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REGIONAL ISSUE IDENTIFICATION AND ASSESSMENT PROGRAM (RIIA)

A METHODOLOGY FOR ANALYZING
THE SHORT-TERM AIR QUALITY IMPACTS
OF NEW POWER PLANTS: ISSUE PAPER 5

BROOKHAVEN NATIONAL LABORATORY

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REGIONAL ISSUE IDENTIFICATION AND ASSESSMENT PROGRAM (RIIA)

ISSUE PAPER 5

A METHODOLOGY FOR ANALYZING THE SHORT-TERM AIR QUALITY IMPACTS OF NEW POWER PLANTS

by
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July 1979

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ABSTRACT

A simplified methodology is presented, based on Gaussian plume relationships, which could be used to assess regulatory constraints and vegetation damage for new power plants. Data input requirements include:

- (a) power plant size (MW),
- (b) fuel type, sulfur content, and level of control,
- (c) nearby terrain elevation difference, with respect to stack base, for critical receptors.

Based on sample calculations the 24-hour PSD increment is seen to be the most restrictive, using the ASME dispersion coefficients. An 800-MW plant (which is close to the optimum size from cost and reliability considerations according to a recent analysis), could be forced to reduce emissions below the levels assumed in this paper if adverse conditions were encountered. For example, terrain features higher than about 300 m at the critical distance from the plant could be restrictive, as could sufficiently persistent winds that would confine 24-hour plume spreading to $< 10^\circ$.

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PREFACE

This paper is one of a series prepared for the Regional Issue Identification and Assessment Program (RIIA) of the Office of Technology Impacts, U.S. Department of Energy. The intent of this report series is to document methodologies appropriate to the regional assessments program and to provide detailed technical analysis of important regional issues; the series thus augments the regional analyses of DOE scenarios published by BNL for the three Federal Regions in the Northeast. The papers in this series prepared to date include:

W. Metz, Socioeconomic Impacts of Proposed Power Plants in the Northeast, Issue Paper 1, BNL 51288, Brookhaven National Laboratory, Upton, N.Y.

R. E. Meyers, L. I. Kleinman, T-Y. Li, and R. T. Cederwall, Atmospheric Long-Range Transport Lead Laboratory Methodology, Issue Paper 2, BNL 51289, Brookhaven National Laboratory, Upton, N.Y.

C. Bryant, Selected Institutional Aspects of Energy Development in the Northeast, Issue Paper 3, BNL 51290, Brookhaven National Laboratory, Upton, N.Y.

E. Kaplan, A Methodology for Analyzing the Water Quality Impacts of Cooling Tower Blowdown, Issue Paper 4, BNL 51291, Brookhaven National Laboratory, Upton, N.Y.

F. W. Lipfert, A Methodology for Analyzing the Short-Term Air Quality Impacts of New Power Plants, Issue Paper 5, BNL 51292, Brookhaven National Laboratory, Upton, N.Y.

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1 INTRODUCTION

1.1 Modeling Requirements

Short-term air quality analysis is quite simple and straightforward, in principle, using Gaussian dispersion models, but has not found widespread application to national energy scenario evaluation because of massive data input requirements. These requirements include not only short-term meteorological data over a sufficient period of record but also detailed descriptions of the sources, including stack and flue gas exit data, and of the surrounding terrain. As a result, it has often been necessary to resort to linear rollback methods, which estimate future ambient pollutant concentrations by scaling past (measured) concentrations by the ratio of future to past emissions. This method is appropriate only for expansion of or additional controls on a single source, assuming that the measured concentration baseline does in fact reflect only that source. Obviously, when new additional pollution sources are being considered, rollback alone cannot provide accurate estimates of future short-term concentrations unless the new sources are co-located with the old and have nearly identical characteristics.* Such conditions are unlikely to be realistic because of capacity constraints for a given site and regulatory constraints on the permissible deterioration of local air and water quality.

To obtain relief from this situation, it is necessary to categorize the type of information which is desired from the model. Two basic types of information are desired: regulatory constraints and input to pollution damage functions.

