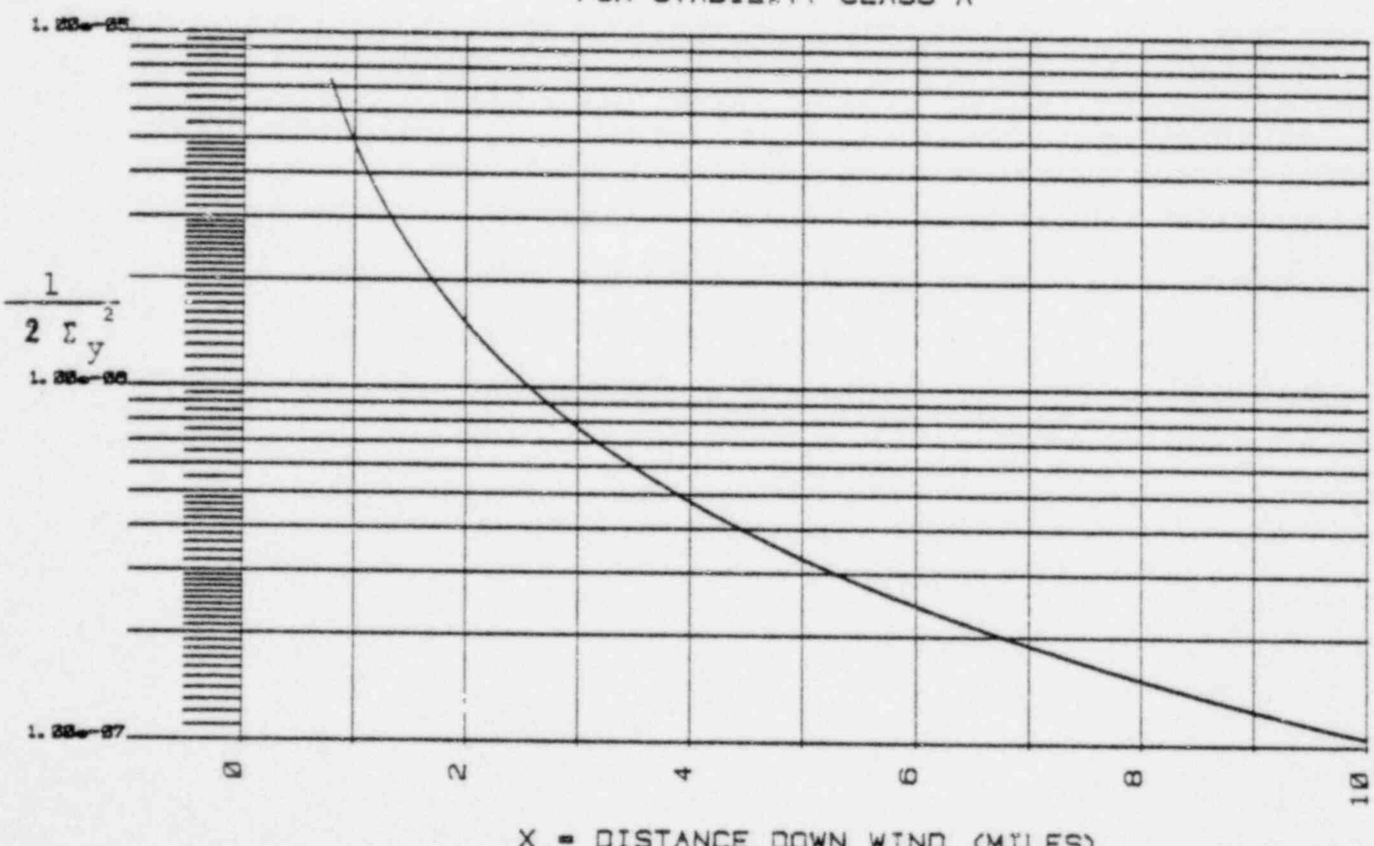


FIG. 16B $(\chi/Q)_x$ / $(\chi/Q)_{SB}$ versus DISTANCE

FOR STABILITY CLASS B

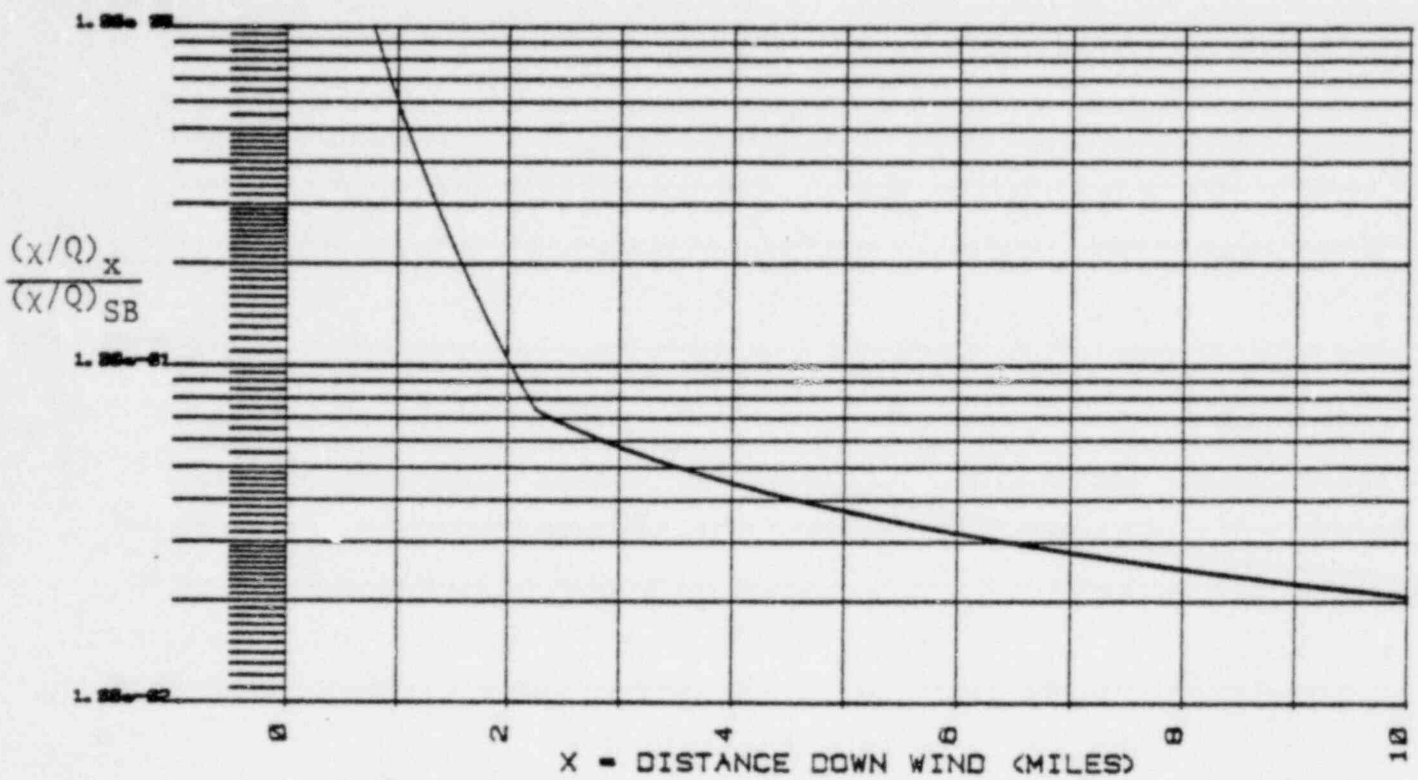


