CONF-770265--

REPORT TO THE U. S. EPA OF THE SPECIALISTS' CONFERENCE ON THE EPA MODELING GUIDELINE

February 22-24, 1977

Chicago, Illinois

REPORT TO U.S. EPA OF THE SPECIALISTS CONFERENCE ON THE EPA MODELING GUIDELINE

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Organized by: Energy and Environmental Systems Division
Argonne National Laboratory*

Conference Chairman: John J. Roberts

Conference Organizers: Donald M. Rote
Albert E. Smith
Kenneth L. Brubaker

Conference Coordinators: Miriam L. Holden, Director
Conference Planning & Management

Albert E. Smith

Sponsored by: Office of Air Quality Planning and Standards
United States Environmental Protection Agency

EPA Project Officer: Herschel H. Slater

Under Interagency Agreement No. EPA-IAG-D7-0013 between ERDA and EPA.

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Schedule - Specialists Conference on the EPA Modeling Guidelines

Tuesday	Wednesday	Thursday
	8:00 Breakfast 9:00	8:00 Breakfast 9:00
9:00 Registration 12:00	9:00 Working groups: I-1, I-2, I-3 (Coffee at 10:00) 12:00	9:00 Working groups: II-1, II-2, II-3, II-4, II-5 (Coffee at 10:00) 12:00
12:00 Lunch 1:00	12:00 Working group lunch 1:00	12:00 Working group lunch 1:00
1:00 Opening address 1:45 1:45 Orientation 3:45 3:45 Coffee break 4:15 4:15 Plenary session on policy issues 6:00	1:00 Plenary session - Working group reports 3:00 3:00 Coffee break 3:30 3:30 Working groups: I-1, I-2, I-3 5:00	1:00 Plenary session - Working group reports 3:00 3:00 Coffee break 3:30 3:30 Working groups: II-1, II-2, II-3, II-4, II-5 5:00
6:00 Open 7:00	5:00 Open 6:30	5:00 Open 6:00
7:00 Dinner 8:00	6:30 Dinner 7:30	6:00 Dinner 7:00
8:00 Plenary session (Cont'd) 10:30	7:30 Writing sessions for working groups I-1, I-2, I-3 10:30	7:00 Plenary session - Wrap-up of issues 10:30

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PREFACE

J. J. Roberts

The problem of air pollution control can be approached via two alternative though not mutually exclusive policies: management of emissions and management of air quality. In the former (which could include emission tax policies), emphasis is placed on the technology for control of effluent (including in-plant process changes); regulatory requirements based primarily on cost/effectiveness considerations are expressed in terms of emission standards reflecting reasonably available or best available control technology.

Air quality management, on the other hand, entails the establishment of air quality goals based upon stated criteria or public policies. Emissions are then limited to the extent necessary to attain and maintain such goals. For example, the Clean Air Act Amendments of 1970 require the federal Environmental Protection Agency to establish National Ambient Air Quality Standards (NAAQS) in terms of a national policy requiring the protection of public health and welfare. Air quality increments designed to prevent significant deterioration (PSD) reflect an air quality rather than an emission management policy.

In the Clean Air Act of 1967, the amendments of 1970, and in the most recently proposed amendments of 1976, the U.S. Congress has consistently endorsed a national policy of air quality management. Though not exclusive of specific requirements for emission control (e.g., new source performance standards, motor vehicles), the thrust of these legislative acts is the achievement of air quality goals through a combination of emission limitations and land-use-related measures.

The success of a policy of air quality management depends very much upon the availability of calculational procedures to relate emissions of air contaminants to resulting levels of pollution in the ambient air.

Such "air quality models"* must be sensitive to quantities and geographical location of emitted pollutants, meteorological conditions governing the dispersion of airborne contaminants, and, as appropriate, the physical and chemical processes affecting transformation and removal.

A number of regulatory programs which implicitly call for the application of air quality models are listed in Fig. 1. Proportional rollback and, in some cases, multi-source urban dispersion models such as the Air Quality Display Model (AQDM) were employed in the development of State Implementation Plans (SIP) pursuant to clean air legislation of 1967 and 1971. Currently many such SIPs are being revised to reflect regional growth, recent pressures to permit substitution of coal for scarce petroleum resources, and other reasons including failure of original analyses to properly predict future levels of air quality and failure of emission sources to achieve required levels of control. Recent court rulings and subsequent EPA regulations concerning prevention of significant deterioration (PSD) call for use of air quality models in two modes: (1) initial classification or reclassification of geographical areas, where the decision requires estimates of the economic and energy impacts of alternative PSD increments; and (2) determination of compliance of a proposed new source with established PSD increments. The latter determination is part of a federally mandated new source review (NSR) process which also entails a determination that the source will not cause a violation of the NAAQS. Where the source is a "major" one as defined by EPA directives and where the source would cause or exacerbate a violation of the NAAQS, then the source can be constructed if and only if a balancing or emission offset procedure is followed.** In many situations, the emission offset evaluation will require use of an air quality model in what is, in effect, a SIP revision.

Figures 2 and 3 present the NAAQS and PSD increments (current EPA values and those recently proposed by Congress). They set forth the quantitative targets and limits which govern the air quality management process.

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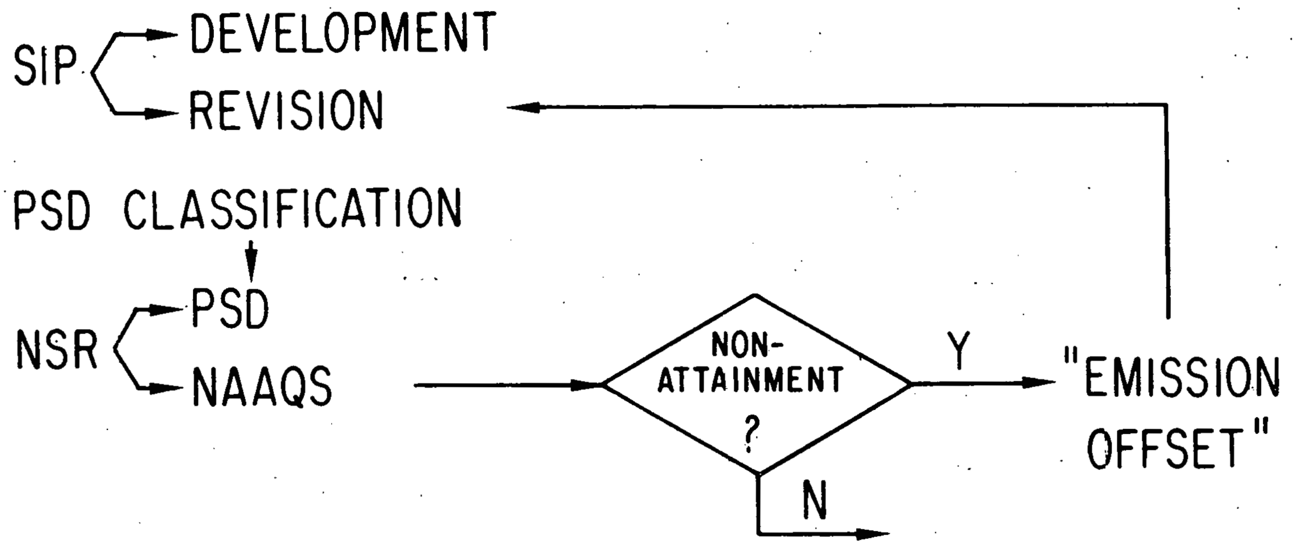
*We shall distinguish such "air quality models" from individual algorithms (e.g. estimation of plume rise) which may be combined in the model. Further, for our purposes a Gaussian dispersion kernel may be considered a sub-model employing algorithms to estimate the rate of dispersion as a function of downwind distance or time. Finally, since complex models are frequently implemented on a digital computer, they may be termed herein computer models or computer codes. Often the name of the computer code (e.g. AQDM) is used synonymously for the air quality model from which it is derived.

**41 Fed. Reg. 55525 (Dec. 21, 1976)

APPLICATIONS OF AIR QUALITY MODELS IN AIR QUALITY MANAGEMENT



INDIRECT SOURCE REVIEW

ENVIRONMENTAL IMPACT STATEMENTS

LITIGATION (ENFORCEMENT/VARIANCE)

FIG. 1

NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)

POLLUTANTS	CONCENTRATIONS IN $\mu g/m^3$				
	1-hr	3-hr	8-hr	24-hr	1-YEAR
PARTICULATES					
PRIMARY				260	75 (G)
SECONDARY				150	60 (G)*
SO_2					
PRIMARY				365	80 (A)
SECONDARY		1300			
CO	40^a		10^a		
HYDROCARBONS		160^+			
OXIDANTS	160				
NO_2					100 (A)

a CO CONCENTRATIONS MEASURED IN mg/m^3

(A) ARITHMETIC AVERAGE

(G) GEOMETRIC AVERAGE

* AS A GUIDE TO BE USED IN ASSESSING IMPLEMENTATION PLANS TO ACHIEVE THE 24 HOUR STANDARD

\+ AS A GUIDE TO BE USED IN DEVISING IMPLEMENTATION PLANS FOR ACHIEVING OXIDANT STANDARDS

FIG. 2

PREVENTION OF SIGNIFIGANT DETERIORATION (PSD) INCREMENTS ($\mu g/M^3$)^a

POLLUTANT	CLASS I AREAS	CLASS II AREAS	CLASS III AREAS
PARTICULATE MATTER			
ANNUAL	5/5	10/19	UP TO NAAQS/37
24-HOUR	10/10	30/37	UP TO NAAQS/75
SULFUR DIOXIDE			
ANNUAL	2/2	15/29	UP TO NAAQS/40
24 HOUR	5/5	100/19	UP TO NAAQS/182
3. HOUR	25/25	700/512	UP TO NAAQS/700

^{a} TOP NUMBER - E P A, BOTTOM NUMBER-CONFERENCE REPORT ON S.3219 TO AMEND THE CLEAN AIR ACT, CONGRESSIONAL RECORD, SEPTEMBER 30, 1976

FIG. 3

Simultaneously, they establish implicitly a level of accuracy desirable in applicable air quality models.

Scientists have been engaged for many years in the study of atmospheric dispersion of windborne material from industrial and other pollutant sources, including military activities. Much has been published on the subject. In addition to definitive texts such as Pasquill (1961 and 1974) and to summary reports such as Turner (1967) are numerous articles and reports describing research on the formulation and evaluation of algorithms and models characterizing the various aspects of the problem. Given these research activities, coupled with the emergence of air pollution control agencies at state and local levels and of consulting firms established to aid both industry and government, one should not be surprised to find extensive proliferation of algorithms, sub-models, models and related computer codes, each designed to facilitate one or more aspects of air quality analysis. Further, even though many models employ a Gaussian kernel to characterize the dispersion phenomenon, results can vary widely depending upon other calculational features such as manipulation of emission and meteorological data, treatment of plume rise and interactions with elevated inversions, evaluation of dispersion coefficients, averaging techniques and statistics routines to estimate compliance with short- and long-term standards. Different user-oriented input/output features may distinguish two otherwise identical calculational procedures. And, finally, the same computer code can be employed in different ways (e.g. one versus five years of meteorological data) or results interpreted in different ways (e.g., in determining compliance with short-term NAAQS).

Thus, with numerous models in the literature and numerous users in the field, the potential exists for chaos, or at least for frequent, honest disagreement, even among different units within the same organization. Confusion of this sort has already emerged where an industry seeking a construction permit in a multistate air quality control region is faced with differing calculational procedures (and thus, in effect, differing emission limits) among the various state and local agencies and, quite possibly, between adjoining Regional Offices of the federal EPA.

It is evident that there is a need for some measure of standardization in air quality analysis. As a minimum such standardization should be applied to calculational procedures used throughout the federal EPA and by state and local agencies in their official dealings with the EPA. The issue then becomes one of determining the degree of specificity (e.g., specific computer codes), what in fact will be standardized (e.g., models vs. algorithms), the rigidity of the requirements (or conversely, the flexibility of the user to select or even develop alternative calculational methods), the extent of coverage (e.g., specification of a particular model vs. specification of the model along with procedures for input of data and interpretation of results), and finally, and perhaps most importantly, the performance criteria which a calculational procedure must meet to quality for inclusion in any official statement of such standards.

The need within the national air pollution control program for a guidance document on air quality analysis persists. Despite the difficulties outlined above, the EPA/Office of Air Quality Planning and Standards (OAQPS) has been given the responsibility for developing the requisite Guideline. A first draft was prepared and circulated for initial in-house review during December 1976. A second draft was published in early February. The target date for a final version of the Guideline is July 1, 1977.

In December Argonne was apprised of this schedule and requested to organize a three-day conference/workshop wherein specialists in air quality analysis would critique the second draft of the Guideline. Recognizing that the federal EPA and the states had to fulfill the important air quality management responsibilities outlined in Fig. 1 employing the state-of-the-art in analytical methods, the conferees were challenged to advise EPA on the best available approaches to modeling air quality impacts and to concur with or where possible recommend improvements to the many aspects of the problem addressed in the Guideline.

The Specialists Conference on the EPA Modeling Guideline was held at the Nordic Hills Inn, Itasca (Chicago), Illinois on February 22-24, 1977. Members of the staff of the Energy and Environmental Systems Division of Argonne National Laboratory served as conference organizers and reporters. Several representatives of the EPA/OAQPS assisted as resource persons. The twenty-four conferees were drawn from private industry, universities, public interest organizations, and federal and state government. A list of participants and affiliations appears at the front of this report.

These participants and the conference, as a body, are considered essenti parts of the decision-making process for development of the Guideline. The sum of the scientific group's experience in the private sector included many years of service as staff members for large corporations and as consultants to the entire spectrum of industrial activity of this Nation. The experience and procedures followed in Canada and in Western Europe were brought to the group by scientists from Canada and the United Kingdom. Those involved in the public sector are active at the local, state, federal and even international levels. Several of the conferees are valued consultants to both private and public activities as well as independent public interest associations promoting environmental issues. All are highly knowledgeable of the capabilities and limitations of air quality modeling.

The conference was organized around a mix of plenary sessions and concurrent workshops. Major policy issues and general technical matters were reviewed by the conferees at-large. These general discussions provided guidance to working groups responsible for examining specific aspects of the Guideline (see Fig. 4). To assist everyone in preparing for the conference, a reference notebook was prepared and distributed along with the draft Guideline several weeks in advance. This notebook contains a brief characterization of each model referenced in Tables 2 and 3 of the draft Guideline along with key excerpts of material referenced in the Guideline. The portion of the notebook containing the model descriptions is reproduced here in Section 3.11.

I wish to thank my colleagues at Argonne for their assistance in preparing the background material, planning the conference, and in general seeing to the myriad of details essential to a successful meeting. We have acted only as organizers of the conference and as recorders and reporters of the positions articulated by the conferees. These conferees endured a very intensive three-day marathon. Their exceptional efforts attest to the seriousness with which they assumed their responsibilities.

The following quotation from Chief Justice David L. Bazelon of the U.S. Court of Appeals for the District of Columbia seems appropriate to conclude these introductory comments. Speaking on the difficulties that the courts face in resolving environmental debates, this jurist observes that the courts are not the proper forum

WORKING GROUPS

I-1 MULTISOURCE, SHORT TERM AND LONG TERM, SET I POLLUTANTS

I-2 SINGLE SOURCE, SHORT TERM AND LONG TERM, SET I POLLUTANTS

I-3 SET 2 POLLUTANTS - NO_2, OXIDANT, CO

II-1 LONG RANGE TRANSPORT AND LOSS MECHANISMS

II-2 PLUME DYNAMICS: WAKES, DOWNWASH, FUMIGATION, MIXING LAYER EFFECTS

II-3 COMPLEX TERRAIN

II-4 CHARACTERIZATION OF TURBULENCE

II-5 VALIDATION AND CALIBRATION

FIG. 4

...either to resolve the factual disputes or to make the painful value choices. What the courts and judges can do, and do well, when conscious of their role and limitations - is scrutinize and monitor the decision-making process to make sure that it is thorough, complete, and rational; that all relevant information has been considered; and that insofar as possible, those who will be affected by a decision have had the opportunity to participate in it.

[Decision makers should openly disclose] where and why the experts disagree as well as where they concur, and where the information is sketchy as well as complete. When the issues are controversial, any decision which is reached may be unsatisfactory to large portions of the community. But those who are dissatisfied with a particular decision will be more likely to acquiesce in it if they perceive that their views and interests were given fair hearing.

(Address to the Atomic Industrial Forum, January 10, 1977)

This Specialists' Conference and the report which now follows represents an important element in such a decision-making process.

1 POLICY ISSUES AND GENERAL TECHNICAL MATTERS ADDRESSED IN THE PLENARY SESSIONS

Moderator/Reporter: J.J. Roberts

Policy issues and technical matters addressed in the plenary sessions dealt primarily with the broader considerations surrounding the application of models, purpose and structure of the guideline document, and criteria and procedures for inclusion therein of "approved" models. These discussions provided guidance to the working groups so that the individual position papers are consistent with philosophical and technical perspectives of the conferees at large. Fourteen specific policy issues and general technical matters are summarized below.

1.1 THE GUIDELINE TENDS TO STANDARDIZE AIR QUALITY ANALYSIS

The principal issue for the conferees is the degree to which it is appropriate for a Guideline to prescribe calculational methods and/or specific computer codes to be used in the analysis of air quality problems. The desirability of some guidance is generally recognized; the degree of specificity of that guidance is the issue. Reference was made to the Congressional Conference Report of September 30, 1976 on Clean Air Act Amendments of 1976 where an amended Section 318 addressed "Standardized Air Quality Modeling" and set forth a general prescription for a conference on this subject which presumably would lead to a "guidance document," possibly published in the Federal Register. Again, here, the degree of standardization is left unclear in that the word "standardized" never appears within the text of the article and, further, that the term "appropriate modeling" appears somewhat in its stead.

A related aspect to the discussion on the extent of standardization concerns the likelihood of approved models attaining some special status in legal contests. It was generally recognized that such would, in fact, be the case although wording could be incorporated to soften a rigid interpretation by emphasizing the opportunity and/or desirability under certain circumstances for the user to, at his discretion, select alternative analytical procedures. The near certainty that the Guideline would attain special status in regulatory matters argues for a cautious approach to designating any particular model as "approved" and emphasizes the importance of proper evaluative procedures.[1] These legal implications also led to recommendations of "conservative" modeling techniques for initial "screening" in the new source review process.[2]

Two widely different perspectives on the issue of standardization were expressed by the conferees. On the one hand, a "scientific" viewpoint emphasized that air quality problems are generally unique and should be treated on a case-by-case basis with appropriate professional counseling. Reference in this case was made to a position recently drafted by the American Meteorological Society (not yet approved by the AMS Council) which responds principally to the above-referenced proposed amendments to the Clean Air Act. The draft position statement expressed specific concern with "the concept that there should be currently established one particular model which will be capable of analyzing all conceivable situations," and went on to point out that the wide range of meteorological, geographical, and other aspects of the air quality modeling problem, especially regarding short-averaging-time standards, precludes the uniform application of a single model and, in some cases, is "not amenable to simple mathematical treatment."

The other distinct perspective could be termed a "regulatory perspective." It was most clearly articulated by spokesmen from industries having to deal with the new source review process as applied to state implementation plans and prevention of significant deterioration. Here, the call was for clearly defined analytical procedures for determining air quality impacts and, thus, compliance with applicable limitations. In this sense, the Guideline was seen as requiring the use of reasonably accepted, state-of-the-art mathematical models by which the applicant could independently assure himself of a reasonable likelihood of compliance <u>before</u> the investment of significant monies in the pre-construction phases of a new development. The call was to identify those types of problems which could be treated by approved models and the gray areas within which special case-by-case analysis would be necessary. It was felt that industry's need for clarity, for reducing uncertainties in the review

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[1]See Section 2.4 and report of the Working Group II-5

[2]See Section 2.3

process, was the principal motivation behind the above-referenced section in the Congressional Conference Report. A related argument in favor of some degree of standardization concerned the review of new pollution sources impacting on more than one state and possibly more than one federal EPA region. This situation is likely to occur under the prevention of significant deterioration regulations. With different states and EPA regional offices applying different air quality models to determine compliance of the proposed source, chaotic regulatory situations can occur.

The conferees have reached a consensus on this issue in that it is agreed that for certain standard types of situations, it would be desirable for the Guideline to identify an "appropriate" or, possibly, "approved" set of algorithms or particular computer code(s) to be applied <u>if</u> the particular model(s) have been properly verified under the conditions for which the standard application would be prescribed. The decision in this regard would be made in accord with an approved set of procedures for testing, validation, and possibly calibration. Secondly, significant flexibility should be provided to the user whereby, with appropriate professional counsel, other analytical methods could be employed where the standard situation was not encountered.

1.2 SPECIFICATION OF COMPUTER CODES VERSUS APPROVED ALGORITHMS

The Guideline as currently proposed lists approved or recommended computer codes to perform different air quality analyses. In fact, however, with the exception of rollback, they all employ the same Gaussian dispersion kernel and thus could be viewed as the same models. It is also recognized that a computer code consists of many algorithms critical to the estimation of air pollution levels; among these are emission inventory estimates (seasonal average and temporally varying), statistical analysis of meteorological data including the initial acquisition and processing of such data, prediction of plume rise, dispersion coefficients, and approximation of area sources.