1.2 Regulatory Constraints

For most potential power plant sites, two showings must be made in order to obtain the necessary air permits: first, that the proposed facility will not create or exacerbate a violation of ambient air quality standards (state or federal), and second, that existing or baseline air quality will not be

*This is because two elevated point sources of identical characteristics, separated by some finite distance, will have their maximum ground level impact locations also separated by this distance, and therefore cannot have maximum impact at the same time and place. Similarly, co-located sources of different characteristics (stack height, for example) cannot impact the same point at the same time. Although there are conceivable circumstances for which simultaneous impact could occur from a tall stack upwind of a shorter stack, such special circumstances would normally be considered beyond the scope of a national energy scenario analysis.

deteriorated beyond the incremental limits set out in Part C, Section 163 of the 1977 Clean Air Act Amendments (CAAA), the so-called Prevention of Significant Deterioration (PSD) increments.*

It is possible, of course, that there are locations where existing air quality just meets the ambient standards, so that further deterioration by new sources up to the PSD increments would result in a violation. However, if the baseline air quality is a result of short-term impacts from existing point sources, simultaneous impact is quite unlikely, as explained in the footnote above. Thus, this situation is likely to be important only for a near-violation of the annual standard.

In all other cases, the governing regulation will be the PSD increment constraint. From a modeling point of view this is fortuitous, since background contributions from existing point sources may be ignored in analyzing this constraint unless the existing source came on-line after the date of the PSD baseline (August 1977).** All sources coming on-line after this date must be considered jointly for compliance with PSD increment consumption. As a practical matter, as explained above, only multi-unit sites are likely to result in substantial additive short-term impacts at the same time and place.

A further regulatory constraint for modeling purposes is the limit on stack height set forth in Section 123 of CAAA, the so-called good engineering practice (GEP) stack height. This section effectively limits stack height to a multiple of adjacent building height and thus removes an additional degree of freedom from the analysis of new sources. It is this constraint that facilitates a generic analysis of short-term power plant impact, as described below.

1.3 Damage Functions

In addition to checking for regulatory constraints to a given siting scenario, a further purpose of short-term modeling is to evaluate damage due to air pollution. With respect to crops and vegetation damage, the 3-hr standard (SO_2) is most appropriate.*** With respect to human health, the 24-hr standard

*In order to provide for future growth, states may elect to allocate only a percentage of these increments to any individual new source.

**The PSD baseline concentration is determined for a given AQCR by the date of the first PSD permit application or Aug. 7, 1977, whichever is later.

***It is recognized that ozone may cause significant vegetation damage as well, but these effects are often regional and are beyond the scope of this analysis.

is appropriate, but these standards have been set to protect human health with a margin of safety, so that it is difficult to conceive of health damage occurring at levels in the neighborhood of the PSD increments. It is possible, however, that calculations would be made for some unregulated pollutants for which there are no standards as yet, such as sulfates, for example.

From a practical modeling standpoint, it is important to define the type of receptor for which modeling results are desired, so that the local topography may be considered. One of the important parameters in diffusion modeling for elevated release sources is the elevation of the receptor with respect to stack height. Modeling in very rough, complex terrain is especially difficult and currently the subject of investigation. Fortunately, evaluation of crop damage is not pertinent to such complex terrain situations, so that a simple estimate of elevation difference between field and stack top (or stack base, since stack height will be a derived parameter) is all that is required. Since power plants must be located near a source of water, some estimate of elevation difference can usually be made from a topographical map, using water elevation for the stack base and the highest terrain elevation suitable for agriculture within, say 20 km, for the crop receptor elevation.

It is recognized that there may be situations warranting evaluation of non-agricultural vegetation damage, for which rougher terrain may be appropriate. It may not be possible to analyze such cases generically, but it is anticipated that these requirements will be less important, since locations of commercial value are less likely in extremely rough terrain.

1.4 Analytical Approach

In the analysis which follows, closed form solutions to the Gaussian plume equation are developed for worst case meteorology for 3-hr and 24-hr situations. The modeling technique uses a "universal" relationship for stack height based on GEP requirements and shows that the resulting ground level concentrations are virtually independent of power plant size, within the meteorological constraints. The important parameters, then, become terrain elevation and degree of pollution control. The use of "worst case" meteorology obviates the need for a detailed meteorological data base. It is necessary only to check that the worst case conditions are in fact reasonable for the location in question, a site-specific consideration.