Fig. 18B $1/(2(\Sigma_y)^2)$ vs Distance

FOR STABILITY CLASS B

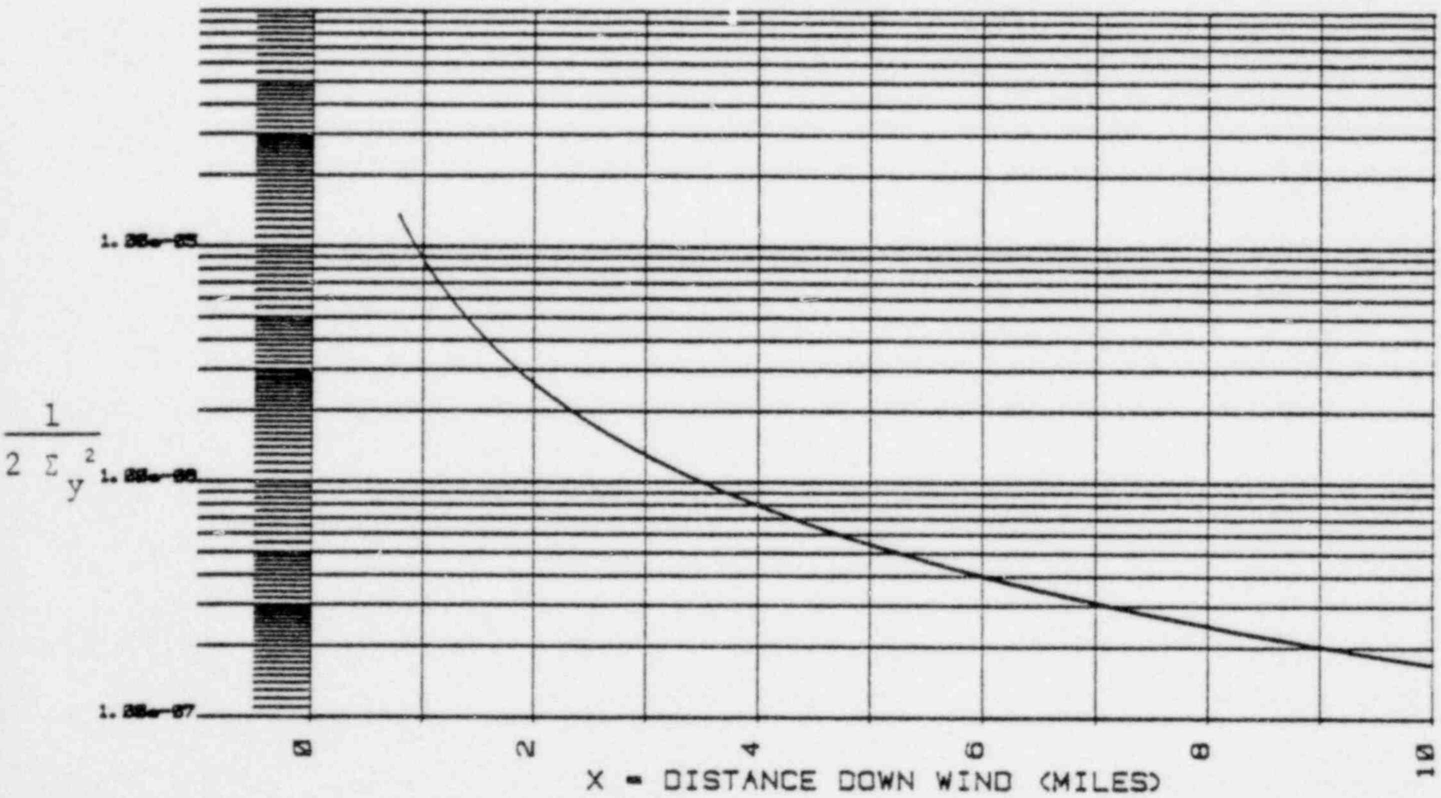


FIG. 16C $(\chi/Q)_x$ / $(\chi/Q)_{SB}$ versus DISTANCE