Thus, while there is a strong sentiment among the conferees to have the Guideline focus as exclusively as possible on the identification of approved algorithms which could then be used in creating an (implicitly) approved computer code, it becomes readily apparent that the number of steps in performing the overall air quality analysis are so closely interrelated that such an approach would be difficult to pursue, especially at this time. Thus, the Guideline should, where appropriate, reference specific computer codes, although evaluation studies should be conducted on individual algorithms as well as on such complex air quality models. The working groups, however, had many reservations about the specific models listed in the Guideline, due in part to the lack of sufficient verification experience, and in many cases could not give blanket approval to their use.

1.3 APPLICATION OF STANDARD COMPUTER CODES FOR "SCREENING" IN THE NEW SOURCE REVIEW PROCESS

Whereas there is strong reluctance on the part of many conferees to accept a particular code as a standard for a particular application, there is general agreement that certain codes could be applied in a "screening" process wherein a determination could be made that the source is in compliance because the associated estimate of air quality impact is suitably far below any regulatory threshold. The concept is one of applying the analytical procedure with sufficient conservatism to identify those situations which are clearly within the allowable limitations. This approach would distinguish a computer model as being appropriate for screening but not necessarily sufficiently reliable to be endorsed as a standard for analysis where the decision is a close one and where a more refined analysis and/or interpretation of the results of such an analysis may be required. There still remains the necessity of characterizing those geometrical, meteorological and other conditions under which the code is applicable in the screening process.

The use of standard models as screening tools to eliminate "non-problems" from more extensive new source review requirements has several constructive ramifications:

1. If the conservative estimates demonstrate that air quality goals could be readily achieved, a quick approval action is possible.

2. If the conservative estimates indicate a potential problem, on the basis of the results, the source can alter its design or implement a program involving further measurements and/or a refined modeling approach which might yield a more realistic assessment of air quality impact. The fact that

the standardized model results were conservative provides a procedural recourse for sources to provide more information on the expected impact.

3. From an advancement-of-technology point-of-view, pressure is maintained on all parties to produce accurate modeling techniques. If the standardized models are too conservative, too few "non-problems" are identified and EPA will therefore strive for more realistic prediction methods to reduce the conservatism. Similarly, because refined approaches will be required for a reconsideration of a potential denial, sources will be interested in engaging in efforts which will tend to improve our understanding of the technical issues.

1.4 EVALUATION AND CALIBRATION

The ability of a computational procedure or any of its algorithms to properly characterize the physical processes that govern the transport and aerochemistry of air pollutants and thus to predict pollution concentrations with acceptable accuracy is clearly the most important criterion in evaluating that model for inclusion in this Guideline. Currently, there is no systematic procedure being employed by the Federal EPA for the evaluation of air quality models. Such a procedure would require criteria for acceptability and for inclusion in a guideline, procedures for carrying out a test program including specifications on data and on the range of conditions under which the model must be evaluated. The evaluation process would include an internal (EPA) review as well as, ultimately, an independent peer group review. This evaluation process certainly would be an extensive one involving significant effort on the part of persons developing and promoting particular theories and models. A more extensive discussion of the requirements for such a systematic procedure are described in the report of Working Group II-5.

Most of the models referenced in Table 3 of the proposed Guideline and recommended by the EPA have undergone some evaluation. However, in general, it was agreed that the existing models would not meet the criteria likely to be imposed via the above-mentioned systematic evaluation procedure. EPA itself is well aware of these limitations and will welcome specific recommendations for a comprehensive evaluation procedure.

The multi-source, long-term air quality models in Table 3 of the draft Guideline generally employ a calibration step to fit, usually by linear regression techniques, the model predictions to a set of observed long-term averages. The resulting regression coefficients are then employed in all further use of that model for predictions of future levels of air pollution under varying source and meteorological conditions. Positions for and against such calibration were expressed. That calibration has been commonly used with apparently acceptable results would argue for its endorsement as an acceptable procedure; that the use of calibration implies a failure of the model to properly represent the physical processes would suggest that more attention be paid to those failings that to a statistical procedure to conceal their details. The decision on this matter was left up to the working group on multi-source models, wherein the use of calibration techniques was endorsed for evaluation of long-term average concentrations in urban, multi-source configurations.

1.5 THE DRAFT GUIDELINE SUGGESTS A HIERARCHY WHICH EVOLVES TOWARD ROLLBACK AS THE PROBLEMS BECOME MORE DIFFICULT

The conferees could not understand the rationale for this seemingly contradictory proposition. Rollback techniques, as the EPA admitted, are rarely an acceptable option in the eyes of the EPA regional offices. While perhaps appropriate for a first-cut estimate of the degree of required emission control and possibly where the geography and aerochemistry of the problem would permit an assumption of homogeneity, it makes no sense to use a super-simple model in complex situations. In general, it was recommended that rollback not be included as an acceptable option for SO_2, particulates, and CO.* Its application to photochemical oxidants and NO_2 is discussed in more detail under the report from Working Group I-3.

Another aspect of concern for the use of rollback is under conditions where there are an insufficient number of monitoring sites to assure that the maximum pollution levels are used in determining the constants of

*Working Group I-1 did, however, accept the proposition that "if the meteorological or topographic complexities of the region are such that the use of any available air quality model is precluded, then the model used for strategy evaluation may be limited to a Rollback Model."

proportionality. Thus, one might significantly underestimate the degree of required controls in areas not monitored. Conversely, rollback can overestimate the degree of control required by focusing on "hot spots" which are not characteristic of the area.

1.6 ESTIMATING SHORT-TERM AIR QUALITY IMPACTS: STATISTICAL VERSUS ENUMERATIVE APPROACHES

Two very controversial issues emerge under this general topic. Firstly, the PSD increments are stated as increments never to be exceeded, a condition which has somewhat frightening implications when viewed in terms of a statistical treatment of meteorology and air pollution and the unpredictability of rare events. The EPA explains that this dilemma would be resolved by applying the models to a fixed and limited meteorological history (up to five years) wherein, if the model did not indicate a violation of the PSD increments, approval would be given for construction of the source. Further, it is suggested that the PSD increments would be enforced only during the review process and thus constitute a procedural type of regulation rather than one which would be enforced after the fact if monitored pollution levels showed the increments to be violated. This position seems somewhat contradictory to the basic concept of SIP development and revision.

The second issue which comes under this general heading concerns the procedure for the calculation of short-term impacts, whether for determining compliance with short-term (three and twenty-four hour) national ambient air quality standards or with PSD increments. The most common way of employing a model such as CRSTER is to calculate air pollution levels at each receptor site for each hour in a given period of recent history, usually one to five years. The results of this analysis are then applied in an enumerative sense whereby as long as no more than one violation per year at any site is found to exist, the NAAQS short-term values are assumed met, and where no value exceeds the appropriate PSD increment, that limitation is assumed satisfied.

An alternative, and to many persons a more satisfying approach, would be to generate or in some way employ a statistical representation of the air quality at any given receptor site and apply the results of such an analysis to the test of compliance. This approach would require some, possibly minor, redefinition of the NAAQS and PSD limitations. Consistent with this statistical approach, a model such as CRSTER would be run over an appropriate period of time with the resulting computed values fitted to a suitable cumulative frequency distribution function. It was observed that similar problems occur in interpreting the short-term data from air quality monitoring sites which may be subject to occasional and undetermined malfunctions producing erroneously high values.

It is common engineering practice to use statistically computed criteria for design to meet extreme meteorological conditions. Drainage for flood control and wind loads on structures are two examples. Appropriate meteorological parameters are treated by special statistical procedures to estimate conditions for specified periods ranging from ten to one hundred years. These estimates often exceed the period of record by a factor of two or more. Although meteorological conditions associated with atmospheric transport models are very different from those associated with the above examples, the concept of using a statistical approach to determine compliance is analogous to these established practices.

Although the consensus is that a statistical approach is theoretically more valid, it is recognized that a detailed investigation of the nature of the statistics should be completed prior to implementation. In particular, concern is expressed regarding the appropriate form of the cumulative distribution function to be used in any curve-fitting procedure.

To the extent that enumerative (i.e., deterministic) methods are used to determine compliance with short-term standards, two approaches suggest themselves: (1) the above-described enumerative approach using CRSTER, where the major question is the period of record over which calculations are to be made; and (2) a "worst case" approach where the challenge is to identify the conditions under which maximum ground level concentrations might occur.

In the first situation, it was argued by one conferee that the period of record be equivalent to the plant life (i.e., as long as twenty to thirty years). It was also recognized that even a five-year set of calculations could be unreasonably costly for certain smaller sources.

The worst case approach via models such as CRSTER makes sense to the conferees as a screening mechanism whereby compliance can be assumed if the worst case estimate is conservatively below the allowable increment. However, the use of an idealized plume rise algorithm (as in CRSTER) might overlook special high pollution conditions associated, for example, with aerodynamic downwash. Other specialized situations such as unusual circulations (e.g., sea breezes) and fumigation should be considered as potentially creating the worst case situation.

Finally, in applying a "worst case" analysis, some recognition must be taken of the potential for occurrence of such a situation in order to determine compliance with short-term NAAQS.

1.7 TO WHAT EXTENT SHOULD THE USER'S BURDEN IN ACQUISITION OF DATA AND PERFORMANCE OF CALCULATIONS BE CONSIDERED IN RECOMMENDATIONS SET FORTH IN THE GUIDELINE?

It is generally recognized that for some types of calculations and some computer codes the burden of acquisition of emission and meteorological data and the computer costs can be excessive for small pollution control agencies and for many industrial applicants. Thus, another argument can be made in favor of an inexpensive screening process to limit the number of situations in which more extensive air quality analysis would be required. However, in those situations where the standards are in fact threatened and a more refined analysis is required, the best available methods should be employed. This burden would most likely fall upon the federal EPA and upon state agencies.

To the extent the Guideline recommends models for screening purposes, such models may reflect a desire for simplicity and ease of use. To the extent the Guideline recommends models for general application in air quality assessments, they should be characterized in terms of the potential burden upon the user but the decision as to the appropriateness of that burden should be left to the user.

In a somewhat related aspect, the Guideline would permit the Regional Administrator to select a model other than that recommended "if the data bases required" are "unavailable or inadequate." The degree to which it is incumbent upon the EPA or upon the applicant in a new source review procedure to delay the project until adequate data are assembled should be clarified.

1.8 THE EPA OFFICE OF AIR QUALITY PLANNING AND STANDARDS DECIDED NOT TO INCLUDE OXIDANT MODELING IN THIS EDITION OF THE GUIDELINE

EPA representatives indicate that they have recently organized a task force to develop methods for relating levels of photochemical oxidants to the required degree of hydrocarbon controls. Thus, they chose to leave oxidant modeling out of this edition of the Guideline. The appropriateness of currently available models for the description of chemically reactive pollutants is considered briefly in the report of Working Group I-3.

1.9 AIR QUALITY DATA

The importance of air quality data in evaluating the performance of an air quality model is evident. The conferees are concerned that, in general, insufficient consideration has been given to criteria for proper siting of monitors and acquisition and processing of air quality data for validation and for calibration purposes. The EPA has a task force currently studying the monitoring situation in the USA, but the major thrust of this effort would appear to be a cost/effectiveness approach to minimizing the number of monitors necessary to assure compliance with ambient air quality standards. The establishment of appropriate criteria for monitoring data to be employed in model validation studies would be a part of the evaluation procedure developed pursuant to policy issue 1.4, above. Finally, in addition to the need for better air quality data, there is a need for modelers to be more aware of the data which is available.

1.10 METEOROLOGICAL DATA

In a matter analogous to the concern for the quality of monitoring data, concern is expressed for the inadequacy of meteorological data currently available via the National Weather Service. Further, hourly meteorological observations are not available on magnetic tape from the National Weather Records Center for many sites in the USA. Finally, the NWS program of twice per day urban soundings has been discontinued.

It is generally agreed that little can be done in the near future to change the method of observation and to reinstate the sounding program. The National Climatic Center is preparing hourly records for selected locations at the request of EPA under an interagency reimbursement agreement. Several othe parties from time to time obtain climatic data of this type under similar arrangements.

Concern is also expressed for a lack of adequate meteorological data at elevations approximating the effective stack height of major elevated sources, as well as for how the available meteorological data are used in evaluation and in various algorithms.

1.11 PROPRIETARY COMPUTER CODES

The appropriateness of referencing proprietary computer codes in the Guideline is a controversial issue. The large majority of conferees, including several private consultants, oppose the inclusion of such models in this government publication. EPA representatives indicate that they do not intend to reference such models in the Guideline.

Arguments in favor of including references to proprietary models are consistent with a structure for the Guideline which does not recommend specific computer codes but rather approved, generic methods and algorithms for air quality analysis. It is felt by some that this approach would allow a listing of computer models, public and private, which satisfied the generic criteria. This position is also consistent with a concern for excessive standardization of calculational methods in contrast to more emphasis on case-by-case analysis by qualified experts. Regarding the image of secrecy associated with a proprietary model, it is argued that the regulatory agency could be provided with documentation and possibly listings of the proprietary code as long as the agency did not release this information to the public. Finally, proprietary models can be tested against sample problems in order to demonstrate their consistency with other, approved, public domain models.

This rationale for including proprietary models and the associated procedures for their evaluation as well as their safeguard are countered by a number of arguments. From the viewpoint of a government agency, it would appear to be impractical, if not directly contrary to law, for proprietary models to be used in new source review and, quite probably, in the design of regulations and SIP revisions. Regarding new source review, spokesmen from industry express great concern that the agency could be using a model to which they as applicants had no access. The agency would at the same time face requirements for compliance with various public disclosure laws, state and federal, and in all likelihood could not honor an agreement to safeguard the details of the proprietary model. For example, the general counsel for EPA Region V forbade the use of a proprietary model in regulation development for these very reasons.

As to the use of standardized test problems for establishing some degree of equivalence between models approved via the Guideline and alternate, proprietary models, it is recognized that such may be desirable whenever a private party chooses to use a proprietary model in a permit application or in litigation. The challenge then becomes one of developing a set of test problems which explore the full range of application of the models in order to determine with a fair degree of confidence the question of equivalence.

1.12 SUPPLEMENTAL CONTROL SYSTEMS (SCS)

The Guideline makes no reference to SCS. Although many of the computer codes referenced in the draft Guideline are applicable to SCS determinations, some codes more suitable to transient analysis were not considered. Further, an important part of an SCS strategy is the on-line analysis of air quality and meteorological data and the related, near-term forecasting techniques.

Since the Guideline does not address SCS, the conferees did not consider this subject in significant detail. It is recommended that the Guideline be amended to indicate, probably by footnote, that SCS is not considered within the Guideline and then to provide one or more references for the user who is interested in pursuing the federal requirements and available methods for the implementation of SCS.

1.13 STRUCTURE OF THE GUIDELINE

The utility of the draft Guideline would be greatly improved if certain minor structural modifications were incorporated. Chapter subheadings and greater reliance on tabular presentations along with a table of contents would make the document more readable. As mentioned earlier, SCS must be referenced in order to clarify the intended scope of the Guideline. Similarly, the section on growth does not provide adequate guidance for handling this complex subject. It would be preferable for the

Guideline to acknowledge its limitation in this regard and provide references wherein the user can assess the state-of-the-art of growth projections for air quality management. Finally, the section on model application should be expanded to provide more guidance on use of appropriate emission data.

1.14 PERIODIC REVIEW AND UPGRADING OF THE GUIDELINE

By recognizing the generally unsatisfactory status of past efforts in validation of air quality models and the need for a more extensive, formalized procedure (see policy issue 1.4), the conferees wish to underscore the need for periodic review and upgrading of the Guideline. Further, the absence of coverage of topics such as SCS and photochemical oxidants and the limited treatment of oxides of nitrogen call for a significant expansion in the scope of future editions.

The conferees would be pleased to examine subsequent drafts of this first edition and to participate in the review of future editions. However, it is generally agreed that a more extended and less intensive review schedule, perhaps involving several standing committees, would be preferable to the highly compressed schedule imposed by a two- or three-day intensive conference/workshop.

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2 WORKING GROUP REPORTS

The working group reports are based on discussions held within the working group meetings. These reports incorporate corrections and editorial changes recommended by working group members. Extensive revisions or additional material submitted subsequent to the group meetings by group members or other conference participants have been referenced where appropriate and collected together in Section 3.

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2.1 GROUP I-1: MULTI-SOURCE, SHORT-TERM AND LONG-TERM FOR SET 1 POLLUTANTS

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2.1.1 Changes in Models Recommended in Draft Guidelines

The consensus of the group was that Gaussian plume models are the best available at this time for multi-source situations. The situation most frequently referred to throughout the discussions was the urban area with a large number of sources. Concerns were expressed regarding the need to specify the constraints on the use of a model and on various algorithms implementing a model. In this regard, the group recognized the need for well written user's guides which detail the limits of an algorithm's applicability. It was suggested that a list of features which would make algorithms more desirable might be developed. This was considered a reasonable suggestion but no attempt was made to produce such a list..

After accepting the Gaussian plume model as the best currently available, the specific algorithms in Table 3 of the draft guideline document were considered. It was concluded that knowledge of the state of validation of these models was lacking and that a need existed for validation studies and, more generally, packaged test cases to test new algorithms. The group considered whether to retain the hierachical structure of the draft Table 3 or to simply list acceptable algorithms with the choice of a prrticular algorithm being related to the level of detail required by the task at hand. The consensus retained the hierachy.

The use of the Larsen procedure for estimating short-term averages in AQDM and CDM was discussed. The group concluded that hour-by-hour calculations as done by RAM are a preferable method but did not feel that the statistical conversion of averaging times should be precluded in urban areas where large point sources are not a major influence. The possibility of giving CRSTER the capability of handling multiple sources was discussed and some validation data on CRSTER were presented. It was noted that short-term predictions tend to be accurate to within about a factor of two and that the suggested long-term algorithms tend to overpredict. The point was also made that AQDM, CMD, and the Hanna-Gifford model (properly applied) give equivalent correlations with measured data. The importance of representative meteorological data and a good emissions inventory was stressed by several members. Possible problems with the existing parameterizations of σ_z in the guideline models were noted.

The Texas Climatological Model (TCM) and Texas Episodic Model (TEM) were suggested as additional models for Table 3. These models were represented as being essentially computerized algorithms applying the Hanna-Gifford model with provisions for including the effects of individual point sources. Although there was some reluctance to including models not available from EPA or models in which a member of the group had a particular interest in Table 3, the Texas models were recommended for inclusion given the fact that they have been widely used. So that other models might be included in future revisions of Table 3, development of a formal procedure for approving equivalent models was suggested.

Throughout its deliberations, the group was aware that the data to make the best technical, scientific decision are frequently unavailable but that a need does exist for guidance in making the administrative decisions required by law.

The final concensus of the group for specific changes and additions to the February 1977 draft guideline follow. Where doubt might exist as to where changes were made, additions or changes have been indicated by a bar in the left hand margin. Recommendations of the group for areas needing attention or study follow the suggested changes in the guideline.

<u>On page 15, change Table 3</u>:

Table 3. Multi-Source Models Applicable to Specific Pollutants and Averaging Times[a]

SO_2 and TSP Annual Average	SO_2 and TSP 24-Hour Average	SO_2 3-Hour Average
AQDM/CDM[26,27]/TCM[b]	RAM[31,32]	RAM[31,32]
	TEM[b]	TEM[b]
	AQDM*/CDM*[26,27]	AQDM*/CDM*[26,27]

*Statistical conversion of averaging times required.

[a]Numerical references in the table cite references in the draft Guideline.

[b]Appropriate reference to user's manual. Descriptions of TCM and TEM are contained in Secs. 3.1.1 and 3.1.2.

<u>On page 16</u>:

Similar models have been summarized and discussed by Lamb et.al.,[9] Moses[10], Stern[11], and others. They are available from private consultants and other governmental agencies. However, to meet the need for consistency identified in the *Introduction* to this guideline, selected models have been specified. Based on a determination by the Regional Administrator that another air quality model already in use by a state agency provides equivalent or more reliable concentration estimates, that model may be used. Guidelines[12] which provide a procedure for comparing air quality models are in preparation.

There are limitations to the use of all atmospheric transport and dispersion models. Users must be aware of these limitations and not apply the models outside their limitations. Models listed in Table 3 are readily available; there are many other published multi-source models.

<u>On page 17</u>:

Multi-Source Models Required for Sulfur Dioxide and Total Suspended Particulates (Annual Average)

The Air Quality Display Model (AQDM)[26] or the Climatological Dispersion Model (CDM)[27], or TCM may be used to evaluate multi-source complexes.

<u>On page 18</u>:

If a more detailed or more suitable model is available, especially in a Region with major meteorological or topographic complexities, that model may be used.

Also, if the meteorological or topographic complexities of the region are such that the use of any available air quality model is precluded, then the model used for strategy evaluation may be limited to a Rollback Model.[30]

Multi-Source Models Required for Sulfur Dioxide and Total Suspended Particulates (Short-Term Averages)

The Real-Time Air-Quality-Simulation Model (RAM)[31,32] may be used to evaluate multi-source complexes.

If the data bases required to apply RAM are unavailable or inadequate, the TEM may be used.

If the resources required to operate RAM or TEM are not available, AQDM or CDM may be used to estimate short-term concentrations of SO_2 and particulate matter. These models must be used with procedures for the statistical conversion of averaging times as discussed by Larsen[25] to convert annual average concentration estimates to 3-hour and 24-hour average concentrations. This technique is valid only in urban, multi-source situations and should not be used in situations dominated by single point sources. Other similar techniques for making this conversion may also be used.

<u>On page 19</u>:

If a more detailed or more suitable model is available, especially in a Region which has major meteorological or topographic complexities, that model may be used.