1.5 Implementation

Appendix A presents a suggested rationale for implementing the methodology for use by the national laboratories, involving screening calculations based on a hierarchical decision table to identify cases for which more detailed scrutiny is appropriate. The methodology suggested in this paper is intended to serve as a calculational framework rather than as a prescribed algorithm, since there may be local conditions in various regions that merit special consideration.

2 MODELING METHODS

2.1 Standard Gaussian Plume Equations

The basic analytical tool is the Gaussian plume equation for steady-state diffusion from an elevated point source. For centerline (maximum) impacts, the equation reduces to

$$\frac{x}{Q} = \frac{e^{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2}}{\pi \sigma_z \sigma_y \bar{u}} \quad (1)$$

where $\sigma_z(x)$ and $\sigma_y(x)$ are the parameterizations of the plume-spreading statistics as a function of downwind distance x ; H is the effective release height; and $\bar{u}$ is the average wind speed, which is taken here to be the wind speed at stack height (H_s). Thus the effective release height is composed of the stack height plus a plume rise component ΔH , which has been taken from the work of Briggs¹:

$$\Delta H = \frac{1.6F^{1/3}x^{2/3}}{\bar{u}} \quad (\text{for neutral and unstable atmospheres}) \quad (2)$$

$$\Delta H = 2.9(F/\bar{u}s)^{1/3} \quad (\text{for stable atmospheres}) \quad (3)$$

where F is the buoyancy flux in $\text{meters}^4/\text{sec}^3$, and s is the atmospheric stability parameter $\left(\frac{\partial \theta}{\partial z}\right) \frac{g}{T_a}$ in sec^{-2} . The downwind distance x in Eq. (2) is subject to the constraint of maximum plume rise, given by

$$x_{\max} = 120.71F^{2/5} \quad (4)$$

If Eq. (1) is differentiated with respect to x to find the location of the maximum downwind concentration and its value, closed form analytical solu-

tions depend on the parameterization of σ_y and σ_z . Since the ASME (Brookhaven) coefficients have been shown to yield good results for elevated sources,² these parameterizations are recommended, although a similar analysis could be developed for some other parameterization. They are of the form

$$\sigma_y = kx^p, \quad (5)$$

$$\sigma_z = lx^p. \quad (6)$$

Values of k , l , and p for four atmospheric stability classes are given in Table 1.

Table 1
Values for ASME Dispersion Coefficients

Stability class	Horizontal, σ_y		Vertical, σ_z	
	k	p	l	p
Very unstable	0.40	0.91	0.40	0.91
Unstable	0.36	0.86	0.33	0.86
Neutral	0.32	0.78	0.22	0.78
Stable	0.31	0.71	0.06	0.71

In this case, the maximum concentration is given by

$$\left(\frac{\chi}{Q}\right)_{\max} = \frac{2}{\pi \bar{u} e H^2} \left(\frac{\sigma_z}{\sigma_y}\right) \quad (7)$$

and the location by evaluating

$$\sigma_z(x) = H/\sqrt{2} \quad (8)$$

for the corresponding distance x .

In order to find the worst case wind speed, Eq. (2) or (3) is substituted into Eq. (7), and the result is differentiated with respect to $\bar{u}$. For neutral and unstable atmospheres, the result is simply $\Delta H = H_s$. For large power plants or low stack heights, this can lead to large implied values of the worst case wind speed, given by

$$\bar{u}_{W.C.} = \frac{1.6F^{1/3} x_{\max}^{2/3}}{H_s} \quad (9)$$

It is therefore necessary to confirm that speeds of this magnitude do in fact occur at the site in question over the averaging time of interest. If not, the maximum credible wind speed should be used in Eq. (7). The maximum ground level concentration for all downwind distances and wind speeds is then found by substituting $H = 2H_s$ and the appropriate value of $\bar{u}$ into Eq. (7).

For the stable case, no optimum wind speed solution is found, which confirms that the low wind speed cases are the worst. This case requires use of the plume rise equation for "calm" winds¹ and is likely to be important only for rough, elevated terrain. Stable atmospheric conditions are not considered further in this analysis although it is recognized that these conditions can lead to high concentrations in some cases.