FOR STABILITY CLASS C

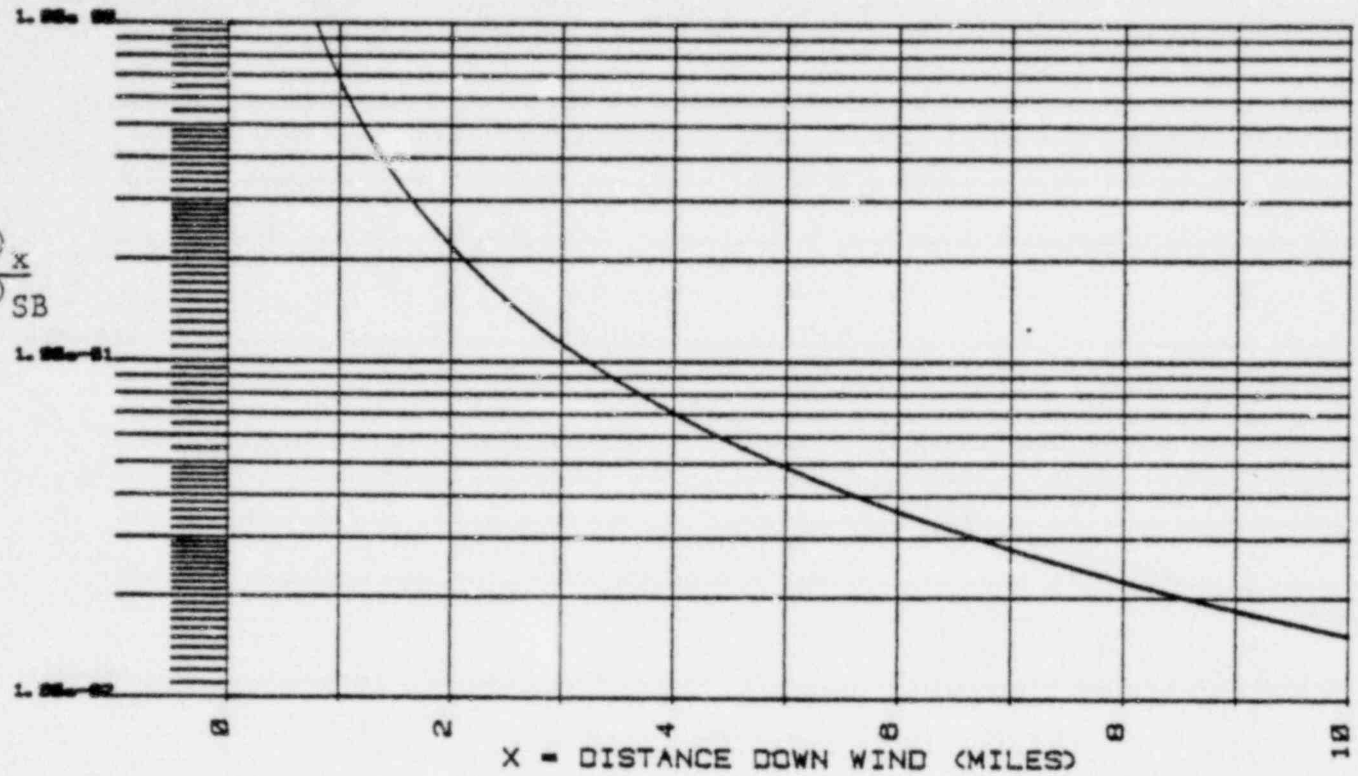


Fig. 16C $1/(2(\Sigma y)^2)$ vs Distance
FOR STABILITY CLASS C

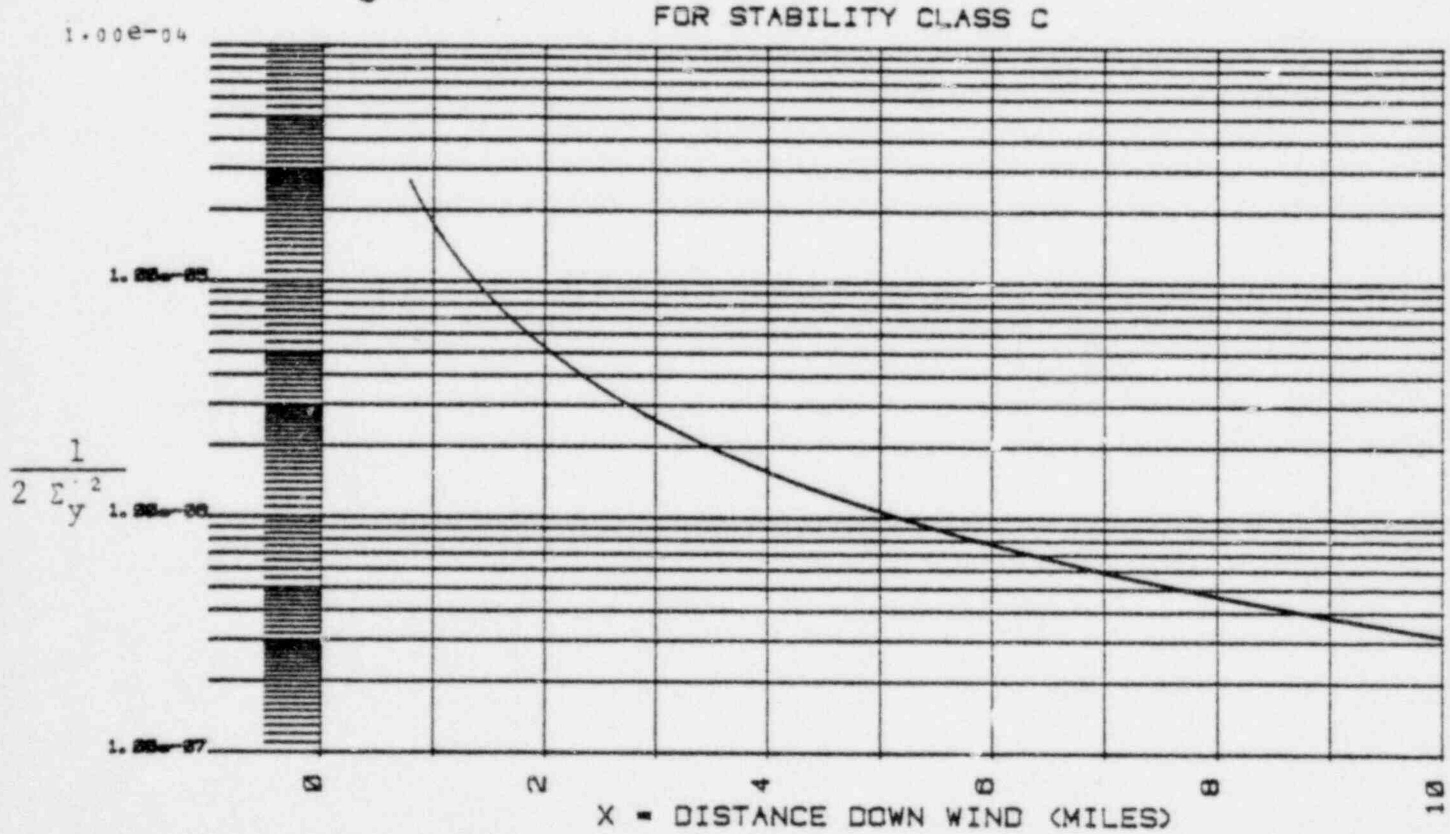