If the meteorological or topographic complexities of the Region are such that the use of any available air quality model is precluded, then the model used for control strategy evaluation may be limited to a Rollback Model.[30]

2.1.2 Meteorological Data

In discussing the section on meteorological data it was pointed out that the data listed was that required by the models listed and that more detailed data was likely to be needed as models improve. Several comments indicated that representative meteorological data is not always readily available despite an implication to the contrary in the draft guideline. The group felt that the requirement of a five year data base was reasonable if five years of data were available. This was strengthened by one member who reported on a situation where consistent results began to be obtained at about 5 years when a total dosage model was used with increasingly long meteorological data bases in the 1-10 year range.

The consensus of the group is expressed in the following recommendations for specific changes in the draft guideline.

On page 30:

Specific meteorological data required to describe transport and dispersion in the atmosphere are wind direction, wind speed, wind shear, atmospheric stability and mixing height appropriate to the site. These parameters may be derived from routine measurements by National Weather Service (NWS) stations and the data may be available both as individual observations and in summarized form from the National Climatic Center, Asheville, N.C. If other sets of data which encompass wind direction, wind speed, atmospheric stability, mixing height or other indicators of atmospheric turbulence and mixing are available, they may be used. Local universities, industrial companies, pollution control agencies and consultants may be sources of such data. A five year data base is desirable.

On page 32 add the paragraph:

It is to be noted that future availability of meso and micro meteorological data collections will make practical more detailed meteorological analysis and subsequent improvement of model estimates.

2.1.3 Source Data

There were no major problems with the draft guideline statements about source data for multi-source urban situations. The consensus held, however, that other than area-wide diurnal variations could be important and that emission models should be used where available. The group suggested the following change in wording to express its consensus.

On page 35:

For multi-source urban situations, detailed source data are generally impossible to obtain. In these cases, source data shall be based on annual average conditions. Area source information required are types and amounts of pollutant emissions, the physical size of the area over which emissions are prorated, representative stack height for the area, the location of the centroid or the southwest corner of the source in appropriate coordinates. Where emission models are available, output from such models should be used. Short-term models may be modified to accept such data.

2.1.4 Supplementary Comments and Information

Supplementary comments and information on multi-source modeling were submitted by several conference participants. Both members of the working group itself and others contributed. This material can be found in Sec. 3 and is referenced below.

R. Porter submitted additional information on the Texas models. Sections 3.1.1 and 3.1.2 describe the Texas Climatological Model (TCM) and the Texas Episodic Model (TEM), respectively, in the format used in the conference notebook.

G. Melvin presented a description of Illinois' Air Quality Short Term Model (AQSTM) in the format of the notebook in Sec. 3.9.6. The group did not discuss this model.

A. Boyer presented a minority report (Sec. 3.1.3) suggesting limitations on who should be required to apply multi-source urban models. The group as a whole did not take a position on this subject. He has also described the use of urban and single source models by the Ontario EPA in Sec. 3.9.7.

S. Hanna has provided an extensive description of the development, application, and suggested uses of the Hanna-Gifford model in Sec. 3.9.1. Included is a description of the model in the notebook format including a formulation treating chemical reactions.

M. Williams has suggested adding monitoring requirements to the conditions under which rollback may be used and has commented on the choice of receptor sites. He recommends specific wording changes for pp. 19 and 29 of the draft guideline in Sec. 3.9.2.

M. Smith submitted criticisms of RAM in Secs. 3.9.3 and 3.9.4. Section 3.9.4 is a letter from Dr. Howard M. Ellis of Enviroplan, Inc. The criticisms relate to the lack of validation, problems with σ_z values, and the full load operation assumption. Section 3.9.4 also suggests that some measure of actual operating rates be used if five, rather than one, years of meteorology data are employed.

2.1.5 Further Recommendations

1. Packaged test cases should be developed for comparing and testing models. These cases should include the required emissions and meteorological data for input and the appropriate measured air quality data against which model predictions can be checked.
2. User's Guides should delineate clearly the limits of applicability of model algorithms in order to avoid misuse. There is also a frequent lack of clarity in the specification of the inputs needed by particular algorithms.
3. EPA should encourage continuing effort, either in-house or under contract, for validating the models they are recommending. Such information is necessary for an informed scientific endorsement of particular models and such information has not been presented at the conference.
4. A formal procedure should be developed for approving other models and placing them in the guideline.

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2.2 GROUP I-2: SINGLE SOURCE, SHORT-TERM AND LONG-TERM, SET 1 POLLUTANTS

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CONTENTS

2.2.1 *Distinction Between Models and Computation Procedures*

For the purposes of these deliberations a clear distinction should be made between <u>models</u> and <u>computational algorithms</u>. The latter are sometimes called computer programs or computer codes. A model is a set of mathematical relationships, based on scientific principles, often using adjustable parameters. Examples of atmospheric concentration models are: rollback, fixed box models, Gaussian models, and moving box models.

A computational algorithm is a set of detailed instructions for implementing a model. For example, AQDM, CDM, CRSTER, PTMAX, PTDIS, and PTMTP are <u>all</u> computational algorithms for implementing <u>the same</u> basic Gaussian model. For identical input data they must give the same result, if they faithfully represent the agreed underlying model.

This distinction was made because the group agreed that the Gaussian model is the state-of-the-art model for operational estimates of TSP and SO_2. The choice of particular algorithms to be used depends on the amount and quality of input data available, the detail required in the answer, the available budget, and other factors.

2.2.2 *State-of-the-Art Point Source Model*

The working group recognized that no model available today, nor probably in the foreseeable future, is free of serious limitations, but it was unanimous in recommending the Gaussian statistical model as the state-of-the-art model for all point source evaluations.[1]

It should be mentioned that the use of the term "Gaussian" is understood to refer to the distribution of the pollutant about a plume centerline. Consequently, the use of a particular algorithm to compute the position of the plume centerline does not alter the fact that the model is still basically a Gaussian model.

Each of the computational algorithms listed on page 14 (Table 2) of the draft Guideline contains the Gaussian assumptions for the representation of plume dispersion as a key feature. Therefore, the group agreed that each is acceptable in principle.

Several concerns were expressed regarding specific assumptions or the management of data in several of these algorithms. However, none were sufficiently basic to warrant discarding the Gaussian model in favor of another approach. The major concerns are listed below:[2,3]

1. There is evidence that the σ_z curve representing the A stability category in the Pasquill-Gifford formulation may result in serious overestimates of short-term maximum values from tall-stack sources.

2. The system of using a random adjustment to winds recorded in 10° intervals may not be adequate to represent full horizontal plume spread. This system is used in CRSTER (see results of Group II-4 discussions).

3. From analysis of limited power plant data it appears that the 24-hour predictions of CRSTER may be too low for relatively flat terrain. It is worth determining whether this is a typical result of the model.

4. There is controversy over the technique used for adjusting the algorithm to terrain variations. More generally, how should the Gaussian model be modified when a plume approaches elevated terrain?

5. There is evidence that stability estimates, and the resultant σ_z and possibly σ_y values, should be functions of source height, and not independent of it as shown in the Pasquill-Gifford curves. This may influence the applicability of the Gaussian model to tall stack calculations.

6. Effluent released during one segment of time may have an effect on the concentration at a receptor at some later time. This could influence multi-hour concentration estimates.

7. Plume rise is not considered as a final, settled issue. As with the diffusion algorithms these estimates should be reviewed.

It should be noted that some of these concerns are specific to the "CRSTER" algorithm, namely points 2 and 3, while others apply to the Gaussian model in general. It should be emphasized that in all cases, the participants were concerned with the problem of calculating short-term ground-level concentrations resulting from point source and especially tall-stack emissions. Each of the items listed were only briefly discussed by this working group since the subsequent working groups on specific issues would presumably deal with these concerns.

This working group also expressed concern about applying this set of algorithms beyond 50 kilometers from the source. The concerns ranged from vague uneasiness because of the lack of data on dispersion and model validation at greater distances to the recognition that physio-chemical processes, such as deposition at the air-land or air-sea interface would alter the Gaussian distribution of the pollutant. Conversion and loss processes are not treated by the Guideline models. Neglect of these latter factors should result in an overestimate of ground level concentrations. However, extrapolation of the Pasquill-Gifford dispersion curves to large distances could result in an underestimate of ground level concentrations.

Although not specifically agreed upon as a recommendation, it was clear that all members of the group favored expanded efforts to refine and improve the algorithms listed in the proposed Guidelines by careful comparison with data.

2.2.3 Availability of Regulatory Algorithms (Programs, Codes)

It was unanimously agreed that regulatory agencies (EPA, state and local agencies) should be required to state clearly which models and algorithms (programs, codes) they will use to review construction permit applications.

If published, widely available algorithms (e.g., those on the UNAMAP tape, available from NTIS) are used, then a listing of algorithms together with a brief description of how optional features are selected and which algorithms apply to particular cases should be adequate. If, on the other hand, they use models which are not readily available, they should be required to make copies of computer tapes and complete program documentation, and make these available to any interested party at nominal cost.

The purpose of this requirement is to enable those who apply for permits to know exactly how their request will be evaluated.

Wherever practical, regulatory agencies should use nationally-available models, rather than ones peculiar to their agency. This recommendation minimizes the number of different regulatory situations a multi-state source must face. If there is some significant advantage (i.e., special algorithms for accurate treatment of land/sea breeze, fumigation, etc.) in using a non-standard model, then this recommendation should be ignored. In such cases the requirement for adequate documentation must be re-emphasized.

There should be some criteria for deciding whether alternative algorithms or models are acceptable. It was unanimously agreed that such criteria could include the use of reference or bench-mark type test problems designed by the EPA.

2.2.4 Recommendation for "Screening Procedure"

The computational effort and resource expenditure required to carry out single source calculations with the CRSTER algorithm as outlined in the Guideline were judged likely to be excessive for small sources. This judgment took into account the fact that both the CRSTER and alternative computation algorithms (some of which are much easier to implement) were based on the same Gaussian model. Instead of the indiscriminate use of CRSTER for all sources, a screening procedure was recommended. Only sources failing the screening test or failing to qualify for the screening test should be subjected to an analysis with the more elaborate CRSTER algorithm.

The question of precisely what criteria should be used in qualifying a source for the screening procedure and in deciding compliance with the controlling standard was discussed at some length. It was generally agreed that sources having stack heights greater than 100 meters would automatically be subjected to the more complete analysis by the "CRSTER" model. Application of the "CRSTER" model must of course be limited to cases where the physical stack height is substantially greater than the surrounding terrain variations. Reservations were expressed because applicants might use this cirteria as a basis for stack design. Hence, it may be necessary to consider additional criteria which take into account effluent or heat emission rate as well as stack height.

To pass the screening test the predicted concentration using the screening procedure must be less than or equal to 50% of the controlling standard concentration.

The recommended screening procedure is as follows:

a) A hypothetical joint frequency distribution of wind speed and stability is developed containing all possible reasonable combinations of those 2 meteorological variables. This distribution is to be used in the selection of appropriate short-term meteorological conditions.

b) Computations are carried out using one of the UNAMAP point source models to determine the 1-hr. maximum concentrations.

c) Longer-term concentrations estimates are developed using simple ratios to the hourly maximum concentration estimate.

   It is tentatively suggested that the ratio of 1-hr. maximum to 24-hr. maximum be taken as 3 for stack heights less than 100m.

d) The estimated maximum concentration is compared with the controlling standard concentration. If the estimated value is $\leq$ 50% of that standard, the test is passed and no further analysis using the CRSTER model may be required.

It should be pointed out that the screening procedure may have to take into consideration special effects such as fumigation, downwash, or terrain complexities using appropriate algorithms. (See the reports of the Working Groups on Complex Terrain and Plume Dynamics.)

This recommended screening procedure is quite similar to that outlined in "Draft-Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10: Reviewing New Stationary Sources" SRAB, MDAD, OAQPS, EPA, February 1977. The latter guideline suggests the use of an approach similar to that used by the "VALLEY" model for complex terrain cases.

See footnote 4 for further comments.

2.2.5 *On the Question of Enumerative vs. Statistical Use of the Estimates of Short-Term Concentrations*

In regard to this question there was general, although not unanimous, agreement that a statistical approach should be used. However there were differences of opinion regarding the precise nature of the statistical approach, the length of meteorological records required, and which concentration value (highest, second highest) should be applied as the control. It was generally felt that the question of the precise nature of the approach is sufficiently important to warrant a detailed investigation subsequent to the conference.

The following statement reflects the consensus of the majority of participants of this working group:

In evaluating the modeling results to predict compliance with short-term NAAQS (not to be exceeded more than once a year) or PSD (not to be exceeded), the test shall consist of computing the predicted concentrations at each of the several worst receptor points, for a specified period of time[5], using the state-of-the-art modeling technique (e.g., CRSTER or its equivalent). These worst receptor points are defined by the highest concentrations for the averaging time of concern (3 hours or 24 hours). The resulting set of computed values for each of the several points chosen shall be fitted by a suitable cumulative frequency distribution function[6].

In order to be consistent with both the inherent uncertainties in the frequency of occurrence of rare events and the use of the second highest concentration as required by the NAAQS, the following demonstration of compliance seems appropriate: The distributions shall be considered to demonstrate compliance if the cumulative distributions functions indicate that the short-term NAAQS will not be exceeded twice in a calendar year, more than one year in each _x_ years at any given point, and that the PSD increments will not be exceeded more than once per _y_ years.

We understand that the use of the second highest value was chosen to correspond to the realities of ambient air quality monitoring. The realities of modeling are different. Thus - for modeled compliance - a preferable demonstration of compliance would be: The distributions shall be considered to demonstrate compliance if the cumulative distribution functions indicate that the short-term NAAQS will not be exceeded, on the average, more than once per calendar year, and that the PSD increments will not be exceeded more than once per y years. In the latter statement the term "on the average" is understood to be based upon a limited but specified length of record, say one to five years.

The x and y in the above paragraphs have been purposely left undefined. It was believed that a thorough study of the consequences of possible choices of those values should be made before values can be assigned[7].

FOOTNOTES FOR SECTION 2.2.

1. This recommendation was made for cases where there is no appreciable depletion of plume material and where the topography is relatively simple.

2. In a post-conference contribution (see Section 3.9.2) M. Williams expressed some additional concerns regarding CRSTER and RAM and pointed out a documented case in which plume rise was suppressed by an elevated inversion layer. Such phenomenon are not properly treated by these algorithms.

3. At the conference, M. Smith passed out copies of comments prepared by H. Ellis regarding the "RAM" and other guideline recommended algorithms. See Sections 3.9.3 and 3.9.4.

4. It is worthwhile calling attention to a post-conference submittal in which A. Boyer (see Section 3.9.7) describes a regulatory approach taken in the Ontario Environmental Protection Act. This approach, which is a variant of the screening procedure concept, requires the applicant to make estimates of impact based on a simple point source model applied under certain meteorological conditions. It is then the responsibility of the control agency to determine whether the combined effects of multiple sources, each complying with single source standards, when operating under a wide spectrum of conditions, is acceptable.

5. The length of meteorological record to be used for the calculations was not firmly agreed upon. Some were happy with a minimum of one year and a maximum of five years if the data were available while others preferred a minimum of two years. One participant suggested that the projected life time of the plant might be a more appropriate record length to insure compliance with the standard. The majority, however, were reluctant to recommend a specific record length without first examining the whole question in much greater detail.

6. At least one working group member expressed formal concern over the difficulty of fitting air quality data with a suitable functional form. See comments by Wevodau, Section 3.2.1. This concern plus others lead this member to conclude that the enumerative approach, as recommended in the draft guideline, was more acceptable at this time. Also see a comment submitted by a non-working group member, R. Porter, Section 3.2.2,

in which the suggestion was made to include with the fitting procedure a formal test of "goodness of fit".

7. In addition to the statement above, Mike Williams expressed reservations about the use of modeled second highest concentration estimates. His statement was submitted after the Group I-2 meeting was adjourned and was therefore placed in Section 3.2.3 under the title "Rationale for Elimination of the Maximum of Second Highest for Modeling Purposes". An additional comment made outside the group meeting which addressed William's comment was submitted by R. Porter and was placed in Section 3.2.2.

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2.3 GROUP I-3: SET 2 POLLUTANTS (CO, NO_2, PHOTOCHEMICAL OXIDANT)

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2.3.1 *Overview and Philosophy*

In order to recommend a model for general application, it is necessary that the model meet appropriately specified performance criteria. In our opinion, while a number of models are now available for use, it is not possible as of this writing to appraise the performance of these models for one or more of the following reasons:

- performance criteria do not now exist
- evidence of verification has not been satisfactorily reviewed
- adequate evidence of verification is not available
- acceptable evaluation exercises have not been undertaken

As a consequence, we recommend the identification of only generic classes of models for use, avoiding the recommendation of any specific model.

While this position is in our view a wise and appropriate one to adopt, we realize that it falls short of meeting the short-term needs of the user community. In order to partially satisfy this need, we propose a two level hierarchy of model usage --

- screening (general estimation and potential problem identification)
- refined exercise (attempt at "best" prediction)

In the case of CO prediction models, we tentatively recommend* specific models for screening use, but at this time we can only recommend several generic types of model as being potentially suitable for refined calculations in practical applications. The specific models tentatively recommended for screening purposes may be deemed suitable for certain types of refined calculation at some time in the future upon completion and/or presentation of adequate verification studies.

In the case of the photochemical pollutants, we again recommend specific methods for screening purposes but only generic types of approaches for refined calculation. In this case however, the screening procedures are not potentially suitable for refined predictions.

In any case, it is incumbent upon the user to assure himself that a model is truly appropriate for a particular application, be it for screening purposes or refined calculation.

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*Subject to evidence of verification.

Since we are unable to recommend specific models for refined use at this time and recognizing the eventual need for such recommendation, we would strongly encourage that the following steps be undertaken as quickly as possible and with sufficient talent and resources:

- Establish relevant and unambiguous performance criteria. We would encourage the convening of a panel of experts to achieve this end.
- Establish an independent group having a charter to perform a continuing evaluative function -- that is, determining if candidate models satisfy the specified performance criteria.
- Incorporate new information and knowledge into these recommendations annually and introduce specific model endorsements as rapidly as feasible (perhaps bimonthly or quarterly).

2.3.2 *General Considerations*

Applications requiring the use of air quality models for set 2 pollutants fall into a wide variety of categories, of which the following are examples:

- State Implementation Plan Revisions
- Air Quality Maintenance Plans
- Regional Transportation Plans, including Transporation Control Plans, Transportation System Management, Transportation Improvement Program Requirements
- EIS/EIR's
- NSR
- Indirect Source Review
- PSD
- Others

A need for both <u>regional</u> and <u>local</u> models is apparent from a consideration of these applications and both needs can rarely be satisfied by a single model. By our definition, local models deal with distance scales of the order of 1 km or less and regional models with distance scales greater than 1 km.

Several generic classes of models can be identified, each having advantages and disadvantages. The principal classes and some of their limitations are:

- Gaussian
  a) considerable simplification of real phenomena
  b) cannot treat low wind speed cases
  c) cannot properly treat cases involving complex terrain
  d) cannot properly treat cases involving complex source geometries (mainly depressed and elevated roadway sections)
  e) cannot treat time varying behavior

- Numerical
  a) specification of the appropriate values of the diffusion parameters can be difficult
  b) generally requires more meteorological data than routinely available
  c) the effects of numerical errors (e.g., pseudo-diffusion) must be evaluated

- Statistical/Empirical
  a) low spatial and/or temporal resolution
  b) often site or region-specific

- Physical
  a) specification of the appropriate values of the diffusion parameters difficult
  b) site-specific
  c) difficulty in achieving dynamic and geometric similarity

A general assignment of model classes to local and regional scale applications may be made as follows:

Local/Site-specific	Regional
Gaussian	Numerical
Numerical	Statistical/Empirical
Physical	Gaussian

Care needs to be exercised in complex circumstances in which these general assignments may be inappropriate and in which a sophisticated analysis may be required. We emphasize that the burden is on the user to consider his specific application and needs carefully, taking the limitations of different models or model classes into account.

The main criterion that should be used in selecting a model for a specific application is the past performance of the model in situations which approximate the applications at hand as closely as possible. This verification evidence should include work by an independent group other than the model developer if possible, and should cover a wide range of conditions in order to clearly define the limitations of the model. If past verification is inadequate, a verification study should be required as part of the analysis, including the specification of evaluation procedures and performance guidelines. Verification is important because it provides the best mechanism for identifying model limitations in practice and for determining the suitability of different models for specific applications in an appropriate manner.

Cost/benefit considerations should play a role in determining the level of sophistication with which the air quality analysis is to be carried out. Some of the relevant factors are:

- the economic consequences or cost of making a specific decision compared to the cost of the analysis necessary to justify the decision technically,
- the extent to which an increased level of effort in doing an analysis is justified by an increased level of confidence in the results,
- the available resources (money, skilled manpower, computer)
- the data requirements (meteorological, emissions, air quality).

We suggest that the information in the Guideline on the following topics be updated periodically:

- the codification or identification of typical applications
- model verification information, classified particularly with respect to typical applications

2.3.3 *Carbon Monoxide Model Recommendations*

Consistent with the philosophy outlined in Sec. 2.3.1, we can tentatively recommend certain models for use as "screening" tools, subject to evidence of verification. The term "screening" tools applies to methodologies which provide approximate and conservative estimates of the air quality impact of a specific source type so as to identify those situations which require no further air quality impact evaluation:

Model	Source Category
HIWAY+	Individual Project Reviews
Hanna - Gifford - HIWAY+	Transportation Network Review
(Point and Area Source+ Models Recommended in Sections 2.1 and 2.2)	Point Sources

These models must, of course, be used in a manner consistent with the scientific principles and assumptions inherent in their development. Further, the user should apply these models only to situations similar to those in which they have been verified. Also, it is recommended that U.S. EPA immediately subject these models to further verification procedures.