2.2 Sector Averaging for Longer Time Periods

The above relationships are appropriate for short-term concentration estimates, 1 to 3 hr, typically. For longer terms, the meandering of the wind (horizontally) must be accounted for, and this is frequently accomplished through the concept of sector averaging. The Gaussian relationship for σ_y is then replaced with the assumption that the plume is arbitrarily (usually uniformly) distributed over some increment of wind direction range, typically a 22.5° sector, which is appropriate for a 24-hr average estimate, for example. There may, however, be extreme conditions for which smaller sector widths are appropriate. The Gaussian equations then become

$$\frac{\chi}{Q} = \frac{e^{-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2}}{\sqrt{2\pi}\sigma_z\bar{u}c} \quad (10)$$

where c is the sector width, given as $c = 2x \tan(\phi/2)$ for a sector of angle ϕ . After substitution of Eq. 6, differentiation with respect to x , and simplification, the appropriate maximum downwind concentration in this case becomes

$$\frac{\chi}{Q} = \frac{e^{-\frac{1}{2}\frac{p+1}{p}}}{\sqrt{2\pi}\bar{u}H \tan\frac{\phi}{2} \sqrt{\frac{p}{p+1}} \frac{H}{\ell} \left(\sqrt{\frac{p}{p+1}}\right)^{1/p}} \quad (11)$$

where the distance of maximum impact is given by

$$x = \frac{H}{\ell} \left(\sqrt{\frac{p}{p+1}}\right)^{1/p} \quad (12)$$

Similarly, differentiating to find the worst case wind speed leads to

$$\Delta H = p H_s \quad (13)$$

and

$$\left(\frac{\chi}{Q}\right)_{\max} = \frac{e^{1/p} \left(\frac{e H_s^2 p}{p+1} \right)^{-\frac{1}{2} \left(\frac{p+1}{p} \right)}}{\sqrt{2\pi \bar{u}} \tan \phi / 2} \quad (14)$$

where the "worst case" or maximum value of $\bar{u}$ is used.

2.3 Influence of Terrain Elevation

All of the above equations are strictly appropriate only in essentially flat terrain; elevated terrain features can cause concentrations to increase over the values given above, either because the z term is no longer zero or because of streamline distortion due to flow over the terrain.

Two generalized terrain configurations were considered: a level plateau beginning with a bluff at some distance close to the plant, and a ramp beginning at the plant with a continuous elevation increase with downwind distance. Since this paper does not consider individual wind directions, the worst cases may be considered by collapsing the most prominent terrain features in any direction onto a single composite radial profile.

For the plateau case, Eq. (7) applies, except that the effective stack height is reduced by the effective bluff height (frequently assumed to be half of the physical height because of streamline distortion).⁴ The reduced physical height leads to higher optimal wind speeds, as shown by Eq. (9), which may turn out to be a limiting factor.

In the case of a ramp of slope α , Eq. (1) is replaced by

$$\frac{\chi}{Q} = \frac{e^{-\frac{1}{2} \left(\frac{H - \alpha x}{\sigma_z} \right)^2}}{\pi \sigma_z \sigma_y \bar{u}} \quad (15)$$

Differentiation with respect to x leads to

$$2\sigma_z^2 = (H - \alpha x) \left[H + \left(\frac{1-p}{p} \right) \alpha x \right] \quad (16)$$

When substituted into Eq. (15), the family of maximum concentrations is given by

$$\frac{x}{Q} = \frac{2e^{-\left[\frac{1 - \frac{\alpha x}{H}}{1 + \left(\frac{1-P}{P} \right) \frac{\alpha x}{H}} \right]}}{\bar{u} H^2 \left(1 - \frac{\alpha x}{H} \right) \left[1 + \left(\frac{1-P}{P} \right) \frac{\alpha x}{H} \right]} \frac{\sigma_z}{\sigma_y} \quad (17)$$

The worst case will occur at some optimal value of wind speed $\bar{u}$, which is related to stack height because of plume rise:

$$H = H_s + H = H_s + \frac{1.6F^{1/3} x_{\max}^{2/3}}{\bar{u}} \quad (18)$$

Substitution of (18) into (17) to eliminate either x or u did not yield a convenient closed form solution, but through numerical calculation it was observed that the maximum concentration was not very sensitive to wind speed values near (preferably slightly less than) the worst case wind speed for level terrain (Eq. 9). A graphical approach was thus selected for the solution of Eq. (17), which is made difficult since the optimal value of x , downwind distance, is generally not known a priori and will depend also on the distance along the composite radial elevation profile which yields the largest effective ramp slope (α).