FIG. 16D $(\chi/Q)_x$ / $(\chi/Q)_{SB}$ versus DISTANCE
FOR STABILITY CLASS D

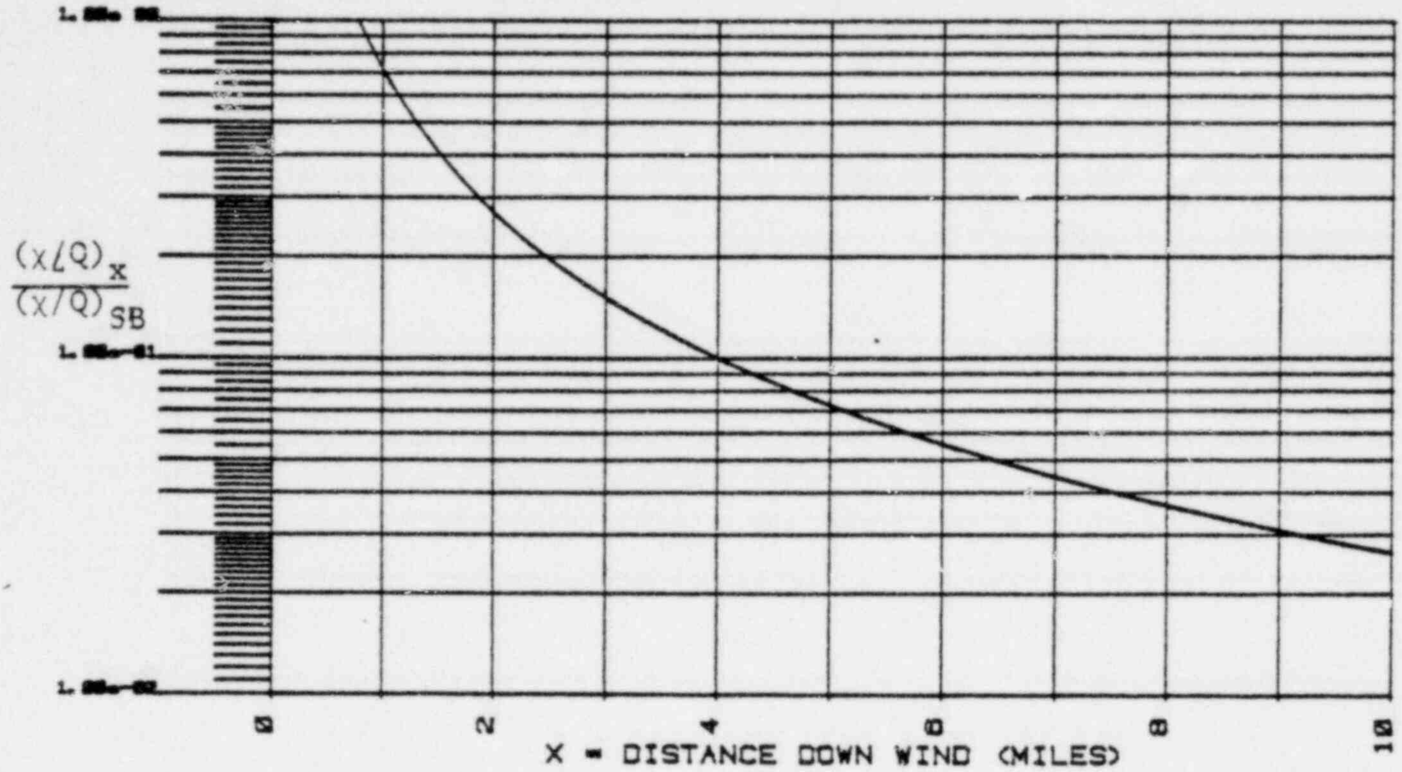


Fig. 16D $1/(2(\Sigma_y)^2)$ vs Distance