2.3.4 Short-Term Photochemical Pollutant Model Recommendations

In this section we divide our discussion into two parts, one dealing with the use of models for screening purposes and one with the use of models for more refined predictions. We also give recognition to the problems of point source and regional modeling of photochemically reactive pollutants.

2.3.4.1 Screening Purposes

The purpose of a screening exercise is to eliminate from further consideration those sources which are very unlikely to cause or contribute to ambient concentrations in excess of the air quality standards. A suggested technique for screening NO_x sources with respect to NO_2 standards is to use a simple gaussian diffusion model in conjunction with the appropriate Briggs formula to compute plume rise. It should be assumed that all NO_x is emitted in the form of NO_2 and that NO_2 is a conservative pollutant. Future verification work may allow the assumption of 100% conversion of NO_x to NO_2 to be relaxed, thereby increasing the utility of this technique as a screening procedure. The Gaussian model is used to estimate the highest 1-hr. maximum ground level concentration taking into account the existing background concentration, potential for downwash of the plume,

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+Subject to evidence of verification. A specific concern is the validity of this model for "worst-case" low wind speed conditions.

terrain, other sources and the full range of possible meteorological conditions. The approach should be conservative in nature.

As a first approximation, several techniques may be used to estimate the regional impact on oxidant levels of the emission of oxidant precursors. The technique under development by EPA (EPA, January 1977), commonly known as the Dimitriades - Dodge Isopleth technique, should be viewed at present as the preferred screening procedure. The technique, if adapted for the user's specific area and circumstances, provides a quick estimate of the degree ot control required. (A code for such use is now being developed under contract to EPA). If the necessary data are unavailable for developing a site-specific system of curves, the more general curves should be used. If it is not possible for either set of curves to be used, the only available alternative is Rollback; however, we have serious reservations concerning the use of this procedure.

2.3.4.2 Refined Predictions

Once it has been determined through a screening exercise that exceedances of the air quality standard may occur, it may be appropriate to pursue a more refined modeling approach. Such approaches can be divided into point source and regional models.

In order to calculate the temporal and spatial distributions of NO_2 and O_3 that occur in the atmosphere, it is essential that a numerical modeling approach be used. Numerical models have the ability to treat through realistic mathematical representation of the transport, diffusion, and chemical reaction processes that occur in the atmosphere. Two classes (grid and trajectory) of regional numerical models have been developed. These models are currently undergoing testing and evaluation. Until these validation studies are completed, these models must be exercised with caution.

2.3.4.3 Models for Reactive Plumes from Point Sources

Several models which are designed for this specific type of application have recently been developed or are currently under development. Simulation of the transport, dispersion and chemical evolution of plumes of reactive material from point sources requires treatments of the simultaneous spread of the plume, entrailment of ambient air with pollutant concentrations and chemical composition different from that within the plume, the effects of these phenomena on the chemical dynamics within the plume, and advection of the plume, all on a time dependent basis. Clearly, models designed specifically for this type of application should be used.

The data requirements for reactive plume models are more demanding than for Gaussian models. In many cases considerable care must be exercised in selecting the most appropriate and representative inputs, in particular the meteorological and ambient air quality variables. This may require the expertise of experienced modelers and meteorologists, depending on the type of problem. Of course, this does not preclude the applicant from supplementing existing data bases, designing an aerometic monitoring system, and collecting field data to more adequately establish inputs. A model's performance can be evaluated only through appropriate and well considered verification studies based on sound inputs and comparative data.

2.3.4.4 Regional Models

The assessment of the temporal and spatial impacts of a new emission source of NO and RHC on regional air quality requires the use of regional airshed models. Airshed models require substantial amounts of data, including a gridded emission inventory for both mobile and stationary sources of NO_x ($NO + NO_2$) and RHC. In addition, depending on the chemical mechanism, it may be required to further classify the RHC according to subgroups (such as olefins, aldehydes, paraffins and aromatics). This gridded emission inventory generally requires a resolution of 1 to 5 km depending on the application. In addition detailed meteorological data are required to describe the wind flow, diffusion, and inversion fields. Grid models are most appropriate for assessing air quality impacts on a systems basis while reactive plume models are most useful for assessing the impact of isolated sources. These models are complex and require experienced modelers who can properly interpret the results and assess the impacts. It is of importance to note that because of complexities of the models and their substantial data requirements, their use will most likely be restricted to applications in those regions where sufficient data are available. Even in such regions, a careful editing of the data bases must be undertaken to ensure proper interpretation of model results.

Again, as with the reactive plume models, the reliability of model predictions can only be assessed through carefully planned and designed validation studies. Where input data are available, it is strongly recommended that validation studies be considered an integral part of the modeling endeavor.

2.3.5 Long-Term NO_2 Model Recommendations

An appropriate screening procedure for determining impacts of new sources on long-term (annual) NO_2 levels would be to make use of an appropriate model now in use for conservative pollutants (such as CDM in urban areas, for example) together with the assumptions: 1) that all NO_x emissions are really NO_2 emissions and 2) that NO_2 is a conservative pollutant. After sufficient experience with this procedure, it may be possible to assume less than 100% conversion of NO_x to NO_2 and thereby to improve the usefulness of the technique as a screening tool.

In order to obtain a refined estimate it will be necessary to make use of more sophisticated techniques applied on a case-by-case basis.

Supplementary Material

Descriptions of two reactive plume models may be found in Sec. 3.3.1 and 3.3.2.

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2.4 GROUP II-1: LONG-RANGE TRANSPORT AND LOSS MECHANISMS

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2.4.1 *Summary of Discussion*

The section in the EPA draft Guideline that is directly related to long-range transport considerations is the first paragraph on page 21, which reads in part "It is recommended that estimates should not be made for distances greater than 100 kilometers and that air quality impact beyond this distance be assumed to be negligible." The point is made further on in the paragraph that impacts at this distance and beyond are "likely to be small and for all except very large facilities," and the Regional Administrator is directed to consider specific large individual sources on a case-by-case basis if a threat to air quality standards or prevention of significant deterioration (PSD) increments exists at these distances.

In the general discussion which arose from these remarks, the following points were made and agreed upon by the participants:

- The guideline should refrain from specifying a single distance cutoff. It was considered preferable to give a range of distances to indicate some degree of uncertainty regarding the maximum distance at which relatively simple models could be used for estimating pollutant concentrations, and a range of 50-100 km was deemed appropriate although a lower value of 25 km was also considered.

- Observational evidence indicating that Class I PSD increments have been or could be exceeded at distances of the order of 100 km from a single or a small number of sources was presented and discussed. It was felt that the assumption of negligible impact beyond 100 km would be invalid in a sufficiently large number of cases that it should be deleted from the guideline. (Specifically, data from Ref. 2 were presented which indicated that SO_2 concentrations approaching 50 $\mu g/m^3$ were observed approximately 90 km downwind of a group of four power plants in eastern England. Several participants reported knowledge of other studies which also provided evidence for potential PSD increment exceedances. These were provided after the conference and are given as Refs. 1, 3-5.)

- Regarding the different averaging times specified in the PSD regulations for SO_2, it was felt that if the short-term (3 and 24-hour) increments were not exceeded, then neither would the annual increment. Attention should therefore be focused on the possibility of a short-term exceedance in evaluating the potential impact of a new source.

- The need for treatment of individual situations on a case-by-case basis should be emphasized.

- Plume depletion and chemical conversion in plumes from elevated sources can be significant at distances of the order of 25 km, and are normally significant at distances of 50-100 km and beyond under conditions of appreciable vertical mixing. Plume depletion is normally significant at considerably shorter distances for near-ground level sources.

Attention was then focused on questions relating to the modeling of transport, dispersion and depletion over distances beyond 50 km and the following points were agreed upon:

- Techniques for long range transport modeling are available. (Refs. 6-16, provided by participants after the conference.)
- Only limited comparison of predictions of these models with observational data is available and the models cannot be considered validated.
- A treatment of vertical dispersion using an approach based on K-theory is generally more appropriate than one using a Gaussian approach whenever plume depletion by dry deposition is significant, due to the ability of the former to incorporate a more realistic boundary condition at the earth's surface.
- Trajectory analysis of the type usually done in the available models requires wind, pressure and temperature data both at ground level and aloft at representative sites within the area of interest.

Based upon this discussion, several changes in the EPA guideline were recommended.

2.4.2 Recommendations

It is recommended that the paragraph in the draft EPA Guideline on Air Quality Models and Associated Data Bases which deals with long range transport, specifically the first paragraph on page 21 of that document, be altered to read as follows:

"The administration of the national prevention of significant deterioration policy may require that the air quality impact of a source be estimated for great distances downwind. It is uncertain, however, what the impact of sources at such great distances is. There are several reasons for this. Our knowledge of the dispersion coefficients for air quality models* becomes increasingly tenuous with downwind distance. Distances beyond 50-100 kilometers require substantial travel time at the most frequently experienced wind speeds. As travel time increases, the daily weather cycle is more likely to alter plume trajectories and dispersion characteristics. The impact at distances greater than 50-100 kilometers is likely to be small, however the impacts are not necessarily negligible for large sources.[1-5] Techniques are available to examine these impacts,[6-16] but only limited experience in their use is currently available. If it appears that a large source (for example, a 2000-MW coal-fired power plant meeting new source performance standards) may constitute a threat to ambient air quality standards or prevention of significant deterioration increments at large distances, that source should be considered on a case-by-case basis with available techniques."

Supplementary Material

A description of models used by the Central Electricity Generating Board, England, for medium and long range predictions may be found in Sec. 3.9.5.

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*Vertical dispersion in these situations is more appropriately treated with models which are based on K-theory. There also are inherent difficulties with Gaussian models in cases where plume depletion is significant. Plume depletion would normally be significant at distances of the order of 50-100 kilometers and beyond under conditions of appreciable vertical mixing, and at considerably shorter distances for near-ground level sources.

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Long Range Transport Models

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2.5 *GROUP II-2: PLUME DYNAMICS UNDER SPECIAL CONDITIONS*

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2.5.1 Introductory Remarks

Despite the wide range of problems implied by this title, the working group focused on only a few situations not routinely treated by the standard models but which may lead to violations of short-term NAAQS or PSD increments, especially in Class I areas. Three situations were considered:

1. Aerodynamic downwash;
2. Sea breeze and other anomalous circulation patterns;
3. Interactions of the plume with an elevated inversion layer:
    a. Fumigation
    b. Trapping

The members were in unanimous agreement on the proper way to approach these issues in a guideline document. Firstly, the guideline should state clearly that it is incumbent upon the various parties involved in the decision making process to determine whether or not any of these phenomena are likely to occur, and, if so, whether in a manner likely to cause violations of short-term limits. Secondly, this screening process, as well as any subsequent analyses, must be carried out under the guidance of persons knowledgeable in the physical processes involved. Thirdly, since the situations for downwash and unusual circulations require a case-by-case analysis, no standard models or rules-of-thumb should be formally recommended in the guideline. And, finally, to assist the user of the guideline in selecting the best available and most appropriate analytical methods for estimating such impacts, one or more pertinent references should be cited.

2.5.2 Aerodynamic Downwash

Included in this problem area are all situations wherein the dynamics of the effluent in the immediate vicinity of the source are influenced in a significant manner by nearby structures and terrain. Two closely related approaches have, in general, been taken to simulate these conditions within the structure of the standard Gaussian plume model:

1. An equivalent volumetric source is assumed, with a cross-sectional area approximating that of the obstacles - usually the building upon which the stack or vent is situated;

2. An enhanced σ_z is employed, usually with an assumption of zero plume rise.

These approaches are documented in references 1, 2, and 3 in sufficient detail to permit the user to handle the most common problem of a single building and its stack.

In a closely related matter, the members were agreed that the rule-of-thumb, "a proper height for a stack is 2 1/2 times that of any nearby structure," should not be arbitrarily applied to avoid downwash conditions since (a) in many instances the rule is unreasonably conservative, causing unnecessary expense and unsightly high stacks, and (b) in other instances it may be inadequate especially if localized terrain effects influence the air flow in the vicinity of the source. (See Ref. 4 for a further discussion on these topics.)

The members recommended that the guideline include a listing of situations in which downwash effects might occur. These would serve as warnings to the user that special attention should be given to the potential for downwash. They would not represent explicit criteria. Included in this list should be:

1. Relative heights of stack and nearby structures or land features (both upwind and downwind);

2. Dimensions of the building and stack, in particular the aspect ratio relative to the wind direction;

3. Emission characteristics - thermal flux and effluent velocity at part load operation as well as at design values; and

4. Multiple stack configurations.

2.5.3 *Sea Breeze and Other Anomalous Circulation Patterns*

The phenomenon commonly known as a "sea breeze" can have a substantial influence on the transport and diffusion of pollutants. The EPA modeling guideline should recommend that is be accounted for in major modeling studies in areas where the sea breeze can be important. Three areas in which the sea breeze can be important are in long-term modeling, short-term modeling on a regional scale, and short-term modeling of individual sources. For individual sources the sea breeze fumigation, documented by Lyons[5] and

Hales[6], can lead to high short-term concentrations of pollutants. For short-term studies of a large area, the sea breeze can strongly influence local circulation, changing wind and stability patterns and, again, possibly causing high short-term levels in areas where they wouldn't be otherwise expected. This has been documented by Gatz[7]. For long-term models the sea breeze effect can have a marked effect on the stability climatology of the shore area, affecting wind patterns, stability, cloud cover, and precipitation patterns. Great care must be taken to ensure that the data used in such a model is representative of the area. (See Estoque[8]).

A meteorological problem which is similar physically - but dissimilar topographically - is that of the mountain/valley winds. This, too, is a local, thermally-induced wind field which must be taken into account in any type of diffusion modeling in an area prone to these winds, or serious errors can and will occur. The need for correct, representative data is never more crucially felt than while modeling in both these problem areas.

While the committee feels compelled to point out this deficiency in the present draft guideline, we do not feel competent to draft an alternative and wish to suggest that an experienced, knowledgeable scientist in this area be retained to draft this portion of the Guideline.

2.5.4 *Interactions of the Plume with an Elevated Inversion Layer*

The group considered two topics under this heading:

1. Short-term downwash of a plume during transition from stable to unstable conditions (fumigation)

2. Plume interaction with mixing height

Fumigation downwash may be a significant factor in evaluating large sources relative to Class I 3-hr. PSD increments. The guideline user should be aware of this and seek expert advice if fumigation is reasonably anticipated to be a significant factor. The group recognizes that there are many cases in which fumigation will not significantly affect 3-hr. (or longer) concentrations, but we cannot offer specific procedures to determine if fumigation is a significant factor. Fumigation is discussed in Turner's Workbook[9], "Meteorology and Atomic Energy"[10] and TVA Studies[11]. In evaluating the effect of fumigation on 3-hr. concentration, the user must take into consideration the short duration of fumigation at a given receptor site.

Current models (e.g., CRSTER) assume no concentration at ground level if effective stack height is greater than the mixing height.* The group generally agreed this assumption is not uniformly valid.** Trapping probably does occur sometimes even when the calculated effective stack height is greater than the height of the mixed layer, and thus the idealized assumption in models such as CRSTER may lead to underestimation of short-term maxima. However, we are unable to recommend a change in current models at this time, in part because of the uncertainty in the manner currently used to estimate hourly mixing heights. The group believes this topic needs additional field evaluation in order to identify those physical conditions under which plume trapping can be assumed to occur.

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* See Sec. 3.9.6 for a summary of a model called "AQSTM" which was contributed by G. Melvin. This model treats atmospheric trapping and other phenomenon discussed in this section.

**See Sec. 3.9.2 for a discussion of a case in point by M. Williams which was submitted after the conference.

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2.6 GROUP II-3: COMPLEX TERRAIN

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CONTENTS

2.6.1 Summary of Discussions

The group was in unanimous agreement that it is not possible to specify a general model for providing a definitive statement concerning the air quality impact of a source or group of sources locating in complex terrain. While a number of generic types and specific algorithms are available, it is not possible to appraise the performance of these models or algorithms during this workshop for one or more of the following reasons:

- Lack of performance criteria,
- Lack of evidence for adequate simulation of physical processes for all possible situations, and
- Lack of acceptable evaluation exercises.

The discussion was limited to topographic complexities (e.g., lake or sea breezes were not discussed) and single sources. Considerable discussion was devoted to the use of the Valley algorithm. Some validation data for Valley were presented and explained(see Sec. 3.6.2). It was clear that Valley was not uniquely defined for various members of the group. One opinion held that specific meteorological conditions, 2.5 m/sec winds and F stability for a total of 6 out of 24 hours, were intended to be used in the algorithm. (This is the version described in the conference notebook.) Other users reported that they relax this restriction in practice and use site-specific meteorology. The point was also made that conditions conducive to highest concentrations depend on the specific situation and may frequently occur with moderate wind speeds, not always under stable conditions. It was also noted that even as a screen, Valley is not applicable in all situations because it might not treat critical situations like circular flows and inversions in valleys. Doubts were also expressed concerning the use of Valley as a conservative screening technique. Concern was also expressed that specifying the meteorology would allow some group to seize on these conditions and say they should always be used to estimate maximum concentrations even when such an assumption would be incorrect. One Valley user expressed confidence in using the algorithm as a screening procedure in mountainous terrain with the specific meteorological input. Another noted that in less severe terrain results obtained from Valley with site-specific meteorology were only negligibly less well correlated with observed concentrations than results from a Gaussian model using a plume half-height correction and that in general it appears to give satisfactory results, at least from viewpoint of a regulatory agency. It was decided that two positions concerning Valley had developed and should be noted:

- Some members of the group felt comfortable with Valley, at least as a reasonable screening procedure in complex terrain, and
- Most members of the group, however, felt that Valley could not be recommended for general use in complex terrain or even as a screening tool in all situations although steps could be taken to render its use less objectionable as a screen in certain circumstances.

Additional discussion centered on other available algorithms for and experience with treating complex terrain. Results using a half-height correction to a Gaussian plume model in three river valleys in Illinois were presented. This experience also indicated that the worst agreement occurred under calm conditions or with circulating flows. It was noted that poor agreement between predicted and measured values is usually attributable to poor source or meteorological data. In general, the group felt that good meteorological data is almost always a problem, particularly in complex terrain.

A method of correcting the Gaussian formula based on theoretical considerations of flow around a hemispherical obstacle was also presented. The method appears to work better than the full-lift assumption.

One proposal considered the use of a combination of meteorological and air quality modeling to develop the concept of air shed zoning.[23] (See also Sec. 3.6.1.) This approach was presented as being particularly applicable to the designation of land areas for the purpose of the prevention of significant deterioration.

A computerized flow correction model for use in mountainous terrain was also described but the group did not take any position on such work.

The group made several attempts to develop some guidance material. One suggestion was to enumerate the limitations on the use of various types of models (Gaussian, K-theory, statistical, etc.) in complex terrain. This approach was abandoned in favor of suggesting an administrative procedure for use in complex terrain situations. The procedure is described in Section 2.6.2. It includes a screening technique which is detailed in Section 2.6.3. Pertinent references are cited including some analytical routines. Given the dearth of applicable, validated techniques, the group's consensus called for requiring that a thorough and comprehensive effort be made to evaluate sources in complex terrain and for assigning considerable priority to developing and validating models for complex terrain.

2.6.2 *Recommended Procedure for Complex Terrain*

Given the agreement that no single model can adequately treat all complex terrain situations, the group suggested that a specific procedure be established that will lead to a rational and adequate assessment of a source locating in complex terrain and that will result in a two level hierarchy of a model usage consisting of conservative screening procedures followed by detailed analytical studies when the screens are not passed and in the development of data which will lead to further model refinement or input data acquisition.

The following process is recommended for use in evaluating sources desiring to locate in complex terrain:

1) Review available data (air quality, meteorological, source data, etc.) and the physical situation (action by source alone).
2) Develop a rationale with regard to a particular analysis technique (by analogy if necessary) (action by source alone).
3) As a screening procedure, the source reviews initial results with Agency. (See recommendations in subsection 3.)
4) If no agreement is reached based on the screen or if the source does not pass the screen, then the source has an option to develop detailed site-specific data and perform detailed analyses.
5) Agency evaluates detailed analyses.
6) Source constructs (if approval granted); however, air quality monitoring may be required.
7) Air quality data reviewed as necessary.

This approach requires control agencies to have access to the services of qualified personnel who are highly knowledgeable in dispersion climatology and the characteristics of atmospheric flow in complex terrain. In addition, the EPA must serve as a clearinghouse for data concerning the application of various models in complex terrain situations.

It is further recommended that specific procedures can be applied for use as screening tools for specific physical situations. Within the time limits of the session, such a procedure could not be fully developed. However, an outline of phenomena which should be considered in various complex terrain situations and suggestions for modifications to flat-terrain models are presented in the following section of this report along with the references to some of the appropriate literature.

For those sources which do not pass the screening procedures, detailed studies may be conducted by the sources to develop the meteorological data necessary to select and verify an analysis procedure which will result in an air quality impact assessment sufficiently refined to make the necessary siting decisions. At this point the assistance of a meteorologist knowledgeable in complex terrain problems and familiar with the area of interest is required.