2.4 Effect of Elevated Inversions

Elevated inversion layers that restrict vertical mixing can also affect ground level concentrations. If the plume is trapped above the stable layer, it is commonly assumed that the ground level concentration is zero. If the plume is trapped below a stable layer aloft, concentrations will be increased relative to the computations in this paper. The worst case of such trapping results in a doubling of the concentration for unlimited mixing. Because of the generally transient nature of such elevated layers, doubling should only be applied to one or three hour concentration estimates.

3 POWER PLANT CHARACTERISTICS

3.1 Stack Height Constraints

The above development leads to a family of solution when the stack height (H_s) and the source strength (Q, F) are free parameters. However, the imposition of GEP stack height constraints links the two together.

Briefly, the GEP stack height (H_G) is defined³ as

Figure 1. Stack and Building Heights.

$$H_G = H_B + 1.5L \quad (19)$$

where L is the lesser of building height H_B and width W (in the direction perpendicular to the wind). For buildings of aspect ratio less than unity ($W > H$), Eq. (19) yields the familiar "2 1/2 times" height rule for isolated buildings.

In theory, the volume of any combustion source should be proportional to the throughput rate, for constant residence time. This would lead to a relationship between unit size and stack height, involving Eq. (19). An investigation of power plant boiler house heights was made,* and such a relationship was determined (Figure 1). The empirical equation

$$H_B = 9.19(MW)^{0.326} \quad (20)$$

is valid for oil- and bituminous coal-fired plants. Gas-fired units tend to be smaller; lignite and sub-bituminous coal-fired plants somewhat taller. In developing Eq. (20), 25 data points were used which had a correlation coefficient of 0.934. The larger units tended to be new plants under construction

*The original relationship was developed for 13 new power plants, for which relevant data were obtained from the architect/engineer's firms and operators. Additional data are shown on Figure 1 for the New York Power Pool system and from Reference 9, which confirmed the relationship given by Eq. (20).

and the smaller units, existing plants. However, the empirically derived exponent of 0.326 is comfortably close to the $1/3$ power expected on theoretical grounds.

Stack heights were then estimated on two bases: first, on the basis of an aspect ratio of 1.8, which gives a minimum stack height of $1.833H_g$; second, the maximum stack height of $2.5H_g$. It should be recognized that multiple-unit plants will generally be able to claim the maximum height, since there will be some wind direction for which the adjacent building widths are additive (and obviously the stack design must be based on the worst case: those wind directions that might lead to downwash).

3.2 Power Plant Characteristics

Obviously in order to carry through calculations for the purpose of estimating ambient concentrations, some assumptions must be made regarding fuel types, efficiencies, and boiler design. The following data were used for illustrative calculations.

3.2.1 Fuel Rates

The plant heat rate was assumed to be 9750 Btu/kWh, including scrubber losses, and the coal heating value, 10,833 Btu/lb, approximately the 1976 national average.

3.2.2 Sulfur Content (Coal)

Two percent sulfur content was assumed with 80% removal by wet scrubbing. This gave a factor of 0.9075 g/sec SO_2 emitted per MW of capacity.

3.2.3 Flue Gas Exit Conditions

Two exit gas temperatures were assumed: $170^\circ F$ ($350^\circ K$) and $250^\circ F$ ($394^\circ K$), according to varying amounts of stack gas reheat from the saturation temperature of about $125^\circ F$ ($325^\circ K$).⁵ The reheat energy requirements are assumed to be included in the above plant factors. The flue gas flow rate was assumed to be 13 lb/sec per lb of fuel burned, including air heater leakage, which gives an expression for F of $1.3875 \text{ m}^4/\text{sec}^3 \cdot \text{MW}$ for the $250^\circ F$ case and $0.771 \text{ m}^4/\text{sec}^3 \cdot \text{MW}$ for the $170^\circ F$ case.

Multi-flue stack configurations (more than one boiler feeding a common stack), which would lead to additional plume rise, were not considered. However, because of maintenance shut-downs, the worst case would be one boiler on line at a time, which is the case considered in this paper.

Figure 2. Worst case wind speeds (for maximum concentration).