FOR STABILITY CLASS D

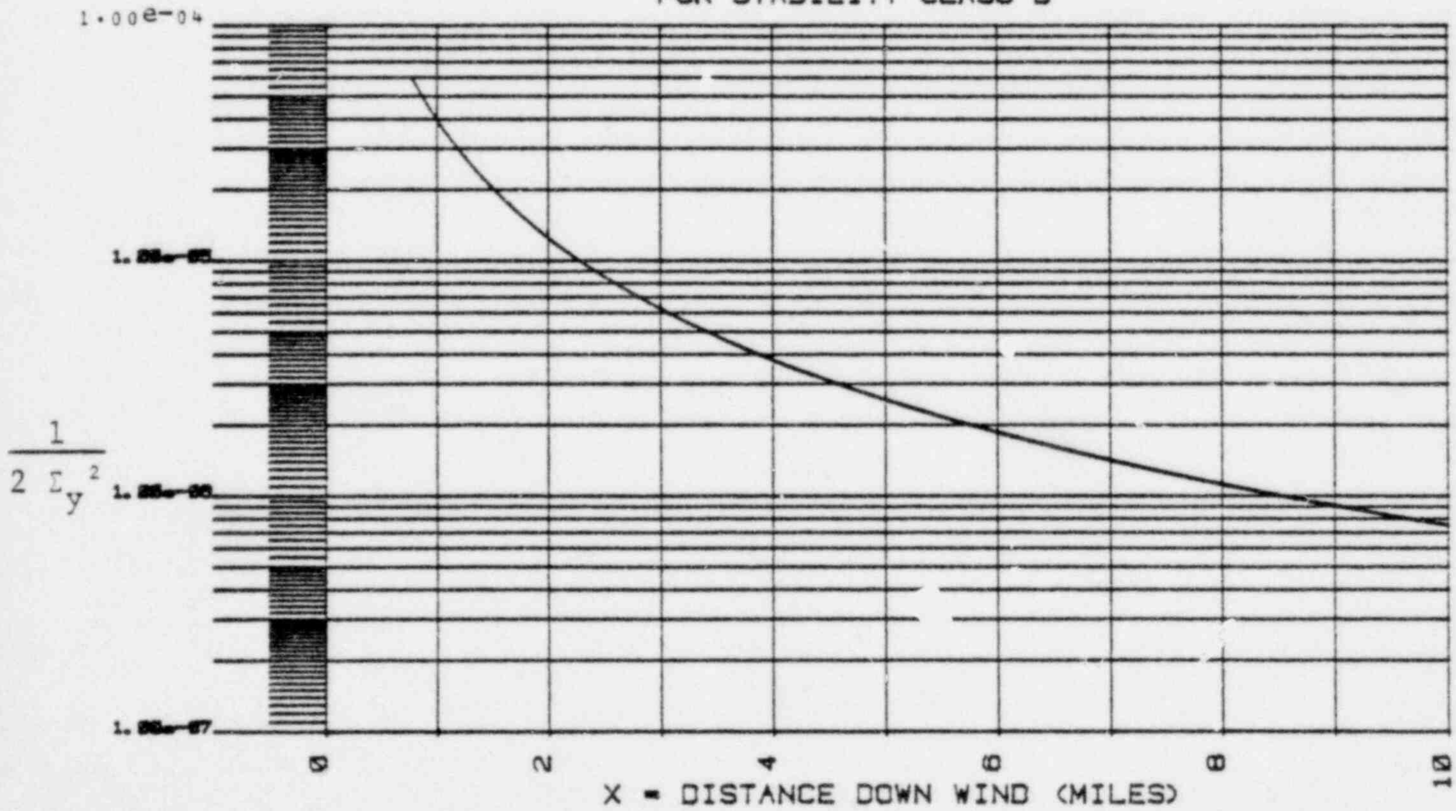


FIG. 16E $(\chi/Q)_x$ / $(\chi/Q)_{SB}$ versus DISTANCE
FOR STABILITY CLASS E

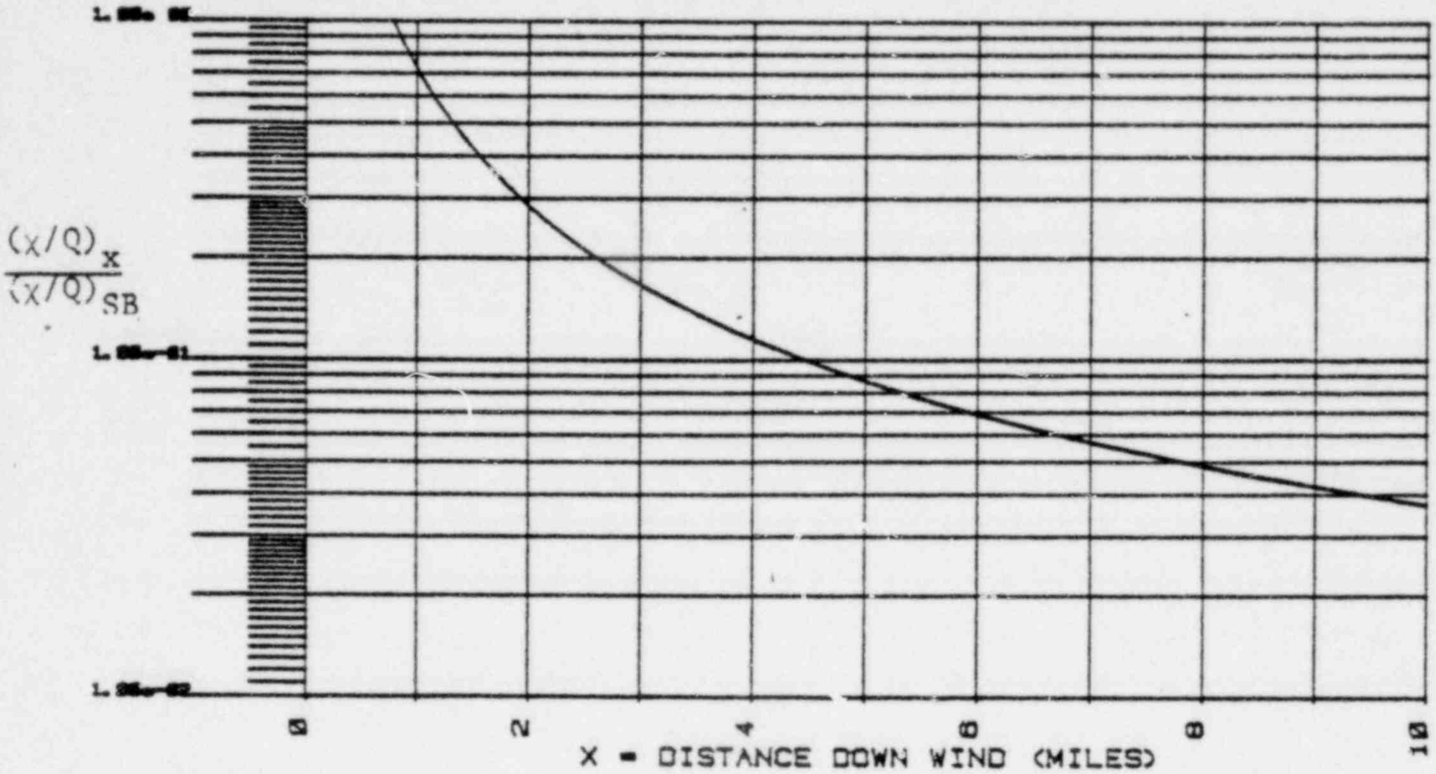