2.6.3 Assistance in Defining Screening Techniques in Complex Terrain

This section provides a general discussion of phenomena which should be considered in addressing compliance with air quality goals in regions of rough terrain. The purpose is to provide some guidance on appropriate modeling techniques as a function of various source configurations with respect to topography and meteorological situations which might be expected. Modifications are suggested which could be incorporated in a dispersion model originally developed for flat terrain analyses and which would be one of a number of generic types (e.g., Gaussian, "K-theory"). The modifications are proposed in the context of developing "conservative" models which would tend to overpredict air quality impact and which would be appropriately used for "screening" purposes. Two broad categories of meteorological flow situations have been defined: 1) plume interactions with terrain under organized flow conditions, and 2) effects of local meteorological phenomena on dispersion in complex terrain.

2.6.3.1 Plume Interactions with Terrain under Organized Flow Conditions

This section is concerned with how a plume affects ground-level concentrations in flow situations which might be considered to be organized in the sense that the wind field would have high spatial correlations from one location to another and would not be significantly affected by local circulations. These are flows which lend themselves to some simplified types of theories (e.g., potential flow, modified potential flow, etc.). The approaches discussed below are categorized by different geometry and atmospheric stability classification considerations.

(A) Alterations to Plume Trajectories Due to Terrain Effects

Plume Height Greater than the Height of Nearby Terrain. Under these conditions, models which are appropriate for flat terrain can generally be utilized with some modest modifications. If the plume height is much greater than the terrain, flat terrain assumptions may be valid if some consideration is given to the possible enhancement of turbulence due to "roughness."[1] For plume heights not much greater than terrain heights, some modifications to the plume centerline trajectory seem appropriate. If the plume is embedded in a stable layer above the terrain, it is a reasonable approximation to assume that the plume trajectory would be horizontal for purposes of computing ground surface concentrations. (Note, however, the comment about the possible effects of "lee wave" phenomena.)

For a plume approaching a terrain object during neutral atmospheric stability conditions, modifications which are suggested from potential flow theory appear appropriate. A commonly used modification to Gaussian models involves adding an increment to the plume height over the terrain equal to approximately one-half the terrain height (distances estimated from the valley floor). A more conservative estimating technique would be to allow a smaller lift of the plume centerline above the terrain. This is, however, a potentially poor assumption when the plume height is nearly equal to the terrain height. Under non-stable conditions, allowing full lift of the plume, that is, a terrain following trajectory, would appear to be generally nonconservative, although it appears from a theoretical point of view to be reasonable for flow normal to two-dimensional type ridge orientations.[2]

Plume Height Lower than the Height of Nearby Terrain. If the plume height is initially lower than the height of nearby terrain, the approach to defining the flow pattern and, hence, plume centerline trajectories, depends critically on the local topography, atmospheric stability, and airflow. Potential flow theory provides some insight on the approach for neutral atmospheric stability conditions. If the flow is normal to a ridge, a plume embedded in the flow will accelerate and lift over the ridge with an actual centerline-standoff distance equal to approximately one-half the plume height above the upwind valley flow. Because of the flow acceleration, however, the streamline spacing decreases and, through distortion effects, the vertical dimensions of the plume decrease. The net effect suggest <u>no</u> alternation of the effective standoff distance in the exponential term in a Gaussian model.[3] A numerical simulation appropriate for this flow situation should account for these kinematic effects automatically. If the flow is normal to a more isolated three-dimensional terrain object (as opposed to a two-dimensional ridge), the effective standoff distance (considering both trajectory alternations and plume distortion effects) will be less than that for flow over a ridge shape. A value of about one-half the effective plume height in the absence of terrain is an approximation suggested for terrain objects with roughly equal horizontal and vertical dimensions. Under stable atmospheric conditions, for flow normal to a two-dimensional ridge, the flow may pass over the ridge if the stability is weak and wind speed is not too low. If the temperature inversion is strong and the wind weak, the flow may "block" and effluents would tend to stagnate upwind of the terrain. In either case, careful consideration would be given to how the principle of conservation of mass will act to alter plume trajectories and constrain the types of flow situations possible. On-site meteorological measurements, as well as any information on air quality concentration patterns, are extremely useful in such situations. For stable flow normal to more three-dimensionally shaped objects, the possibility of "blocking" is greatly reduced because the flow will tend to pass around the sides of the terrain. The possibilities for relatively high ground level concentrations exists under these conditions, however, if the plume flows directly toward the terrain. The frequency of occurrence of possible meteorological conditions which would cause this flow situation should be carefully assessed.

Under these postulated situations, insight regarding the expected plume behavior can be greatly enhanced with field observations and/or scaled-down physical modeling studies (stratified wind tunnel or water-towing tank experiments). However, the frequency of occurrence and persistance of meteorological conditions cannot be determined by these techniques.

(B) Alterations to Turbulent Diffusion Rates in Complex Terrain Modeling Studies

General Considerations. A number of field measurement studies have indicated that the association utilized in flat terrain of stability classification indices with turbulent diffusion rates are not necessarily valid in complex terrain. In particular, a number of phenomena tend to decrease the possibilities for very low diffusion rates associated with stable classifications.[3,6,7] A shift of stable classifications toward neutral appears often to be appropriate for purposes of estimating atmospheric turbulence levels. Under stable conditions, the presence of terrain may also greatly enhance crosswind "meandering" of a plume which in effect reduces time-averaged concentration values.[8]

Considerations in the Near-Field of Sources. For purposes of examining the impact of emission sources on nearby high terrain (within 10 km) careful consideration should be given to the effects of buoyancy-induced entrainment on plume dilution during the rising phase of plume growth.[4,5] Inclusion of buoyancy-induced turbulence can result in markedly different estimations of plume centerline and ground-level concentration values.

Far-Field Air Quality Impact. Additional considerations must be given to estimating the impact of plumes which travel large distances (30 km or more) before encountering high terrain:

1) If at the location of the encounter, the plume dimensions are the same order or larger than the terrain dimensions and the plume centerline is below the terrain height, then near centerline concentrations can be expected to occur at ground level.

2) The transport wind field may be highly variable both spatially and temporally. Therefore, methods for estimating dispersion rates under these conditions need to be given special attention.

3) Removal of gases and particulates by chemical reactions, scavenging, and deposition processes may be important to include in the estimation techniques to provide realistic estimates.

(C) Other Factors Affecting the Estimation of Air Quality Levels under Organized Flow Conditions

Lee-Side Flows. Observational data and physical model experiments show that under stable atmospheric conditions, the flow may accelerate on the lee side of mountain ranges and cause streamlines to closely approach the lee surface. It is possible that this type of flow could cause a down draft of a plume toward the surface and would increase ground-level concentrations. This type of flow is often characterized by the production of lee-waves downwind of the mountains. Flow separation effects on effluent dispersion of sources both upwind and downwind of an obstruction are discussed in a subsequent section.

Channeling Effects. Topographic features will alter larger scale meteorological flows to tend to follow terrain contours. This results in "channeling" of winds into preferred directions and therefore an increased persistence of winds in directions along valleys. These effects are of special importance in the analysis and application of wind data at a site for purposes of estimating 24-hour and annual average concentrations where, for point sources, persistence of wind direction is a major concern.

Fumigation and Limited Mixing Depth Effect. Special attention should be given to possible high ground-level concentrations on high terrain during meteorological flow conditions characterized by fumigation of elevated plumes to the surface by vigorous mixing. Other factors being equal, larger ground-level concentrations can be expected under these conditions in rough terrain than in flat terrain. Another concern is limitations to dilution rates associated with the "lidding" effects of an elevated inversion above high terrain. This phenomena needs further understanding; an approach similar to that adopted for fumigation simulations may be reasonable. Numerical simulation models which can account for the effects of spatially and time varying meteorological parameters would be especially appropriate for applications of this type.

2.6.3.2 *Effects of Local Meteorological Phenomena on Dispersion in Complex Terrain*

(A) Surface generated flow systems
- (i) Upslope-downslope
- (ii) Surface inversion dynamics
- (iii) Mechanical forcing and turbulence

(B) Interaction of surface generated flows with larger scale meteorology
- (i) Separation and decoupling
- (ii) Channeling
- (iii) Lee waves and blocking

(C) Worst case estimates

(A) Surface Generated Flow Systems

A major complication in dealing with dispersion over irregular topography is the fact that a simple atmosphere-surface interface does not exist as it does over a flat surface. The amount of solar energy received by irregular terrain surfaces varies widely with elevation and orientation of the surface toward the sun (aspect). This differential heating gives rise to locally forced wind systems and atmospheric stability variations which have to be considered. The irregular terrain, simply by its presence, also acts to alter an otherwise straight wind.

(i) Upslope-Downslope

The general character of surface winds in mountainous terrain is readily identified. Winds blow upslope (toward higher elevation terrain) on clear sunny days and downslope (toward lower elevation terrain) at other times.[12,13,14,19] This description is deceptively simple because complex valley-mountain geometry often disrupts this flow.[14,19] Modeling the dispersion from ground or low level sources must take into account these persistent and regular upslope-downslope winds. Since such winds are rather shallow, often not exceeding 100-200 meters depth, [10,13,19] tall sources may be subjected to quite different flows underlining the need for site specific data taken at both the source emission and effective plume height levels. One must be certain in areas of complex terrain to ensure that the winds used for dispersion analysis in fact represent the immediate environment of the site.

(ii) Surface Inversion Dynamics

Surface based inversions often form in mountain valleys.[13,19] Ground based emissions, low level sources, as well as tall sources, can be trapped by such conditions. Maximum surface concentrations may occur as a result of the limited vertical mixing, especially during times of minimum inversion height. Gaussian models are of limited value for calculating such concentrations. Rather, a model which divides the total emission by the volume flow rate of air in the valley below the inversion, a so-called box model, is more appropriate.[15,22] This technique may be suitable as a conservative screening method.

(iii) Mechanical Forcing and Turbulence

Turbulence can be forced, enhancing mixing and dispersion, by the presence of topographic relief.[16] Such a condition is difficult to analyze although terrain types can be identified which give rise to mechanical turbulence. Abrupt changes in elevation, isolated topographic features and very irregular surfaces all can contribute to mechanical forcing.[11,16] Physical modeling techniques (wind tunnel, water channels) can be used most successfully to qualify and quantify such mechanical turbulence generation.[17] Physical modeling techniques do not, however, deal with the frequency of occurrence and persistance of the meteorological conditions modeled.

(B) Interactions of Surface Generated Flows with Larger Scale Meteorology

A major complication of mountain meteorology is the fact that normal passage of large-scale meteorological systems is greatly altered by the topography. The expected surface induced flows, for example, may be strongly altered or not occur at all as a result of larger scale patterns. These local effects of larger scale systems can have a major effect on dispersion modeling.

(i) Separation and Decoupling

Particularly when wind blows perpendicular to a ridge the flow may separate from the downwind (leeward) side. Separation causes a closed circulation which can bring a plume down to the surface as well as a wake effect often far downwind of the obstacle.[9] It is not uncommon for various types of flow systems to exist within a mountain valley reasonably independent of, or decoupled from, the aloft meteorology.[9,14,19] The modeling of a plume under such situations can be very complex, especially if the plume travels between each flow regime. Phenomena based flow fields can be introduced into Gaussian models to be used as screening techniques. However, a preferred modeling technology is again the use of wind tunnels and/or water channels, but the problem of persistence would need further evaluation.

(ii) Channeling

Wind components blowing parallel with a valley often descend well into the valley and channel a strong flow along the valley axis.[9,12,14,19] The conventional Gaussian model is appropriate so long as the wind field is properly specified.

(iii) Lee Waves and Blocking

Lee waves generally occur with stable flows and set up a standing pattern of waves downwind of major terrain features.[9,16] Depending upon how close to the surface these waves and their associated flows occur, either separation or a high velocity surface flow may result.[9,19] Blocking, another result of stable flow, occurs upwind (windward) of terrain and basically represents a region of stagnation.[9,18] Upwind slopes with a reasonable flow component perpendicular to the ridge line may be subject to such blocking under stable atmospheric conditions. A box model such as described above could be calculated using the ridge top as mixing height and a surface area appropriately defined. Such a process could be used as a screening technique. An alternative is the use of combined meteorological and dispersion modeling.[23]

(C) Worst Case Estimates

Worst case estimates of ground level concentrations under terrain-disturbed flow conditions may be addressed with simple modeling techniques if care is taken in selecting model input variables. Perhaps the most important effect of topographic flow features is the severe constraint on representativeness of input data including mean wind, stability, and turbulence, since these flows exhibit strong space-time variability, particularly in the vertical. Some determination must be made that the plume is involved in the same flow regime as the meteorological input data throughout its path to the potential receptor site.

Many drainage flows are relatively shallow (< 200 m in depth) and wind measurements near ground level may not apply to an elevated plume if it is above the drainage regime. Also the lateral radius of representativeness of wind measurements becomes very small in broken terrain.

If the net transport is properly estimated and if alterations to dilution rate due to local effects are accounted for, Gaussian plume or box modeling concepts may be reasonably applied to obtain bounds on ground level concentrations of pollutants. In establishing procedures for estimating the impact of a proposed facility the following steps should be considered :

1. Examination of topographic charts on several scales with varying degrees of smoothing will aid in determining the basic setting with regard to basin structure, channeling, downwash, drainage,and stagnation potential.

2. A quantitative critical review of existing meteorological records from sites within the same general topographic domain will aid in establishing the existence and occurrence frequency of topographic effects on transport. These data are likely to be sparse and not properly located for a site analysis, so site meteorology must be considered next.

3. Based on the insights gained from the first two steps, perform a series of observations to establish the radius of representativeness. This should include elevated winds by means of pibals and concurrent observations from combinations of topography such as different slope faces, valley-mesa, hillside-plain, and source-receptor points. In documenting local flows, consideration should be given to their recurrence frequency, depth, lateral extent, diurnal pattern, net wind speed,and some measure of turbulence intensity.

4. The preliminary analysis outlined above gives a basis for estimating bounds on ground level concentrations for screening purposes and aids in the design of subsequent monitoring

networks. Using the morphology of local flows and the design of the proposed facility, an assessment can be made of the interaction of the plume with these wind domains, including the likely pollutant trajectories.

Examples of simple model applications given the insights from steps 1-4 above are:

a. *Plume Involved in Drainage Wind.* These flows maintain a downslope component and are estimable from smoothed topographic charts. The turbulence in these winds is often greater than would be implied by a simple ΔT predictor and should be measured in order to not underestimate dilution. Flows may vary from 1 to 10 m/sec but are often remarkably steady and amenable to Gaussian plume modeling along the determined (possibly curved) plume axis. The daytime counterpart to the drainage wind is generally weak, brief and sporadic and is dominated by the large scale flow regime of the day.

b. *Plume Elevated above Drainage Flow.* If it is determined that the plume and receptor are in the more uniform wind field above the local drainage wind,traditional modeling techniques [for organized flows] may be applicable to worst case determinations.

c. *Stagnation.* A plume imbedded in a stagnant flow created by a basin structure or blocking by a ridge may be treated using modified Gaussian plume techniques.[21,22] (The Valley model is an example of one such technique.) Plumes above a stagnant region in a well defined wind field may be more amenable to the traditional Gaussian plume model applications.

d. *Separated Flows.* These are local in character and depend on the existence of some general meteorological conditions of stability and wind speed. The geometry of the source and the obstacle producing the separation is very important. With an upstream source estimated to be involved in the separated flow region, a well mixed zone on the lee side of the obstacle ("box" model) may be adopted. With the source in a lee side downwash, maximum ground level concentrations would be due to a nearly direct path of pollutant to the ground in a fumigation mode.

2.6.4 Supplementary Comments and Information

Supplementary comments and information were submitted by both members of the working group and others. This material can be found in Sec. 3.6 and is referenced below.

D. Fox submitted a description of the TAPAS model in the format of the conference notebook (Sec. 3.6.1). This model can be applied in complex terrain.

In Sec. 3.6.2, H. Slater discusses the Valley model and some comparisons of observed and estimated concentrations including a description of the conditions under which the data were obtained.

M. Williams (Sec. 3.9.2) has suggested a specific change in the wording for p. 30 of the draft Guideline. The suggestion concerns the choice of wind speed when an elevated source impacts high terrain. He presents data on the unacceptability of ground level inferences of stability, wind speed, and direction during stable conditions. He also suggests some changes in the Valley algorithm. In Sec. 3.6.4, he also comments on the use of plume half-height corrections, the uniformity of the wind field in the lower atmosphere under stable conditions, and the influence of terrain elements on stable plumes.

The letter from Howard M. Ellis of Enviroplan submitted by M. Smith (Sec. 3.9.4) comments on the use of a half-height rather than a full-height (CRSTER treatment) reduction in effective stack height in complex terrain and on turbulence and dispersion enhancement.

G. Melvin (Sec. 3.9.6) has presented a description, in the notebook format, of the Illinois' Air Quality Short Term Model (AQSTM) which can be used in complex terrain.

In Sec. 3.6.3, D. Henderson has commented on the use of local meteorological conditions in Valley and on the conditions under which the model is ›st applicable. He has also noted factors which determine the degree of conservatism of a box model.

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2.7 GROUP II-4: CHARACTERIZATION OF TURBULENCE

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Moderator/Reporter: D. M. Rote

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2.7.1 *Introductory Remarks*

This working group dealt primarily with detailed aspects of the Gaussian plume model in general and with some issues specific to some of the algorithms recommended in the proposed guideline. The problems associated with special modeling situations such as complex terrain were not discussed.

The general consensus of the group was that while some serious concerns were raised and some important questions needed to be answered, none were so serious as to prevent interim use of the Guideline recommended simple terrain algorithms such as "RAM" and "CRSTER".

The most important issue raised by the group was the validity of the subjectively extrapolated portion of the σ_z curve for the Pasquill-Gifford stability class A and its applicability to the computation of ground level concentrations from tall stack emissions. Similar questions were also raised regarding the upward turning stability B curve and the downward turning stability D, E, and F curves for σ_z. The group supported the method of multiple images for treating dispersion in a limited mixing layer and stressed that for elevated releases the surface based stability parameter must be accompanied by information about the layer containing the plume. Of special importance is the position of the plume relative to a ground based or elevated inversion layer.

There was significant difference of opinion about the validity of the prediction of neutral hours by the "STAR" computer program and the implications for both ground based and elevated releases.

The group unanimously agreed that these questions deserved serious attention and recommended that a thorough and systematic study be conducted of both the theoretical arguments and available data.

These issues are more fully discussed in the following text. Discussions on several additional issues, including some specific to the CRSTER algorithm are also presented.

2.7.2 *Vertical Profiles of Wind Speed*

The working group unanimously agreed that the representation of the increase of wind speed with height now employed in the EPA modeling systems is satisfactory.[1] This system takes the form of a power law with the exponent varying according to stability categories.

2.7.3 Comparison of STAR, ΔT, and σ_θ

In order to make any dispersion evaluation, the available meteorological data must be stratified according to categories representing the diffusive capacity of the atmosphere. A variety of simplified approximations have been used to represent this variable.

The group notes that the various systems, when applied to the same data, give widely different distributions of stability categories. Many authors have pointed out these differences, but a pair of examples show the extent of the problem.

Table 1 compares the frequency of the Pasquill-Gifford stability categories estimated from tower temperature difference (ΔT) measurements with a set derived from standard deviation of the wind fluctuations (σ_θ) measurements. The discrepancies are enormous, with differences as great as a factor of 3 or 4 among the major unstable, neutral and stable groups. Table 2 compares a "STAR" calculation with the ΔT and σ_θ estimates. Again the variations are huge.

A question was raised regarding the prediction of neutral stability categories by the "STAR" program. While the group did not unanimously agree, some participants expressed the opinion that the "STAR" program tended to predict unrealistically high numbers of neutral hours especially for low level sources.[2]

It is the consensus that the technique of estimating stability now used in the EPA computer evaluations (STAR) can be used in the interim but that it be reviewed to resolve this question and to develop an alternate system which will eliminate the unrealistically large percentages of neutral hours if neccessary.

We doubt that ΔT, at least over modest height intervals, will serve as an alternative because of instrumental accuracy problems, and because it is based on only one of the several key factors responsible for turbulence. A possible alternative might be based on wind fluctuations for estimates of horizontal dispersion and either ΔT or net radiaion measurements for vertical dispersion.

Table 1

JOINT FREQUENCY OF σ_θ (30') and $\Delta T_{200' - 5'}$ DATA* (%)

MARCH 1971 - FEBRUARY 1972

Category	A	B	C	D	E	F	G	Sum	
A		0.10	0.51	1.24	5.58	2.03	1.75	11.40	
B	0.20		0.72	0.89	4.02	1.33	0.66	7.91	36.28 Unstable
C	0.57	0.33		1.88	9.97	1.97	1.00	16.97	
D	1.41	0.84	3.61		29.21	3.35	1.59	45.90	45.90 Neutral
E	0.82	0.45	1.87	2.78		1.50	0.61	11.28	
F	0.01	0.03	0.13	0.19	0.26		0.04	0.77	20.05 Stable
G	0.00	0.00	0.00	0.00	0.00	0.00		0.00	
Sum	3.20	1.84	8.09	12.87	60.29	12.29	5.65		
		13.13		12.87		76.23		102.23	
		Unstable		Neutral		Stable			

*From: Environmental Report, Trojan Nuclear Power Plant, Oregon.

Table 2*

	A	B	C	D	E	F	G
STAR**	1.08	7.68	7.93	57.17	8.74	17.39	
ΔT	3.20	1.84	8.09	12.87	60.29	12.29	5.65
σ_θ	11.40	7.91	16.97	45.90	11.28	0.77	0.00
		Unstable		Neutral		Stable	
STAR		16.69		57.17		26.13	
ΔT		13.13		12.87		76.23	
σ_θ		36.28		45.90		20.05	

*Data based on an Environmental Report on the Trojan Nuclear Power Plant, Oregon as reported in a letter dated November 22, 1976 from James Carson to Maynard Smith. (See reference materials at end of report)

**The STAR program used selects only six stability classes.

For further discussion on problems associated with surface based meteorological data, see Section 3.9.2 for some remarks by M. Williams regarding the LAPPES Program data.