4 CONCENTRATION ESTIMATES

4.1 Meteorological Conditions

The above equations were used to estimate ground level maximum SO_2 concentrations for a family of power plants ranging from 25 to 1000 MW in design capacity. Since use of the worst case wind speed relationship, Eq. (9), removes the selection of wind speed as an arbitrary input parameter, it is necessary to check whether these speeds are reasonable. The following power law relationship was used to convert from stack height to 10 m as the reference height:

$$\frac{u}{u_{10}} = \left(\frac{z}{10} \right)^n$$

where $n = 0.09, 0.11, 0.14$ for very unstable, unstable, and neutral atmospheres, respectively.

Figure 2 presents the results of these calculations, and the optimum speeds are seen to be between 2 and 13 m/sec (4 and 30 mi/hr). Converted to the 10-m reference level, these speeds are seen to be reasonable for the neutral stability class, but the upper range can be too high¹⁰ for the unstable and very unstable classes. Conventional assumptions for the maximum credible wind speeds for these classes are 15 and 8 mi/hr, respectively (at the 10-m reference height). For this reason, concentration estimates for these stability classes were limited to these maximum speeds, adjusted to stack height.

4.2 Neutral Atmosphere Calculations

Figure 3 presents calculations for the neutral atmosphere conditions, which comprise the widest range of credible wind speeds. Short-term (1-3 hr)

Figure 3. 1-3 hr maximum concentration estimates for two stack heights and exhaust gas temperatures, neutral atmosphere.

Figure 4. Concentration estimates for low stack 170°F case, level terrain, neutral atmosphere.

Figure 5. Terrain elevation correction factor.
(neutral atmosphere)

estimates are given for the two stack heights and the two exit gas temperatures, for no terrain elevation. In all cases, the lowest concentrations occur for the smaller plants, up to about 100 MW, but the increase with size is quite modest.

These SO_2 concentrations are well below the 3-hr PSD increment for Class II areas ($512 \mu\text{g}/\text{m}^3$), so that persistence for > 3-hr, leading to consideration of the 24-hr PSD increment, becomes the critical factor.

Accordingly, sector averaged concentrations are given for the worst stack case and for flat terrain for two sector widths, 10° and 22.5° in Figure 4. Again, the trend with plant size is quite modest, slightly favoring the larger plants.

Terrain corrections (Figure 5) can be appreciable as the terrain height approaches the stack height. However, conventional modeling allows the assumption that, for neutral and unstable conditions, the plume is lifted by half of the terrain feature elevation difference,⁴ so that the effective ramp slope α could be taken as half of the value obtained from topographical maps. Part of the concentration increase shown in Figure 5 is due to the shorter travel distance resulting from sloping terrain.

Figure 6. Maximum 1-3 hr concentration estimates for unstable and very unstable atmospheres.

4.3 Unstable Atmospheric Calculations

Figure 6 presents the results for the ASME dispersion unstable and very unstable classes. The maximum concentrations for these two classes are quite similar because of the limitations on wind speed. For the purposes of assessing possible regulatory limitations, these values should be doubled to allow for possible elevated inversion effects as discussed above. The appropriate PSD limit here is the 3-hr value, since unstable conditions are not likely to persist with constant wind direction for a sufficient time to threaten the 24-hr value. Also, because of the normal diurnal cycling, limited mixing conditions are not likely to persist at precisely the critical height for long periods.

5 UTILIZATION OF MODELING RESULTS

The simplified analysis described above is capable of providing short-term incremental concentration estimates at the point of maximum ground level impact for single sources. To estimate background concentrations, the long-range transport (LRT) model⁶ can be used.* The sum of point-source impact and

*Background SO₂ concentrations are usually unimportant to short-term air quality. However, accuracy would be improved if LRT results were sorted by corresponding meteorological conditions rather than by using the long-term average background.

background is appropriate for comparison with ambient air quality standards, for determination of attainment status. The impact estimates alone are appropriate for comparison with the PSD increments, and the appropriate statistic for RIIA evaluation is percent of PSD increment consumed.

With respect to damage functions, it is important to note whether the function is linear or has a threshold. For example, chronic deposition of sulfur may have a linear beneficial effect on crop yields, provided that no acute exposure thresholds (leading to foliar damage) are exceeded.⁷ In such cases, the area weighted long-term concentration is appropriate, as provided by the BNL LRT model, for example.