Fig. 16E $1/(2/\Sigma_y)^2)$ vs Distance
FOR STABILITY CLASS E

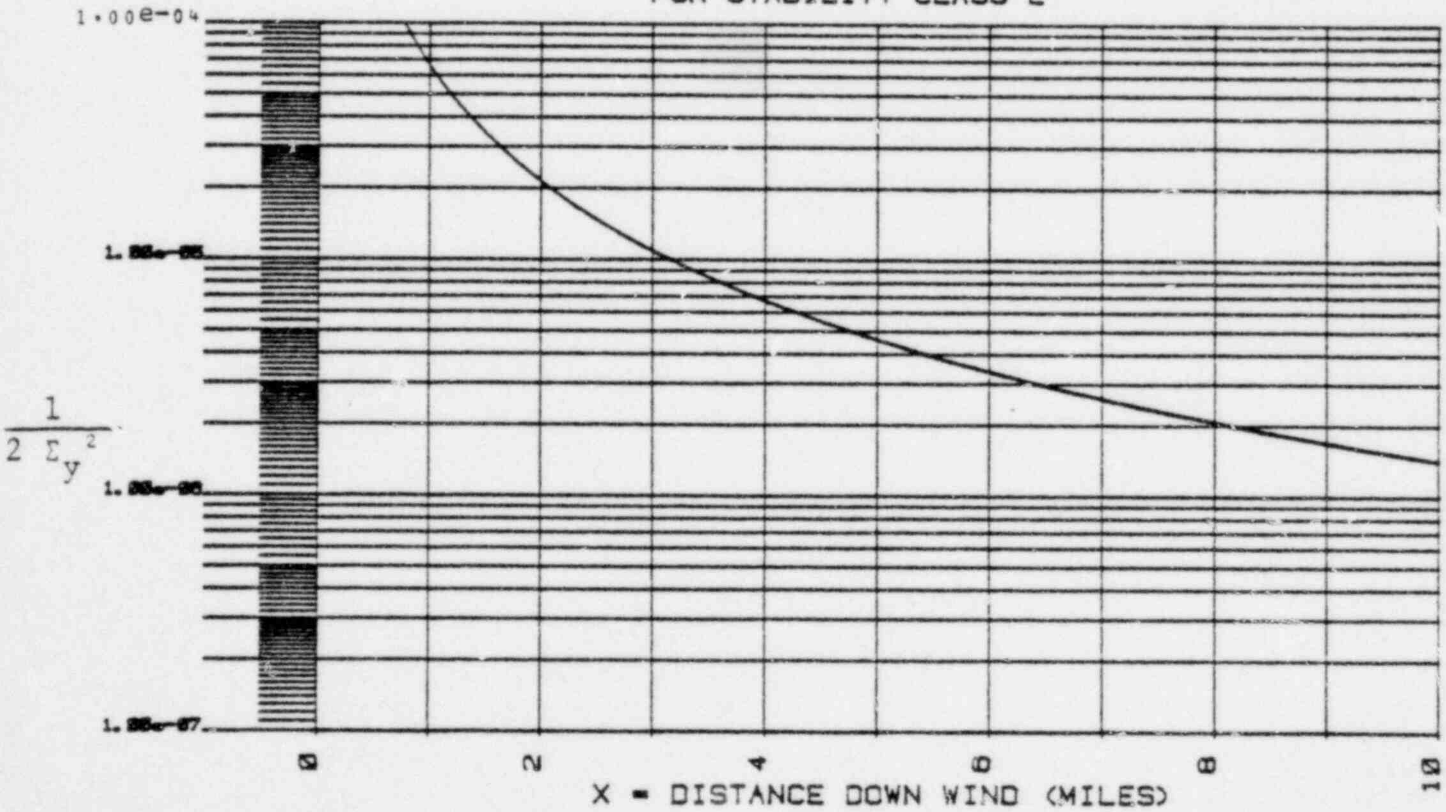


FIG. 16F $(\chi/Q)_x$ / $(\chi/Q)_{SB}$ versus DISTANCE