2.7.4 *Mixing Height Interpolation Scheme Used in CRSTER*

There are reservations about the interpolation scheme used in CRSTER to obtain hourly mixing heights. This system should be tested against available data and the results should be documented. The scheme should be examined and could be improved using hourly surface temperatures to interpolate the mixing heights between the standard hours of radiosonde observations.

2.7.5 *Vertical Dispersion Estimates*

There is evidence[3] that in their present form, the Pasquill-Gifford σ_z curves are unsuitable for calculation of the ground level concentration due to emissions from tall stacks. In particular, the stability A and, to some extent, the stability B curves may result in large overestimates of the short-term maximum ground-level concentration (1-hr. to 3-hr. averages especially) and in underestimates of its distance when compared with observations. Extrapolation of the A curves for σ_y and σ_z beyond the 800m range leads to values of σ_z/σ_y equal to 10, which seems physically unreasonable.[4]

Also, there is evidence that the present σ_z curves for D, E and F stability (which turn downward) result in underestimates of the maximum ground-level concentration on various time scales and overestimates of its distance. The degree of the underestimates or overestimates is roughly proportional to the plume stabilization height or stack height.

The group strongly recommended that the changes to be made to correct these deficiencies be determined through a systematic study of available data for a wide variety of conditions and other pertinent information on the effects of tall-stack plume characteristics on ground-level concentrations. Possible changes suggested by such a study, especially for tall stack calculations and distances greater than 1 km, might include the elimination of the A curve and the use of the B curve for both A and B stability categories. Alternatively, the σ_z curves for the A, D, E, and F categories may be reformulated to show an approximate linear dependence on distance (on a log-log plot), starting at a distance 100 meters from the source. If this procedure is adopted, the effects of thermal stratification in limiting the vertical growth of plumes can be accounted for by the use of multiple reflection terms in combination with a specified mixing depth. These adjustments (i.e., inclusion of multiple reflections) apply only to plumes that stabilize within the mixing layer and thus in practice are most applicable to the A and D categories. It should be noted that the algorithms RAM and CRSTER treat limited mixing in this manner for stabilities A through D.

Additional comments on this subject were submitted after the conference by M. Williams (see Sec. 3.7.1) and D. B. Turner and L. E. Niemeyer (see Sec. 3.7.3).

Finally, in order to account for variations in surface roughness and urban/rural differences, it was suggested that some latitude be given to exercise professional judgement in making minor adjustments in stability class assignments. See related comments by Moore below.

2.7.6 *Initial Plume Dimension*

Plume size at the plume stabilization distance (at downwind distances of approximately ten stack heights) should be determined and incorporated into σ_y and σ_z determinations by adding variances or use of virtual distances to account for initial size of buoyant plumes. A possible algorithm for doing this has been discussed by G. Briggs.[2]

2.7.7 *Horizontal Dispersion Estimates*

D. Moore[3] of the Central Electricity Generating Board (CEGB) presented some recent results of the determination of ground level σ_y values due to elevated sources. The results obtained from surface sampling (with a sampling time of roughly one hour) to distances of 14 km, indicated linear variation with distance for all cases studied. The constant of proportionality varied from 0.04 under strong winds to 0.2 under light winds. These results appeared to be very similar to the Pasquill-Gifford curves which apply to the plume distribution relative to its centerline and which are characteristic of 3-minute sampling time. Currently, the CEGB is using σ_y values which are a continuous rather than discrete function of the stability variable[5].

The group concurred that the present PG curves for σ_y should be used for rural cases and for 1-hour sampling periods for elevated sources. This position takes into consideration the original basis for these curves (ground-level releases 3 to 10 minute sampling times) and the influence of wind shear for elevated sources which effectively enhances the horizontal spread near ground level.

The position was somewhat less clear for near ground releases. The general opinion was that for ground level sources and 1-hour sampling times the present PG curves for σ_y should be adjusted for sampling time using the 1/5 power law.

To account for increased site roughness or heat flux, σ_y values should be shifted one stability category toward unstable (except a shift from B to A).

The incorporation of the Briggs'[5] urban σ_y curves in urban models warrants further consideration.

Extreme caution is advised in the use of so-called "stability G" category. Contrary to the trend for decreased dispersion with increasing stability, the stable, light wind situation which characterizes the "stability G" case has been shown (see for example Van der Hoven[6]) to occur with rather large horizontal plume meander. Thus, the use of Pasquill G results in serious overestimates of short-term concentrations from low-level sources.

2.7.8 Wind Direction Randomization

Most wind data available for air pollution studies are recorded to 10° direction intervals, whereas the time hourly-mean values would have shown variation within these intervals. To assume that the winds are actually fixed on the 10° radials will result in unrealistic maximization of concentrations in these directions. To overcome this tendency, a randomizer has been introduced in the CRSTER computer program to force deviation of the wind from one hour to the next.

Occasionally this randomizer will repeat the same random number for several hours in a row. It may therefore create an unrealistically large 3-hourly calculation. The repetition effect becomes very unlikely over longer periods, and presents no problem.

It is recommended that this problem be reviewed, since three consecutive identical wind directions is exceedingly unlikely in nature. A possible solution would involve an automatic override to prevent successive duplication of random numbers for short-term evaluations.

See further comments contributed after the conference by M. Smith, Section 3.

2.7.9 Review and Comment on Pasquill's Recommendations for Interim Changes to the Pasquill-Gifford Curves[1]

1. No change should be made to the present "PG-curves" for σ_y. It was felt that Pasquill's recommendations regarding σ_θ could not be generally implemented at this time.

2. In regard to adjustments to stability classes to account for surface roughness and the urban heat island effect, a practical compromise was recommended: In an urban area the stability class should be changed by one unit in the direction of unstable to account for the combined effects of surface roughness and the heat island.

3. A correction should be made in the Gaussian model which takes account of the plume dimension at an appropriate distance downwind from the release point (see Section 2.7.6 of this report) but not necessarily following precisely Pasquill's suggestion.

2.7.10 Use of Models in Urban vs. Rural Areas

It was noted that CRSTER is intended specifically for rural calculations (i.e., relatively smooth surface without heat island effects).

For urban cases (rough surface and urban heat island effect) the appropriate version of RAM should be used in lieu of CRSTER. However, the group emphasized that the EPA should be certain that the RAM algorithm has been validated by comparison with field data.

If CRSTER were to be used in urban-type situations the stability class should be changed by one unit toward the unstable.

FOOTNOTES FOR SECTION 2.7.

1. Cramer, in a post-conference contribution, see Sec. 3.7.2, emphasized that this statement should not be interpreted to mean that the power-law exponents currently used by the EPA are not subject to change. He suggested some possible modifications.

2. Ibid. Cramer feels that the PG stability categories predicted by STAR are very satisfactory provided that mixing height, vertical temperature gradient, and the wind profile exponent are also specified for each combination of wind speed and stability.

3. In his post-conference contribution, H. Cramer (see Sec. 3.7.2) has prepared a well documented argument for modifying the PG σ_z curves, this argument deserves careful attention.

4. The group was cognizant of the fact that the original σ_z curves for stability A was based on direct measurements, i.e., observations of vertical distribution, only out to 100m and on indirect measurement, i.e., reduction from observations of ground level distribution, out to 800m (see Ref. 1).

5. In his presentation, Moore advocated that σ_z and σ_y be expressed as analytical/empirical functions of source height, sampling time, and surface roughness, as well as stability, wind speed and downwind distance. See Ref. 4 and Sec. 3.9.5.

REFERENCES FOR SECTION 2.7.

1. Pasquill, F., *Atmospheric Dispersion Parameters in Gaussian Plume Modeling. Part II. Possible Requirements for Change in the Turner Workbook Values*, Environmental Sciences Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, EPA-600/4-76-030b, June 1976.

2. Briggs, G.A., *Lectures on Air Pollution and Environmental Impact Analysis*, AMS, 1975, TD883.A23.

3. Moore, D.J., *A Simple Boundary-Layer Model for Predicting Time Mean Ground-Level Concentrations of Material Emitted from Tall Chimneys*, paper presented for Ordinary Meeting of the Institution (Thermodynamics and Fluid Mechanics Group) in London, November 1974.

4. Moore, D.J., *Calculation of Ground Level Concentrations for Different Sampling Periods and Source Locations*, Atmospheric Pollution, pg. 51-60, Elsevier Scientific Publishing Company, Amsterdam, Netherlands.

5. Briggs, G.A., *Diffusion Estimation for Small Emissions*, Environmental Research Laboratories, Air Resources Atmosphere Turbulence and Diffusion Laboratory 1973 Annual Report, USAEC Report ATDL-106, National Oceanic and Atmospheric Administration, December 1974.

6. Van der Hoven, I., *A Survey of Field Measurements of Atmospheric Diffusion Under Low-Wind Speed Inversion Conditions*, Nuclear Safety Vol. 17, No. 2, March-April 1976.

2.8 GROUP II-5: VALIDATION AND CALIBRATION

PARTICIPANTS

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2.8.1 Principles

While the desirability of providing model recommendations to the user community is well recognized, it is clearly unwarranted to offer such recommendations when supporting information is inadequate or unavailable. Consistent with this philosophy are the following requirements:

- The specification that models must meet certain standards of performance if they are to be endorsed in the Guideline for general use.
- The acceptance of model verification as a common practice in overall model use where performance is not established.

To provide an orderly basis for determining model performance, we foresee the following needs:

- Prescribed standards for model performance*
- Specified model verification procedures
- Established performance evaluation procedures

In order to meet these needs, we strongly recommend that:

- An effort be mounted to establish the appropriate standards and procedures (under the auspices of EPA).
- A continuing function be established within EPA expressly for the purpose of model evaluation.
- Established standards and procedures be revisited on a regular basis.

See Section 2.8.4.

Recognizing that these recommendations do not satisfy the short-term needs of model users, we recommend that the following practices be adopted on an interim basis until the needed functions are put into practice:

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*Also of concern is the extent of generality of model applicability. In other words, there is a need to place constraints on the range of model applicability over which the performance standards are expected to be met.

- the extent of evaluation undertaken for models mentioned in the Guideline be indicated in a manner consistent with Section 2.8.6.

- areas of applicability of the models and constraints (areas of non-applicability) be listed.

Examples of the type of information to be supplied are shown in Section 2.8.5.

2.8.2 *Considerations*

We believe that attention must be given to the following considerations in attempting to prepare guidelines for model evaluation practices and procedures:

- Verification should be viewed in two contexts - general and site-specific usage. The distinction between the two contexts should be maintained wherever appropriate, giving recognition to potentially differing verification requirements.

- Performance standards should vary in stringency and content, giving recognition to:
  - the differences in models
  - variations in desired level of accuracy (compare screening use and refined use of models)
  - loftiness of performance goals. (This gives recognition of the two-step process of (1) selecting a model with a certain potential predictive capability and (2) establishing the extent to which its capability is realized. See Section 2.8.6.

- Verification activities should be carried out with overall project and information-gathering-goals in mind, i.e., give proper consideration to:
  - the problem to be resolved
  - the nature of the Standard to be met (its form, its averaging time, etc.)

- Verification goals should be in concert with potential level of achievement insofar as it is limited by the accuracy of data input to the model and data to be compared with predictions.

- Obligations of the user (in contrast with the control agency) should be specified
- Recognition should be given to the trade-offs between costs and benefits prior to mounting any substantial verification program.

2.8.3 Other Issues

We wish to call attention to certain other issues that bear on model evaluation:

- the "verifiability" of a model - Can a particular model, as a practical matter, be evaluated? In some cases, it cannot.
- the permissibility of calibration - Under what conditions is the practice warranted?
- the differences in verification requirements for long-term versus short-term predictions
- the importance of evaluating models under conditions which "stress" the model, i.e., which are designed to most readily uncover suspected flaws or shortcomings
- the differing evaluative requirements for relative (e.g., rollback) versus absolute (e.g., Gaussian plume models) predictors
- indication of the types or categories of statistical procedures to be used in model evaluation, at a minimum

We believe that each of these issues should receive full consideration in preparing a guideline document.

2.8.4 Proposed Mechanism for Meeting Requirements

Clearly a well defined mechanism must be established as quickly as possible to meet the requirements outlined above and indeed to insure in a larger sense that suitable models are properly developed and rationally applied.

The Clean Air Act of 1970 requires modeling as a tool to achieve the intent and goals of the Act. Accordingly EPA has the total responsibility for all aspects of modeling from concept through application. Since the requirements for validation and performance as described herein are a key part of the overall modeling problem, EPA has the responsibility to carry out these tasks. It is a major effort on a continuing basis requiring additional internal support together with assistance by grant, contract and consultants. In short, EPA must establish within its organization a group responsible for carrying out the tasks described; to do so on an ad hoc basis is totally inadequate.

There are a number of advantages in having an identifiable group within EPA with total responsibility for the modeling effort including:

1. Model evaluation, performance, and applicability can be more readily achieved and documented and the results made available to all parties.
2. Results of model applications can be evaluated and retained in a data bank for use in subsequent model improvements.
3. Uniform methods can be established for processing new models.
4. A higher degree of standardization can be achieved in the use of models both for enforcement and air quality management.

This proposed mechanism would provide for a periodic review of models in use as well as those proposed for adoption and probably would involve formal meetings with outside experts. However, the effectiveness of such formal meetings would be greatly enhanced by having the benefit of the results of a continuous effort within EPA.

2.8.5 *Example Model Evaluation Information*

Examples of evaluation information for models listed in the Guideline may include the following information.

CDM - An urban multiple-source model that has been subjected to limited evaluation for _____ cities. Results indicate that SO_2 calculations are made more accurately than those for TSP. Correlation coefficients ranged from _____ to _____ for SO_2 and correlation coefficients ranged from _____ to _____ for TSP.

CRSTER - A single point source model for the calculation of the distribution of short-term concentrations around the source. Studies at four power plants indicate the maximum concentrations calculated are within a factor of 2 of the observed concentrations at local monitoring stations.

Examples of limitations are:

CDM is an urban model that should not be applied to rural situations.

RAM is a multi-source short-term model that has not been evaluated. It is composed from algorithms such as the Gaussina plume model and plume rise equations similar (identical?) to CRSTER and in a similar application could be expected to give similar results.

None of the models listed have been validated in complex terrain. Use of differential receptor heighrs has not been validated.

2.8.6 Levels of Model Performance and Quality

We should recognize that models operate at varying levels of performance and quality, and should be tested (validated, verified) against the standards of the various levels. We suggest that there are roughly four such levels, which in descending order are:

Top Level. A model in this level will predict concentration of any pollutant at any time, any place, any averaging time, with uncertainty equal to the uncertainty in the input data (emissions, meteorology). An example of this type from physics is $F = ma$. For that model we truly can predict with accuracy equal to input data accuracy, for all size and time scales, excluding relativistic and uncertainty principle limitations.

To validate a model in this category would require comparing its time and space resolved predictions with equally time and space resolved observations, using all sorts of meteorological inputs.

Second Level. A second level model would not claim to give accurate time and space resolved answers but would attempt to predict time-resolved distributions of results which were comparable to observed ones. For example, the observed mean and s.d. of the concentration at any point should agree with the predicted one, within the uncertainty of the input data. An example of this type from biology is mendelian genetics, which predicts the distribution of properties (quite accurately) but generally does not predict, for example, which seed will contain which properties. After the fact we have worked out a great deal of "first principles" to explain the distribution, but that came after the fact.

Third Category. A third category would be models for which we have plausible scientific bases, but for which we have not yet been able to show that the models do truly make accurate predictions. For such models presumably a verification of their predictive powers is possible, but not necessarily easy. An example from physics of this type is the existence of "black holes." Current theory says they may exist, while direct observation currently seems possible but not easy.

Fourth Category. A fourth category of models are ones for which the scientific bases is questionable but perhaps plausible and for which experimental verification is unlikely or impossible. A non-related example is the way we all raise our children; we have poorly-founded but plausible ideas of how one should do it, and no effective measures of their performance.

If we accept the idea that there are such categories of models, we can enunciate the following ideas:

1. Although models in lower categories may have uses for screening purposes, for disputed regulatory decisions one should use as high a category model as is available.

2. There should be little effort devoted to models of a lower category if a higher category model is available for the same task.

3. The category into which a model falls should be determined on the basis of validation and testing, rather than any other way.

4. The validation requirements for the various categories should be different from category to category. For the first category the requirements must be for space and time resolved correspondence between calculated and observed concentrations. For the second category it would be correspondence between computed and observed space (but not time) resolved means and standard deviations of the concentration distributions. For the lower two categories, validation within the category would seem unnecessary; the objective of validation would be to move the model to a better category.

5. EPA should be asked to classify existing EPA models into these categories and indicate what levels of performance they believe can be reached in the next five years for each pollutant and each averaging time.

This whole set of ideas is summarized in Table 2.8.1.

Supplementary Material

A comment on the use of unverified models for making relative predictions may be found in Sec. 3.10.10.

Table 2.8.1. Categorization of Models by Validation Technique

Category	Description	Air Pollution Models which may fall into this Category*	Proposed Validation Technique
I	Time and Space Resolved Source-Receptor Models		Comparison Between Time & Space Resolved Observed & Calculated
II	Statistical Property Only Models (Spaced Resolved)	Single Source Gaussian Plume (e.g., CRSTER)? Multi-Source Gaussian?	Comparison of Statistical Properties of Space Resolved Observed & Calculated
III	Models with Plausible Scientific Bases, but Currently not Validated to Above Levels	Most CO Models, Any Model Requiring Empirical Calibration, Photochemical Models	Move to Upper Category if Validatable
IV	Models with Less Plausible Scientific Bases, Probably not Validatable	Rollback	Not Validatable?

*These choices are to some extent arbitrary and as shown some model fall in more than one category depending on use.

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3 SUPPLEMENTARY MATERIALS

This section contains commentary, opinions, and other written material submitted by the participants both during and after the conference. Except for retyping and minor editorial corrections, no changes have been made in the content or expression of these contributions.

Sections 3.1 - 3.8 contain material germane to the working group reports (Sections 2.1 - 2.8, respectively).

Material which is of more general interest has been placed in Section 3.9.

Comments which refer to the issues discussed in the plenary sessions of the conference and additional issues are contained in Section 3.10.

3.1 GROUP I-1

3.1.1 Description of Texas Climatological Model (TCM)

Submitted by Richard A. Porter at conference.

TEXAS CLIMATOLOGICAL MODEL

Reference: Porter, R. A. and Christiansen, J. H.; "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, Va., September, 1976. (Copy attached.)

Christiansen, J. H. and Porter, R. A.; Users Guide to the Texas Climatological Model, Texas Air Control Board, Austin, Tx, May, 1976.

Abstract: The TCM is a climatological model that predicts long-term arithmetic mean concentrations of nonreactive pollutants from point sources and area sources. The TCM is conceptually similar to the Climatological Dispersion Model (CDM) but incorporates design features that reduce the model run time by as much as two orders of magnitude.

Equations: See references cited above.

A. <u>Source-Receptor Relationship</u>

1. Arbitrary location[redacted] for each point source. Unlimited number of sources.
2. Arbitrary location and square grid width for each area source. The model will allocate area sources into a uniform square grid.
3. Receptor location is arbitrary grid (max. 50 x 50).
4. Release heights for point sources are accepted for any height.
5. The area source algorithm (Gifford-Hanna) does not consider height of release.
6. Receptors are at ground level.
7. No terrain difference between sources and receptors.

B. <u>Emission Rate</u>

All sources have a single average emission rate for the averaging time period (i.e., month, season, year).

C. <u>Chemical Composition</u>

One, two, or three pollutants are treated simultaneously.

D. <u>Plume Behavior</u>

1. Plume rise calculated according to Briggs (1971) neutral/unstable equation.
2. Effective stack heights less than 10 meters are considered 10 meters.
3. Effective stack heights greater than 300 meters are considered 300 meters.
4. No plume rise for area sources.
5. Down-wash and fumigation not considered.

E. <u>Horizontal Wind Field</u>

1. Climatological approach
2. 16 wind direction
3. Mean wind speed calculated for each stability class from the joint frequency function of stability, wind direction, and wind speed.
4. Wind speed corrected for physical stack height (same as CDM).

F. <u>Vertical Wind Speed</u>

Assumed equal to zero.

G. <u>Horizontal Disperion</u>

Assumed to be uniform within each 22.5 degree sector (same as CDM).

H. Vertical Dispersion

1. Gaussian plume.
2. 6 stability classes (Pasquill-Gifford-Turner) A, B, C, D-Day, D-Night, E+F.
3. No provision for variation in surface roughness.

I. Chemistry/Reaction Mechanism

Exponential decay according to user input halflife (same as CDM).

J. Physical Removal

Same as I above.

K. Background

Background may be entered by calibration coefficient for each pollutant.

L. Boundary Conditions

Perfect reflection assumed at ground. Mixing height not a factor because investigation shows no effect for typical climatology using the CDM .47L total mixing scheme.

M. Emission and Meteorological Correlation

Emissions not varied.

N. Validation/Correlation

1. Model is self-calibrating with input of field receptor observations.
2. High correlation achieved of observed to calculated values for Houston TSP 1975, Houston SO_2 1972, Dallas TSP 1972.

O. Output

1. Arithmetic mean concentration for the averaging time of the Climatological input data and emission data (one month to one year).
2. Any combination of the following outputs are available:
   a. Listing of concentration for an arbitrarily spaced square grid of up to 50 by 50 elements.
   b. A print plot of the grid concentrations.
   c. Punched card output for isopleth maping (same as CDM).
   d. A listing of the five high contributors to the concentration (by % concentration) at each grid point.