However, for acute exposures above the threshold, it is important to account for the area of crops exposed, which would be the area "inside" the threshold isopleth. Note that it is not appropriate to use the peak concentration per se to estimate crop damage because, by definition, zero area is exposed to this level. Graphs like those in Figure 7 can be used to estimate the area between the peak concentration and the threshold value. Recent work by Jones et al.⁷ shows that the 3-hr thresholds for acute injury to soybean ($450 \mu\text{g}/\text{m}^3$) and to shortleaf pine ($340 \mu\text{g}/\text{m}^3$) are below the 3-hr PSD increment

Figure 7. Area within isopleths (typical).¹⁰

(512 $\mu\text{g}/\text{m}^3$); thus it is possible that a complying new power plant could in fact result in injury to these species.

In order to derive a net economic figure, the chronic effects (which could be either plus or minus) should be added to the sum of the acute effects. Since the methodology above estimates only maximum concentrations, it is necessary, in addition, to estimate the frequency of occurrence. Assuming that the LRT model represents the mean or median concentration and that the maximum 3-hr concentration occurs only once per year, a distribution of concentrations* could be estimated, which would permit computation of a time-averaged acute exposure level.

6 CONCLUDING REMARKS

A simplified methodology has been presented, based on Gaussian plume relationships which could be used to assess regulatory constraints and vegetation damage for new power plants. Data input requirements include the following:

- a. power plant size (MW),
- b. fuel type, sulfur content, and level of control,
- c. nearby terrain elevation difference, with respect to stack base, for critical receptors.

In addition, a more accurate analysis would result from knowledge of the following data rather than use of default assumptions:

- d. flue gas exit temperature,
- e. maximum credible 3-hr and 24-hr wind speed at some reference height,
- f. minimum credible 24-hr wind persistence range ($^\circ$).

Furthermore, the 24-hr PSD increment is seen to be the most restrictive on the basis of the ASME dispersion coefficients. An 800-MW plant (which is close to the optimum size from cost and reliability considerations according to a recent analysis⁸) could be forced to reduce emissions below the levels assumed in this paper if adverse conditions were encountered. For example, terrain features higher than about 300 m at the critical distance from the plant could be restrictive, as could sufficiently persistent winds that would confine 24-hr plume spreading to $< 10^\circ$.

Finally, the analysis has presented some simple closed form solutions to the Gaussian plume equations which would be useful for screening. Such screening could be used to identify PSD conflicts or additional pollution control requirements, or to estimate air pollution damage.

*Pace et al.² indicate that an exponential distribution over time may represent actual exposures better than a log-normal distribution.

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APPENDIX A

SUGGESTED APPLICATION OF SHORT-TERM AIR QUALITY IMPACT METHODOLOGY

The methodology presented above has application for the evaluation of both regulatory constraints and air pollution damage, for time periods from 1 to 24 hr and for all pollutant species emitted from power plants. The methodology is probably not appropriate for industrial or process sources because of the coupling between source strength and stack height used for power plants. Table A-1 presents a listing of (primary) pollutants, standards, and possible damage functions that might apply. Table A-2 presents the (national) ambient air quality standards, the PSD increments for Class I and Class II, and the significance levels (levels which must be exceeded in order for emissions offset provisions to apply for sources located near non-attainment areas). It is assumed that a file of non-attainment areas is available, by pollutant and averaging time, and that a file of existing ambient air quality levels is available, by pollutant and averaging time, as of the baseline year.

The first step in this recommended hierarchical analysis (for sources not located in non-attainment areas) is to compute the maximum concentrations (i.e., impacts) according to the logic which has been presented in this issue paper and to compare the results with the significance levels. Obviously, very conservative assumptions (high concentrations) must be used for such a screening process; Table A-3 contains suggested input values. This will identify the pollutants of concern which should be given a more thorough analysis (with site-specific inputs to the equations). Potential regulatory siting constraints are then examined, in the order shown. If no constraints are found, computations are made to determine the fraction of PSD increment consumed, which is archived for comparison with future siting and for estimation of (vegetation) damage.