FOR STABILITY CLASS F

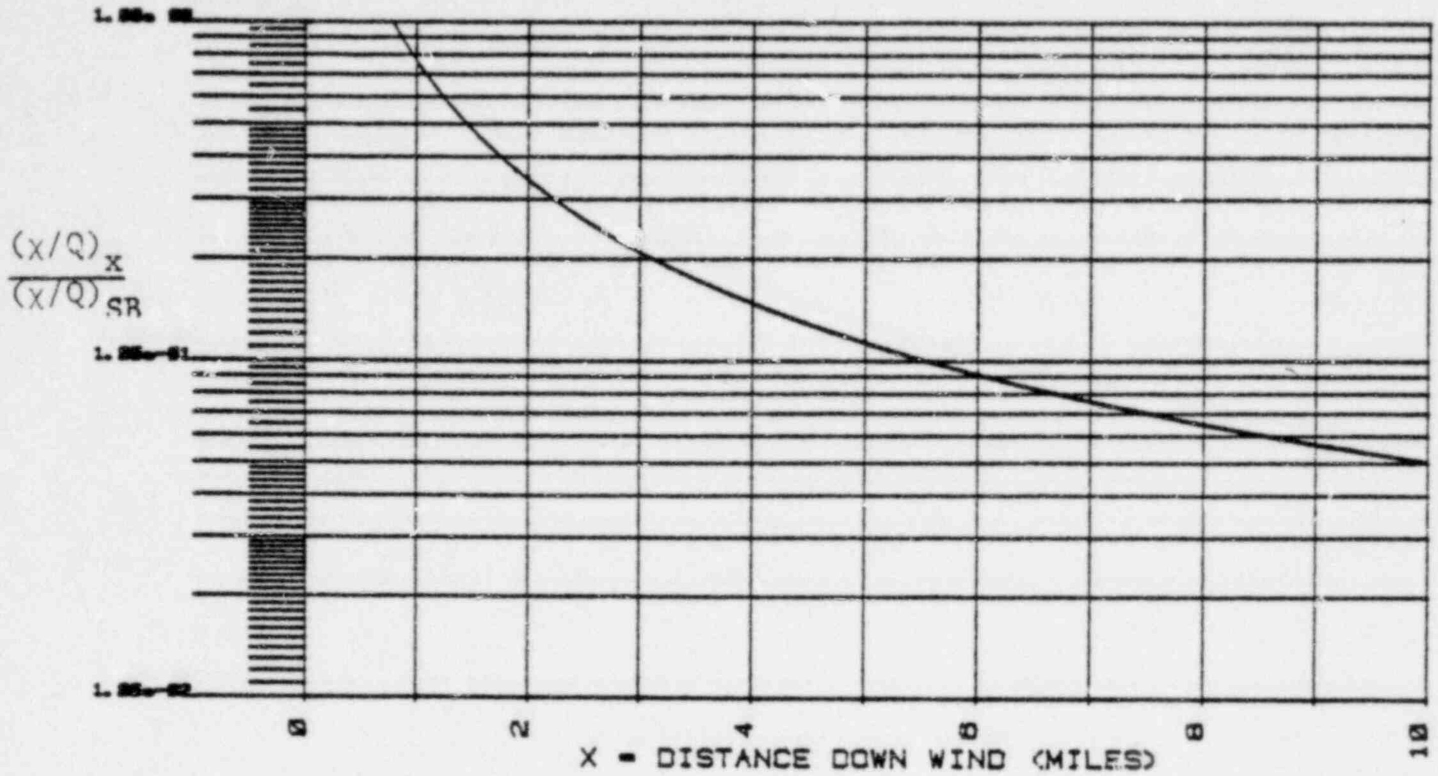


Fig. 16F $1/(2(\Sigma_y)^2)$ vs Distance

FOR STABILITY CLASS F