P. Activity

The TCM has been widely applied for evaluation of new source impact upon existing air quality and for evaluating the impact of growth in urban areas. The model is in use by more than 50 industrial firms, environmental consultants, and government (federal, state and local) agencies throughout the U. S. and Canada. Speed of operation (up to 2 orders of magnitude faster than the CDM) and convenient output formats have made this model popular with a wide variety of users.

3.1.2 Description of Texas Episodic Model (TEM)

Submitted by Richard A. Porter at conference.

TEXAS EPISODIC MODEL (TEM)

References: Porter, R. A. and Christiansen, J. H.; "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, Va., September, 1976. (Copy attached.)

Christiansen, J. H.; Users Guide to the Texas Episodic Model, Texas Air Control Board, May, 1976.

Abstract: The Texas Episodic Model (TEM) is a short-term (10 minute to 24 hour averaging time) Gaussian Plume Model for prediction of concentrations of nonreactive pollutants due to up to 300 elevated point sources and up to 200 area sources. Concentrations are calculated for 1 to 24 scenarios of meteorological conditions, averaging time, and mixing height.

Equations: See references cited above.

A. Source-Receptor Relationship

1. Up to 300 arbitrarily located point sources.
2. Up to 200 arbitrarily located area sources.
3. A uniform square receptor grid of arbitrary spacing with up to 50 by 50 rows or columns.
4. Terrain assumed flat.
5. Unique release height for each source.
6. All receptors at ground level.

B. Emission Rate

Unique emission rate for each source.

C. Chemical Composition

One, two, or three pollutants treated simultaneously.

D. Plume Behavior

1. Plume rise according to one of six equations from Briggs selected according to stability and distance from source. Effective stack heights less than 10 meters are considered 10 meters. Effective stack heights greater than 2000 meters are considered 2000 m.
2. Mixing height penetration factor (P) is a user input. If effective source height (H) is greater than P times the mixing height the plume escapes. Otherwise the .47L mixing scheme from Turner's Workbook is used.
3. Does not treat down-wash or fumigation.

E. Horizontal Wind Field

1. User supplied stability, wind speed, and direction for the averaging time period (10 minutes to 3 hours) or for each 3 hour period to build a 24-hour day.
2. Power law variation of wind speed with release height (same as CDM).
3. Steady state wind for each scenario.

F. Vertical Wind Speed

Equal to zero.

G. Horizontal Dispersion

1. Semi-Empirical Gaussian Plume.
2. User supplied stability class for each scenario (Pasquill-Gifford-Turner).
3. Turner (1969) dispersion coefficients.
4. No adjustment for surface roughness.

H. Vertical Dispersion

1. Semi-empirical Gaussian plume.
2. User supplied stability classes (Pasquill-Gifford-Turner) for each scenario.
3. Turner (1969) dispersion coefficients.
4. No adjustment for surface roughness.

I. Chemistry/Reaction Mechanism

Exponential decay with user supplied half-life.

J. Physical Removal

Same as I above.

K. Background

May be input with calibration factor.

L. Boundary Conditions

1. Lower boundary: perfect reflection.
2. Upper boundary: reflection from top of mixed layer by the .47L
   scheme of Turner (1969) except as described in D.2 above.

M. Emission/Meteorological Correlation

User supplied values of wind speed, wind direction, stability class, mixing height, ambient temperature for each scenario up to 24 scenarios.

N. Validation/Calibration

1. Limited validation with observed vinyl chloride observations.
2. Calibration by user supplied coefficients (A, B) so that Xcal = A + BX predicted

O. Output

1. Concentration mean for each receptor grid point for averaging times of:
   a. 10 minutes
   b. 30 minutes
   c. 1 hour
   d. 3 hours
   e. 24 hours (based on eight 3-hour scenarios.)

2. Output is available for from 1 to 24 scenarios in the following formats:
   a. listing.
   b. print plot.
   c. punched cards for isopleth maps.
   d. culpability list of the high five contributors to the concentration at each receptor grid point.

3.1.3 Minority Report on Application of Multi-Source, Urban Model

Submitted by A. Boyer at conference.

MINORITY REPORT

The Application of Multi-Source, Urban Models

The application of complex multi-source urban models is to be primarily the responsibility of control agencies. The results of multi-source simulations may be used by control agencies to assess the effects of changing source strengths, control measures, or changing land-use patterns. Multi-source simulations may also be used by control agencies for amending guidelines for the application of single source models in areas where many single sources interact.

Individual sources sould not be expected to do more than apply single source models. In those cases where industries or members of the public choose to apply multi-source urban models control agencies should encourage such activity by providing urban source inventories.

3.1.4

Description of the Environmental Research & Technology, Inc. Model ERTAQ
Post Conference Submission by B. Egan

Abstract: ERTAQ is a steady-state sector-averaged Gaussian plume model that calculates concentrations of up to six pollutants from an unlimited number of point, line, and area sources. The model may be operated in either the "sequential" mode to calculate one-, three-, or 24-hour concentrations for analysis of historical "worst-case" impacts or in the "climatological average" mode to calculate long-term averages for periods represented statistically by stability windroses. Dispersion coefficients may be user-specified. In the sequential mode, a fourth class of source, "tall stacks", is available that provides for optional use of distinct dispersion coefficients more representative of this class of source. The model may be applied in both flat and hilly terrain. Up to 128 receptor points may be specified, at each of which the user may specify background concentrations as well as calibration factors. The contributions of individual sources to selected receptors may be isolated at the user's option. In addition, program options are available for user-specified input format, storage of output files, and manipulation of the results of intermediate computations.

Equations:

$$X = \frac{Q}{u} g_1 g_2$$

For sources other than "tall stacks", at user's option, the crosswind dispersion function g_1 may be sector-averaged over 22.5° by

$$g_1 = \frac{1}{2x \tan (\pi/16)}$$

For "tall stacks", the crosswind dispersion function g_1 is given by the statistically "expected" value within the 22.5° sector for receptors within the downwind sector, i.e.

$$g_1 = \frac{1}{\pi x/8} \operatorname{erf} \left(\frac{x \pi/16}{\sigma_y \sqrt{2}}\right);$$

for receptors in the sectors adjacent to the downwind sector,

$$g_1 = \frac{1}{\sqrt{2\pi}\,\sigma_y} \quad \frac{1 - \operatorname{erf}\left(\frac{\pi x}{16 \sigma_y \sqrt{2}}\right)}{2 \operatorname{erf}\left(\frac{\pi x}{16 \sigma_y \sqrt{2}}\right)}$$

This formulation avoids the difficulty of using centerline one-hour values when accumulating concentration estimates for multiple-hour averages.

The vertical dispersion function g_2 is given by

$$g_2 = \sqrt{\frac{2}{\pi}}\ \frac{1}{\sigma_z}\left\{\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] + \sum_{j=1}^{\infty}\left[\exp\left\{-\frac{1}{2}\left(\frac{H+2jL}{\sigma_z}\right)^2\right\} + \exp\left\{-\frac{1}{2}\left(\frac{H-2jL}{\sigma_z}\right)^2\right\}\right]\right\},$$

where L = mixing depth
H = height of plume centerline above the ground-level receptor.

Terrain Correction (tall stacks only):

$$H = H_s + \Delta H - T_f \times \mathrm{Min}\,(z_r - z_s,\ H_s + \Delta H),$$

wherein

H	=	height of plume above terrain at receptor
H_s	=	height of stack above stack base
ΔH	=	plume rise
Z_r	=	topographic height of receptor (above sea-level)
Z_s	=	topographic height of stack base (above sea-level)
T_f	=	stability dependent, user-specified terrain correction factor.

A. Source-Receptor Relationship

Unlimited number of point, area, line, and tall-stack sources at any locations.

Up to 128 receptor points at any selected locations.

Unique topographic elevation for each receptor.

Receptors must be at ground level.

B. Emission Rates

Unique emission rate for each source that may be varied according to diurnal, weekly, or monthly scheduling.

C. Chemical Composition

N/A

D. Plume Behavior

Briggs (1970) final plume-rise formulas
Stack-tip downwash (Gifford) for tall stacks
If plume height exceeds mixing height, concentrations further downwind assumed equal to zero.
Plume and mixing depth both respond to terrain obstacles (see Equations).

E. Horizontal Wind Field

Wind direction constant at all heights over all space.
Wind speed varies with height according to user-specified power-laws dependent on stability class.

F. Vertical Wind Speed

Assumed equal to zero except as implied by terrain correction factors.

G. Horizontal Dispersion

Gaussian plume sector-averaged in various ways depending upon application. 5 stability classes used with user-specified dispersion coefficients; different classes of sources may have different coefficients. "Urban" and "rural" options.

H. Vertical Dispersion

Gaussian plume.
5 stability classes used with user-specified dispersion coefficients; different classes of sources may have different coefficients.
"Urban" and "rural" options.
Option for initial vertical source dimension.

I. Chemistry/Reaction Mechanism

Not treated directly (see J).

J. Physical Removal

Half-life decay factors.

K. Background

May be specified for each receptor or for all receptors. May be calculated if appropriate emissions inventory is input.

L. Boundary Conditions

Perfect reflection at the ground and at the top of the mixing layer. Mixing height follows terrain with correction factor (see Equations).

M. Emission and Meteorological Correlation

None specifically, but see B. Emission Rates (above).

N. Validation/Calibration

Calibration option available which involves external determination of linear calibration coefficients; slope and intercept may be applied in subsequent runs. Comparison with observations made in a number of studies.

O. Output

Concentration values at each receptor. Output routines search complete data sets for high values and identify time periods of interest.

3.2 GROUP I-2

3.2.1 Comments on Section 2.2.5 Submitted by R. Wevodau After the Conference

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WILMINGTON, DELAWARE 19898

ENGINEERING DEPARTMENT
LOUVIERS BUILDING

March 9, 1977

Dr. D. M. Rote
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Dear Don:

I offer the following comments on the first round report of Working Group I - 2:

Item 6 - "On the Question of Enumerative Vs. Statistical Use of the Estimates of Short-Term Concentrations"

I agree with the consensus opinion that a statistical approach is theoretically more valid. However, I believe it is very important that the detailed investigation on the precise nature of the statistical approach be completed prior to endorsement of this approach. At this time, I favor the enumerative approach as recommended in the draft guideline. My main concern with a statistical approach involves the difficulty in fitting air quality data, whether measured or predicted, to a suitable cumulative frequency distribution function.

In model applications to evaluate compliance with air quality standards, I favor use of the second highest value. I agree that fumigation, stagnation, thunderstorm downdraft and terrain-induced mixing, none of which are considered by CRSTER, can be important factors in potential short-term violations. However, substitution of the highest computed value for second highest value is not an appropriate alternative in these situations. This approach skirts the issue.

2
March 9, 1977
Dr. D. M. Rote

In these abnormal situations alternative procedures which do consider such factors should be employed (or developed) instead of using the highest computed value from a model which does not consider these factors.

I believe the report is accurate and representative. You have done an excellent job in coordinating and reporting the opinions exposed during our workshop sessions.

Very truly yours,

ENGINEERING SERVICE DIVISION

RIWevodau

R. I. Wevodau

RIW:bmw

3.2.2 *Comments on Short-Term Analysis and on M. William's "Rationale for Elimination of the Maximum of the Second Highest for Modeling Purposes" (3.2.3 below).*

Submitted by R. Porter after the conference.

Comment 1: Lake shore fumigation should be included in consideration of any short-term standard. Also Briggs (1969, p 51) recommends that plumes will not escape in a lid situation unless the calculated plume rise Δh is greater than 2 times the mixing height. Normal fumigation and thunderstorm downwash are too short in duration to influence a 3-hour mean.

Comment 2: The problem with the second high standard for modeling is that we are attempting to predict concentrations too far out on the tail of the distribution already. 1/365 is even harder to predict than 2/365. Any probabilistic scheme should include a test of the goodness of fit of the calculated data to the assumed frequency distribution. (See the submission to the NATO committees). Results in Frankfurt showed that if the data does not fit the distribution absurd numbers are generated for the second high. See Section 3.10.1 for a more expanded discussion of this topic by Porter.

3.2.3 *Rationale for Elimination of the Maximum of Second Highest for Modeling Purposes*

Submitted by M. Williams after the Working Group I-2 meeting.

Since the modeling used will not consider model uncertainties, the observed second highest concentration at a point may indeed be somewhat greater than the standard if the second highest model value is permitted to approach the standard. It should be noted that CRSTER does not calculate concentrations during fumigation or stagnation. It is also possible that thunderstorm downdraft circumstances or rapid terrain induced mixing may result in high concentration in the real world. The model does not reflect such circumstances, thus it may not represent the actual frequency of high concentrations. Thus, a procedure which uses model calculations for the second highest does not assure compliance with standard. In order to provide a greater margin of safety, i.e., to provide greater assurance that the observed concentrations will not exceed the standard when the model estimate does not, the quantity to be compared with the standard should be the estimated maximum concentration.

3.3 GROUP I-3

3.3.1 Description of the SAI Reactive Plume Model

NAME OF MODEL: Reactive Plume Model (RPM)

Source of Model: Systems Applications, Inc.
950 Northgate Drive
San Rafael, California 94903

Sponsor: California Air Resources Board
Sacramento, California 95825

References: Liu, M. K., M. A. Yocke, and P. Mundkur, "Numerical Simulation of Reactive Plumes," 68th Meeting of American Institute of Chemical Engineers, Los Angeles, California, November 1975.

Liu, M. K., D. Durran, P. Mundkur, M. Yocke, and J. Ames, "The Chemistry, Dispersion, and Transport of Air Pollutants Emitted from Fossil Fuel Power Plants in California," Draft Final Report submitted to California Air Resources Board, SAI Report ER 76-18, April, 1976.

Type of Model: Lagrangian--for either single point or areal source.

Special Feature of Model: This model is designed to estimate concentrations of reactive species downwind of a single point or areal source of pollutants. Assuming the pollutants are well mixed in the vertical, this model is more suitable for plume fumigation and trapping conditions.

Status of Model Development: Operational

CHARACTERISTICS OF THE MODEL FORMULATION

Model Equation: Mass conservation

$$\frac{dC_i}{dt} = \left(\frac{dC_i}{dt}\right)_{chem} + u_h(C_{ai} - C_i)\cdot\left(\frac{1}{W}\frac{dW}{ds} + \frac{1}{h}\frac{dh}{ds}\right)$$

Plume Rise: Input to model.

Turbulent Dispersion: This model contains two options: either the measured plume width and plume depth (as a function of downwind distance) of the classical Pasquill-Gifford methods (Turner, 1969) may be used. Plume dispersion is determined either by the classical Pasquill-Gifford method (Turner, 1969) or from the observed plume width and plume depth as a function of downwind distance. Provision has been made for entrainment of background pollutants.

Wind Shear: Wind velocity at plume height must be used. Although a simple correction according to a power law can be easily incorporated, no treatment of wind shear is currently in the model.

Terrain Interaction: No current treatment but simple consideration (similar to the Valley model) can easily be incorporated.

Chemistry: This model is written in a modular form which can accept any chemical kinetics submodel with a maximum of 50 reaction steps. The kinetic mechanism that is currently in this model is a modified version of the Hecht-Seinfeld-Dodge mechanism (1974) for hydrocarbon-NO_x-SO_2 system.

Spatial Scale: Medium scale (~tens of kilometers)

Temporal Average: Short and Medium (hourly averages).

DATA BASE REQUIRED

Source: Stack location
Either stack emission rates or initial pollutant concentrations within the plume.

Meteorology: Wind speeds
Stability class (or plume width and plume depth)
Radiation intensity

Other: Kinetic mechanism
Ambient pollutant concentrations

CHARACTERISTICS OF THE MODEL COMPUTATION

Computer Language: FORTRAN IV

Computing Time: 10-50 PCU seconds (CDC 7600) for a typical run

Storage Requirement: ~145,000 actual large core.

IBM 370/168 Compatibility: Yes

KNOWN MODEL APPLICATION: This model was applied to the following seven point sources (Liu et al., 1975, 1976; Tesche et al., 1976):

Moss Landing Power Plant, Monterey, California
Los Alamitos Power Plant, Los Angeles, California
Haynes Power Plant, Los Angeles, California
Mobile Oil Refinery, Los Angeles, California
Four Corners Power Plant, Farmington, New Mexico
Hobbs Power Plant, Hobbs, New Mexico
Jefferson Power Plant, Jefferson, Texas

3.3.2 Description of the DEPICT Model

<u>Reference:</u> 1) Sklarew, R.C., and J.C. Wilson, "Applications of DEPICT to the Garfield, Navajo, and Ormond Beach Air Quality Data Bases" Science Applications, Inc. Report prepared for Southern California Edison, July 1976

2) Sklarew, R.C., Wilson, J.C., and Frabrick, A., "Evaluation of Air Quality Models Point Source Models" Science Applications, Inc., July 1976, under contract to the California Air Resources Board, Sacramento, CA.

<u>Abstract:</u> The DEPICT (Detailed Examination of Plume Impact in Complex Terrain) is a 3-dimensional eulerian numerical point source model. The model calculates the temporal and spatial concentrations of inert or reactive pollutants in flat or complex terrain. The model is modular in design and has the ability to update algorithms in an efficient manner. The model currently uses either the Eschenroeder 16-step or the Hecht-Seinfeld 39-step chemical mechanisms for the reactive pollutants. The model is applicable to assess air quality impact for point sources located in rural environments.

<u>Equations:</u> Conservation of Specie Equation

A. <u>Source-Receptor Relationship</u>

Point sources only; (10 maximum) uniform grid squares, user defined grid.
Sources can be treated as ground level or elevated releases.
Receptors are located at center of grids.
Receptor locations are 3-dimensional.

B. <u>Emission Rate</u>

User specified emission rate for each pollutant for each point source.
Emission rates can vary hourly for each source.

C. Chemical Composition

D. Plume Behavior

Plume rise calculation is based on the work of Briggs with simple modifications to obtain estimates of inversion penetration.

Four cases are considered:
1) wholly unstable atmosphere
2) deep ground base inversion
3) elevated stable layer
4) shallow ground base inversion.

E. Wind Flow Field

The model calculates a three dimensional wind field using the following equations.

1) $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

2) $$u = \tau_x \frac{\partial \phi}{\partial x}$$

3) $$v = \tau_y \frac{\partial \phi}{\partial y}$$

4) $$w = \tau_z \frac{\partial \phi}{\partial z}$$

Where ϕ is the perturbation velocity potential, and τ's are transmission coefficients based on temperature profile or stability classes (1-7) Wind observations are projected upward from the point measured through the portion of the grid without any measurements based on the power law $u = u_0 (z/z_0)^n$
The initial horizontal wind components are calculated using a $1/r^2$ interpolation scheme of the vertical profiles for each layer.

F. Vertical Dispersion

The vertical diffusivity parameters are calculated based on the algorithms of Smith and Howard.

$$K_z = 0.45\, \bar{u}\, \sigma_\varepsilon L$$

where $\bar{U}$ = wind speed at point of interest

σ_ε = standard deviation of the wind vane fluctuation and is dependent on stability class.

L = turbulence scale length (in meters) and depends on height above ground and stability.

G. Horizontal Dispersion

The horizontal values of diffusivity are calculated using the relationship

$$K_x = \alpha K_z$$

where α depends on stability class.

H. Chemistry and Reaction Mechanism

The model has the option of using either the Eschenroeder 16-step or the Hecht-Seinfeld 39-step mechanism.

I. Physical Removal

The 16-step mechanism includes a reaction between NO_2 and particulates. The Hecht-Seinfeld has no physical removal process.

J. Background

Treated as an hourly input for the chemical mechanisms.

K. Boundary Conditions

Lower boundary (surface of earth) perfect reflection.
Upper boundary - see plume rise.

L. Emission and Meteorological Correlations

User supplies hourly values of wind speeds measurements (surface and aloft), mixing height measurements, stability fields, and emissions.

M. Validation/Calibration

Preliminary validation of the DEPICT Model has been completed for the following areas:

1) Garfield-Smelter (SF_6)

2) Navajo Generating Station (SO_2)

3) Ormond Beach Generating Station (SF_6, NO, NO_2, O_3)

N. Output

The model predicts the hourly temporal and spatial concentrations for each grid for inert or reactive pollutants.

3.3.3 Description of the SAI Urban Airshed Model

Post Conference Submission by Philip M. Roth

References:

(a) Roth, P. M., S. D. Reynolds, P. J. W. Roberts, and J. H. Seinfeld (1971), "Development of a Simulation Model for Estimating Ground Level Concentrations of Photochemical Pollutants," Final Report and 6 Appendices, APTD 0908-0914, Systems Applications, Inc., San Rafael, CA.

(b) Reynolds, S. D., M. K. Liu, T. A. Hecht, P. M. Roth, and J. H. Seinfeld (1973), "Urban Airshed Photochemical Simulation Model Study: Volumes I-III, EPA-R4-73-030 a-h. Systems Applications, Inc., San Rafael, CA.

(c) Reynolds, S. D. et al. (1976, 1977), "Continued Research in Mesoscale Air Pollution Simulation Modeling," Volumes I-IV (EPA 600/4-76-016 a-d) and Volumes V-VII (in review by sponsor), Systems Applications, Inc., San Rafael, CA.