HIERARCHY OF REGULATORY CONSTRAINTS

1. Source is to be sited in a non-attainment county and meets the "major source" criteria: *
 - a. The site is actually inside the non-attainment area: emission offsets apply and no further impact analysis is appropriate until the offset sources have been identified.
 - b. The site is adjacent to or near (within 50 km) the actual non-attainment area:
 - i. Using a screening test calculation, check whether impacts exceed significance levels for pollutants and averaging times not in attainment for county in question.
 - ii. Detailed analysis: Determine probability of geographic coincidence (low for short-term standard, high for annual standard)..
 - iii. Possible mitigation measures: Compute degree of additional controls required to achieve significance levels (rollback).
2. Violation of ambient standards
 - a. Screening tests
Determine counties where existing air quality levels plus PSD increments would exceed ambient standards. Then, for new plants in these counties, determine whether existing air quality plus impacts exceed standards.
 - b. Detailed analysis
Refine impact calculations with site-specific inputs and estimate probability of geographic coincidence (as above).
 - c. Possible mitigation measures
Compute additional control levels needed to meet ambient standards.
3. Violation of PSD increments
 - a. Screening tests
Determine which PSD class applies at likely maximum impact point for new plant. Determine whether Class I areas exist within 100 km of likely new facility site. Determine percentage of applicable increment consumed.

*Annual emissions > 1000 tons for carbon monoxide or 100 tons for any other criteria pollutant.

b. Detailed analysis

Recompute impacts based on site-specific input parameters. Account for portions of PSD increments already consumed, taking into account geographic coincidence where possible (phased multi-unit facilities, etc.).

c. Mitigation measures

Where excess increment is consumed, compute required controls.

Table A-1
Pollutants and Short Term Standards

Species	Averaging time, hr	Regulatory constraints	Damage functions	Remarks
SO ₂	1	Some state standards	Vegetation	
	3	Ambient standard PSD increment	Vegetation	
	24	Ambient standard PSD increment	Possible health	
Emitted particulates	24	Ambient standard PSD increment	Possible health	TSP background will dominate.
SO ₄ ²⁻	24	Some State standards	Possible health	Background will dominate in Eastern U.S.
NO ₂	1-3	Primary standard not yet established	---	Calculations will require assumption of an oxidation rate and/or consideration of background ozone levels.
CO	1 8	Ambient standard " "	Possible health	Background will dominate in urban areas.
HC	3	Ambient standard for 6-9 AM	---	Standard is an advisory for the purpose of achieving the oxidants standard.

Table A-2
Air Quality Standards and Increments ($\mu\text{g}/\text{m}^3$)

Species	Averaging time	Ambient standard	PSD increment		Significance level
			Class I	Class II	
SO ₂	Annual	80	2	20	1
	24-hr	365	5	91	5
	3-hr	1300	25	512	25
TSP	Annual	75	5	19	1
	24-hr	260	10	37	5
NO ₂	Annual	100	-	-	1
CO	8-hr	10,000	-	-	500
	1-hr	40,000	-	-	2000
HC	3-hr (6-9 AM)	160	-	-	-

Table A-3
Suggested Default Parameters for Conservative Impact Estimation

1. Emissions
 - Annual: as given
 - 24-hr: annual/240 (per 24 hrs)
 - 1-3 hr: 24-hr/22 (per hr)
2. Flue gas temperature: 160°F
3. Stack height: $16.84(\text{MW})^{0.326}$ (in meters)
4. Effective terrain ramp slope: 0.02
5. Elevated inversion height multiplier: 2.0
(1-3 hr concentration estimates only)
6. 24-hr sector width: 15°

GLOSSARY OF TERMS AND SYMBOLS

- c - sector width, m
- C_p - specific heat
- F - buoyancy flux, $m^4/sec^3 = \frac{gQ_h}{\pi C_p \rho T}$
- g - acceleration due to gravity, m/sec^2
- H - effective stack height ($H_s + \Delta H$)
- H_s - stack height, m
- k, l, p - factors in ASME dispersion coefficient algorithm
- Q - source strength, g/sec
- Q_h - thermal stack effluent, cal/sec
- T - stack gas temperature, °K
- T_a - ambient temperature, °K
- $\bar{u}$ - average wind speed, taken as the value at stack height, m/sec
- x, y, z - downwind, crosswind, and vertical coordinates, m
- ΔH - (thermal) plume rise, m
- Δz - elevation of ground receptor over stack base, m
- θ - potential temperature, °K
- ρ - stack gas density
- σ - standard deviation or dispersion coefficient of Gaussian plume, m
- ϕ - sector angle, degrees
- χ - ground level concentration, $\mu g/m^3$