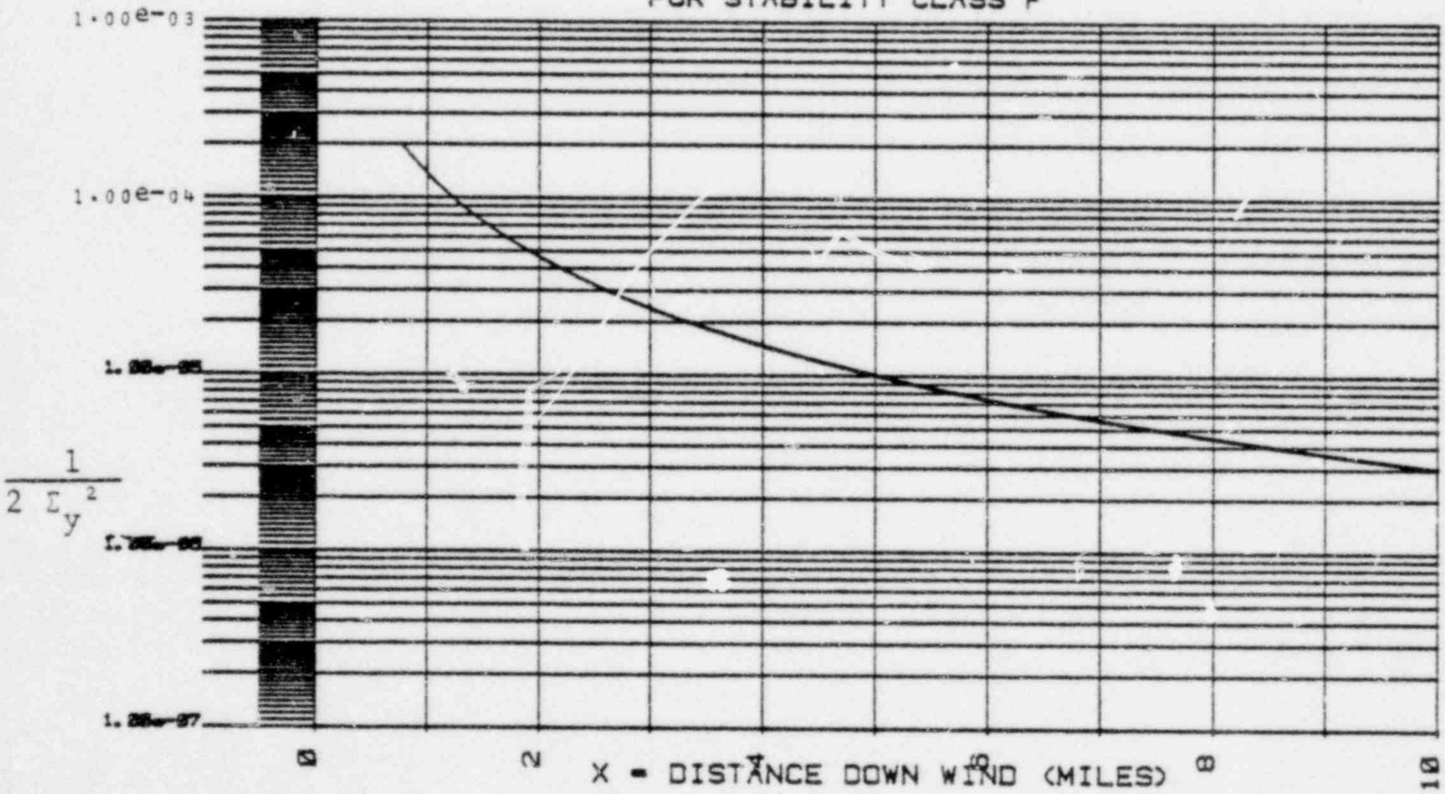
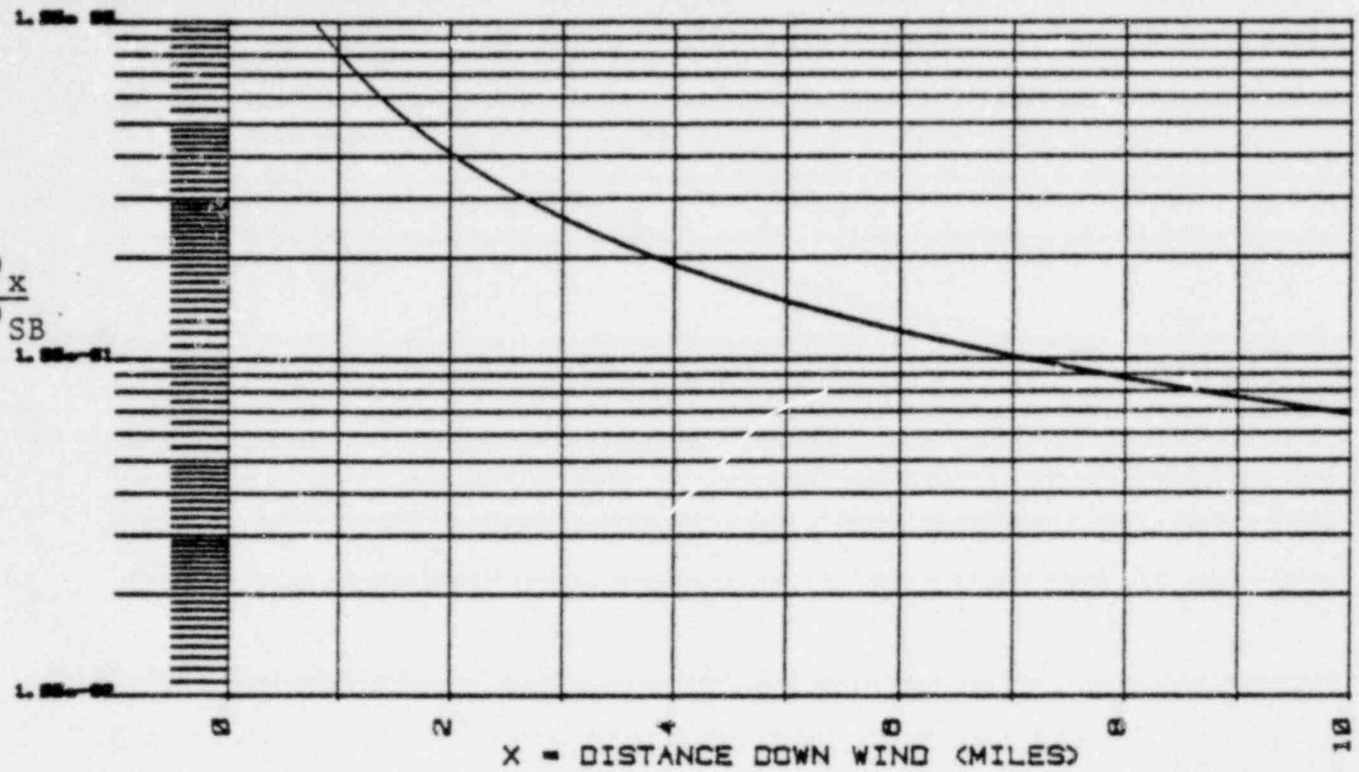


FIG. 16G $(\chi/Q)_x$ / $(\chi/Q)_{SB}$ versus DISTANCE



$1/(2(\Sigma_y)^2)$ vs Distance

Fig. 16G