Abstract:

The SAI Urban Airshed Model is a fully three dimensional grid-based model capable of predicting the spatial and temporal distribution of both inert and chemically reactive pollutants. Basic inputs to the model include the specific meteorological, emissions, and chemical characteristics of the region of interest. Predictions for up to 13 pollutants may be obtained, including CO, SO_2, O_3, NO_2, NO, four hydrocarbon classes, total aerosol, PAN, HNO_2, and H_2O_2. A 42 step kinetic mechanism is employed to represent the pertinent chemical phenomena. The atmospheric diffusion equation is solved numerically on the three dimensional grid to predict the dynamic changes in pollutant concentration levels over a period of up to a few days. The model is applicable to the examination of regional air pollution problems, such as the evaluation of alternative emission control straegies.

Equations:

$$\frac{\partial c_i}{\partial t} + \frac{\partial}{\partial x}(\bar{u}c_i) + \frac{\partial}{\partial y}(\bar{v}c_i) + \frac{\partial}{\partial z}(\bar{w}c_i)$$

$$= \frac{\partial}{\partial x}\left(K_H \frac{\partial c_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H \frac{\partial c_i}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_V \frac{\partial c_i}{\partial z}\right) + R_i + S_i$$

where:

c_i = concentration of specie i
$\overline{u},\overline{v}$ = horizontal components of the wind
$\overline{w}$ = vertical component of the wind
K_H = horizontal turbulent diffusivity
K_V = vertical turbulent diffusivity
R_i = rate of formation of specie i by chemical reactions
S_i = rate of emission of specie i

A. Source-Receptor Relationship

1) Emissions from line and area sources are apportioned to each grid cell and are assumed to be emitted at ground level.

2) Each point source is treated separately. The stack height and plume rise determine the cell in which the emissions enter the grid.

3) Ambient concentrations are calculated for each grid cell. Each concentration represents a spatial average over the volume of a grid cell.

B. Emission Rates

Emissions are calculated external to the main program using EPA or other appropriate emission factors. All emission rates can vary in time.

C. Chemical Composition

Both inert and reactive species are considered. The thirteen pollutants for which predictions are made include: CO, SO_2, NO, NO_2, O_3 four hydrocarbon classes, PAN, H_2O_2, HNO_2, and total aerosol nitrate, sulfate, and organic).

D. Plume Behavior

A point source plume enters the modeling grid at a height calculated from the actual stack height plus the plume rise given by the formula of Briggs. Consideration is given to the determination of whether the plume penetrates an elevated inversion layer, and, if so, whether it breaks through the layer.

E. Horizontal Wind Field

Horizontal wind components are calculated external to the main program using objective analysis techniques in conjunction with avaliable data taken at the surface and aloft. The wind field is fully three-dimensional, thus allowing for the treatment of wind shear effects. Temporal variations are also considered.

F. Vertical Wind

The vertical wind component in each grid cell is calculated using the continuity equation and the horizontal wind component inputs.

G. Horizontal Dispersion

The horizontal turbulent diffusivity (K_H) is assumed to be a constant.

H. Vertical Dispersion

The vertical turbulent diffusivity (K_V) varies in space and time and depends on the height above the ground, wind speed, surface roughness, and the atmospheric stability class. Algorithms developed by Liu et al., and Lamb et al., are included in the model.

I. Chemistry/Reaction Mechanism

A generalized lumped mechanism consisting of 32 reaction steps developed by Whitten et al., is employed to describe the chemical interaction of organics, NO_x and O_3. Organics are segmented into four groups determined by the following carbon bond characteristics: single bonds, relatively reactive (fast) double bonds, slow double bonds, and carbonyl bonds. Six reaction steps are included to treat the oxidation of SO_2. The formation of nitrate, sulfate, and organic aerosol products is parameterized by four reaction steps.

J. Physical Removal

Surface deposition of species is treated in each ground-level grid cell. The rate of deposition depends on the type of vegetation or ground surface in that cell.

K. Background Pollutants

The influence of background pollutant concentrations is treated in the initial and boundary conditions of the governing equations.

L. Boundary Conditions

The pollutant flux for each species must be specified at all points on the boundary (both horizontal and vertical) where the wind is blowing into the modeling region. The boundary condition at the ground incorporates the influence of ground-level emissions as well as surface removal processes.

M. Emission and Meteorological Correlation

Emissions and meteorological inputs to the model are compiled in special data preparation programs. These programs are tailored to each application of the model in order to provide an effective interface between the existing observational data and the emissions and meteorological input file needs of the SAI model.

N. Validation/Calibration

Evaluation studies using an early version of the SAI Model developed in 1973 were carried out for Los Angeles, Las Vegas, and Denver for CO, NO, NO_2, O_3 and hydrocarbons. The latest version has been applied to Denver and is currently being adapted to St. Louis, Los Angeles, and Sacramento.

O. Output

The model produces gridded maps illustrating the spatial distribution of one-hour-average pollutant concentrations over the entire region of interest. Vertical concentration profiles and predictions at air monitoring stations or other user-selected sites may also be displayed. The model output may also be interfaced with contour plotting routines to generate diagrams of concentration isopleths.

3.3.4 Description of the Environmental Research & Technology, Inc. Model ARTSIM 2.0

Post Conference Submission by B. Egan

Reference: "Lagrangian Photochemical/Diffusion Model", Environmental Research & Technology, Inc. (In preparation), May 1977.

Abstract: ARTSIM is a trajectory-oriented model intended for regional application. It simulates chemistry and diffusion in a moving polluted air mass. The chemical model contains 54 reactions and explicitly treats four hydrocarbon classes, namely, alkenes, alkanes, aromatics and aldehydes as well as photochemical oxidants, SO_2, and sulfate. The model computes pollutant concentration as a function of height and time. It contains 3-modules: (1) trajectory generation; (2) source emissions; (3) chemical/meteorological.

Equations:

$$\frac{\partial c}{\partial t} = \frac{\partial c}{\partial z} \left(K(z,t) \frac{\partial c}{\partial z}\right) + R(c)$$

where
c = vector of pollutant concentrations
K(z,t) = diffusion coefficient which varies with height and time
R(c) = vector of chemical reaction rates

A. Source-Receptor Relationship

Area and point sources are used. Elevated point sources may be used. Generalized input structure allows use of source emissions data at various levels of resolution. Source-oriented and receptor-oriented trajectories may be specified.

B. Emission Rate

Rates must be specified for each primary pollutant. Hourly rates for traffic and stationary sources required.

C. Chemical Composition

54-reaction chemical model including NO, NO_2, O_3, SO_2, sulfate, alkenes, alkanes, aromatic hydrocarbons, and aldehydes.

D. Plume Behavior

N/A

E. Horizontal Wind Field

Hourly u- and v-components must be input for trajectory calculations.

F. Vertical Wind Speed

Not included.

G. Horizontal Dispersion

Assumed negligible

H. Vertical Dispersion

Diffusivities are specified at up to 10 vertical levels with arbitrary time resolution. Any atmospheric stability class can be used for various times of day.

I. Chemistry - Reaction Mechanism

See Section C

J. Physical Removal

Physical removal is simulated by a variety of ground boundary conditions and/or chemical reactions in kinetic model.

K. Background

Background concentrations can be specified as initial or boundary conditions.

L. Boundary Conditions

a) Source boundary condition at ground:

$$K(o,t)\,\frac{\partial c_i}{\partial z} = -\,\emptyset_i(t)$$, i denotes ith species, $\emptyset_i(t)$ = source flux

b) Constant-concentration boundary condition:

$$c_i = \text{constant}$$

c) Absorption at the ground:

$$K(o,t)\,\frac{\partial c_i}{\partial z} = v_d\, c_i^n ,$$

v_d = deposition velocity
n = power of c_i

d) Top boundary condition (impermeable boundary)

$$\frac{\partial c_i}{\partial z} = 0$$, for all i.

M. Emission and Meteorological Correlation

N/A

N. Validation - Calibration

a) A. Q. Eschenroeder, J. R. Martinez, and R. A. Nordsieck, "Evaluation of a Diffusion Model for Photochemical Smog Simulation", General Research Corporation, CR-1-273, Oct. 1972

b) AeroVironment, Inc., "Las Vegas Valley Air Quality Study", April 1976

c) AeroVironment, Inc., "Truckee Meadows Basin Air Quality Study", April 1976.

N. d) Stanford Research Institute, "Present and Prospective San Francisco Bay Area Air Quality", December 1974.

O. Output

Species concentrations as functions of time and height above ground. Time resolution is arbitrary down to 1 minute. Variable vertical mesh spacing may be used.

3.3.5 *Description of the Environmental Research & Technology, Inc. Model LAPS*

Post conference submission by B. Egan

Reference: R. A. Nordsieck. "A Local Air Pollution Simulator (LAPS); Volume I, User's Guide," Environmental Research & Technology, 2030 Alameda Padre Serra, Santa Barbara, California 93103, 1977 (In preparation).

Abstract: LAPS employs numerical techniques to calculate concentration fields downwind of single or multiple concentrated sources. These sources may be individual point sources at various heights, an area source strip on the ground at arbitrary orientation with respect to the wind, or combination of the two. The model uses the Lagrangian or trajectory approach with lateral dispersion. Steady or unsteady conditions may be modeled and the averaging times associated with the calculated concentrations are related to the averaging periods of the input emissions and meteorology. Vertical mixing conditions are simulated using time- and space-varying eddy diffusivities. Up to seven pollutants may be modeled simultaneously with optional equilibrium chemical coupling between the species.

Equations:

The basic transport equation modeled by LAPS is:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = D_y(z,t)\frac{\partial^2 c}{\partial y^2} + \frac{\partial}{\partial z}\left\{D_z(z,t)\frac{\partial c}{\partial z}\right\} + Q(x,y,z,t)$$

where

c = pollutant concentration

u = wind speed in x-direction

$D_y(z)$ = lateral eddy diffusivity at z

$D_z(z)$ = vertical eddy diffusivity at z

$Q(x,y,z,t)$ = source-sink term to model pollutant emission fluxes and simple chemical reactions

In the Lagrangian formulation, the coordinate system of the air parcel is oriented with x in the direction of the wind and moves at the wind speed u. Thus, the wind speed relative to the moving coordinate system is zero and the term $u\frac{\partial c}{\partial x}$ is removed from the equation. LAPS solves the reduced equation by a combination of finite difference techniques in the z and t dimensions and multiple superposition of an analytical solution for Gaussian spreading from a finite-width source in the y and t directions.

A. Source-Receptor Relationship

Up to 10 point sources at arbitrary locations.

Unique stack height and efflux parameters for each stack.

Separate uniform area sources allowed over entire region and/or within a finite-width strip located and oriented by user input.

Specific receptor locations not currently calculated, but a ground concentration map is provided and vertical profiles are available at user specified time intervals.

B. Emission Rate

Unique average emission rates of all pollutants for each point and area source.

C. Chemical Composition

Up to seven chemical species can be specified by name and molecular weight.

D. Plume Behavior

Briggs (1971) final plume rise formula for neutral or unstable conditions with $u > 3.1$ mph.

Downwash not treated.

Plume rise limited to inversion height unless stack penetrates base of inversion layer.

E. Horizontal Wind Field

Wind speed is uniform over y and z, but may be varied with time. Vertical mixing induced by wind shear can be modeled through adjustment of the vertical eddy diffusivities.

F. Vertical Wind Speed

Neglected.

G. Horizontal Dispersion

Lateral dispersion is treated using an analytic solution for one-dimensional diffusion from a finite-width source. Each cell in a row at each vertical station is treated as an isolated source which diffuses laterally for one time step. The results of these calculations are superposed to give the complete solution in each row of cells.

The lateral eddy diffusivities can be varied with height and time.

H. Vertical Dispersion

Vertical dispersion is modeled using a Crank-Nicolson finite difference formulation for vertical diffusion with variable eddy diffusivities.

The vertical eddy diffusivities can be varied with height and time.

I. Chemistry - Reaction Mechanism

Equilibrium chemical coupling of NO, NO_2, and O_3 is optional.

First order conversion of SO_2 to sulfate is optional.

Governing rate constants and conversion rates are input parameters.

J. Physical Removal

Fallout not modeled.

Rainout not modeled.

J. (cont'd)

Impaction of particulates or complete chemical uptake at the ground is optional for any species.

K. Background

Vertical profiles of background concentrations are specified by the user for each species.

L. Boundary Conditions

Optional time varying surface fluxes of each species, independently specified for a source step and for the remaining area.

Constant ground concentration may be specified for any species to enable calculation of surface uptake.

Reflection coefficient at sidewalls may be set by the user.

M. Emission and Meteorological Correlation

N/A

N. Validation - Calibration

Thus far, validations have consisted of comparisons with various analytical solutions; for example, for steady-state Gaussian plumes and step changes in flux or concentration boundary conditions. In each case, it has been possible to achieve accuracy in the 10% and under range, which is certainly within the accuracy of real-world input data. No comparisons with measured data have been attempted as yet, owing partially to the scarcity of good measured data, either roadside CO profiles or point source plume concentrations collected with simultaneous car counts or pollutant emissions and meteorological data.

O. Output

Vertical concentration maps giving concentrations at mesh points in an array of up to 10 vertical stations and 20 horizontal stations at user-specified time intervals. (Optional)

O. (cont'd)

Ground concentration maps showing ground concentrations at up to 20 stations normal to the wind direction at user-specified time intervals along the air trajectory. (Optional)

Ground concentration contours - A printer-plotted symbol map derived from the array of ground concentrations delineates up to 10 user-specified contour levels. The user may select which species are to be plotted and specify different contour levels for each selected species.

Concentration vs. distance plot - This option produces a printer-plot of ground concentrations vs. distance along the trajectory for up to five user-selected species.

Ground concentration crossplot - This optional output gives ground concentration profiles normal to a roadway (i.e. a source strip) at user-specified intervals along the road.

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3.4 GROUP II-1

3.4.1 Description of the Environmental Research & Technology, Inc. Model EGAMA

Post conference submission by B. Egan

Reference: Egan, B.A. and J.R. Mahoney, 1972a: "Numerical modeling of advection and diffusion of urban area-source pollutants." J. Appl. Meteor., 11. 312-322.

Egan, B.A. and J.R. Mahoney, 1972: "Applications of a numerical air pollution transport model to dispersion in the atmospheric boundary layer." J. Appl. Meteor., 11. 1023-1039.

Abstract: The Egan-Mahoney advection-diffusion model (EGAMA) simulates the dispersion mechanisms of grid-cell emissions using a numerical solution to the basic tracer equation. The model utilizes moments of the concentration distribution within each grid cell in a computation scheme designed to virtually eliminate numerical, pseudo-diffusion effects. The capability of this model to treat spatial and temporal variations in the wind and diffusivity profiles allows for specialized adaptations for a wide range of modeling, applications, e.g., near-field dispersion of highway sources, fumigation episodes due to sources located near land-water interfaces, and long range transport problems.

Equations: The basic mass conservation equation for a pollutant species in a planer non-divergent flow field may be written:

$$\frac{\partial c}{\partial t} = - U \frac{\partial c}{\partial x} - V \frac{\partial c}{\partial y} + \frac{\partial}{\partial z} (K \frac{\partial c}{\partial z}) + Q - R$$

where	C	=	pollutant concentration
	U	=	component wind speed in mean (x) direction
	V	=	cross wind speed component
	K	=	vertical eddy diffusivity
	Q	=	emission rate
	R	=	Removal or production rate (specific form depends upon mechanism)

A. Source-Receptor Relationship

Emission rates may be assigned to each grid cell. Average concentrations within each model grid cell are computed by step-wise integration for evenly spaced time intervals. Two or three dimensional grid systems may be specified.

B. Emission Rate

Time and spatially variable emissions within each grid cell can vary with time and represent average values over the geographical space encompassed by a single grid cell.

C. Chemical Composition

Transformation and decay as well as surface deposition of the contaminant species under examination may be incorporated. These processes are of primary concern for long range transport applications.

D. Plume Behavior

No plume rise formula per se is incorporated by the model. Emissions are assumed well mixed in the vertical within each grid cell. Preliminary plume rise calculations (e.g., Briggs formulae) can be performed to establish the vertical location of each emission source.

E. Horizontal Wind Field

Steady-state or spatially/temporally varying ambient winds may be specified throughout the grid system. The speed at any point is considered constant during a given time step. The effects of obstacles on altering the flow field may be simulated.

F. Vertical Wind Speed

Normally assigned zero initial value. Vertical wind speeds resulting from flow over obstacles or downwash are internally generated (for example return flow circulation in depressed highway sections).

G. Horizontal Dispersion

Turbulent diffusivities can be specified to simulate horizontal dispersion. In applications with large grid cells, horizontal dispersion is often neglected compared to the transport terms.

H. Vertical Dispersion

The vertical diffusion component is simulated by a conventional forward-time, center-difference technique modified so that variable grid spacing can be specified in the vertical. In regions where parameters or concentrations vary rapidly with height, resolution and accuracy can be improved by smaller vertical grid spacing.

I. Chemistry/Reaction Mechanisms

Program presently allows incorporation of two specie reactive chemistry. Modifications are underway to expand capability to multiple species.

J. Physical Removal

Surface deposition of the contaminant species modeled is simulated at the lower boundary of the grid system. Other removal processes, including chemical transformation and decay can also be incorporated.

K. Background Concentrations

Can be specified as initial conditions throughout the grid system and in the form of boundary values which are advected into the computational region.

L. Boundary Conditions

Winds, diffusivities, and pollutant fluxes at top and bottom of grid system may be specified.

M. Emission and Meteorological Correlation

Could be specified.

N. Validation/Calibration

Extensive validation/calibration study performed for highway applications (2D-version) limited validation of 3D version performed in long range SO_x modeling study.

O. Output

Concentration fields at all grid locations at specified time intervals or time averaged.

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3.5 NO SUPPLEMENTARY MATERIALS

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3.6 GROUP II-3

3.6.1. Description of TAPAS Model

Submitted by D. G. Fox at the conference.

TAPAS

Reference:

(a) Fosberg, M.A. and D.G. Fox. "A Topographic Air Pollution Analysis System" to be submitted to Atmospheric Environment.

(b) Fosberg, M.A. and D.G. Fox. "An Air Quality Index to Aid in Determining Mountain Land Use". In Proceedings of the Fourth National Conference on Fire and Forest Meteorology, Nov., 1976, USDA For. Serv. Gen. Tech. Rep. RM-32, p. 167-170, 1977.

(c) Fosberg, M.A., D.G. Fox, E.A. Howard and J.D. Cohen. "Nonturbulent Dispersion Processed in Complex Terrain", Atmos. Env. 10, p. 1053-1055, 1976.

(d) Fosberg, M.A., W.E. Marlatt and L. Krupnak. "Estimating Airflow Patterns Over Complex Terrain, USDA Forest Service Research Paper No. 162, 16 p., 1976.

(e) D.G. Fox, G. Wooldridge, and others. "An Experimental Study of Mountain Meteorology". In Proceedings of the Third Symposium on Atmospheric Turbulence Diffusion and Air Quality. Amer. Met. Soc., Raleigh, NC, 1976

Abstract: TAPAS combines a simulation of the wind field over mountainous terrain with a Gaussian derived diffusion model. The diffusion model is employed in each grid cell of the calculation in order to provide an estimate of the mixing conditions within these cells. These conditions are combined with the Pollutant Standards Index such that a maximum allowable emission is calculated. These in turn represent an atmospheric constraint for planners to work with.

Equations:

(1) Wind Model
- (a) Cressman objective analysis
- (b) Potential flow over topography
- (c) Influences of surface temperature and roughness. See reference (d)

(2) Dispersion Model

$$\chi = \frac{Q}{2\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(y^2/\sigma_y^2 + z^2/\sigma_z^2\right) - \delta \Delta t\right]$$

$$\equiv \frac{QG}{u}$$

where $Q, \sigma_y, \sigma_z, u, y, z$ are conventionally defined

δ = mean divergence in each cell (from WIND model)

Δt = time interval = X_L/u

X_L = grid spacing

$$I \equiv \text{Mixing Volume Index} = \frac{\chi}{Q} \times 10^6 = \frac{G}{u} \times 10^6$$

For short time standards

$$\Pi = \sum_i n_i Q_i = \frac{\psi - a}{b} \, \frac{\chi_s}{I} \times 10^6$$

For long time standards

$$\Pi_L = \sum_i n_i Q_i \Delta\tau_i = \frac{(\psi - a)}{b} \, \frac{9 \chi_s X_L}{2u} \times 10^6$$

where n_i = number of sources of i^{th} activity

Q_i = Emission rate of i^{th} activity ($\mu g/sec$)

$\Delta\tau_i$ = total time Q_i is emitting

ψ = Pollutants Standards Index (Thom + Ott)

a, b = constants for determining ψ

χ_s = Ambient air quality standard ($\mu g/m^3$)

TAPAS

A. Source-Receptor Relationship

(a) Sources are evaluated on the basis of their instantaneous emission rate (mg/sec) for π values and in terms of their total emission (mg) over the standard time period for the π_t values.

(b) There is no distinction made between point, line and area sources.

(c) There are no specific receptors, Analysis is for ground level concentrations.

B. Emission Rates

(a) Calculated from EPA emission factors external to the model.

(b) Model provides the total allowable emission within each grid cell (ranging from .25 km^2 to 9 km^2) to achieve a preselected level of air quality.

C. Chemical Composition

Only non-reactive pollutants are treated.

D. Plume Behavior

No explicit treatment of plume behavior.

E. Horizontal Wind Field

The wind component calculates an overall driving wind by Cressman objective analysis. This is then altered by topography within the restrictions of potential flow. The potential flow is corrected by surface temperature and surface roughness considerations.

F. Vertical Wind

The calculated wind is constrained to follow the terrain at the surface. The rate of change of vertical velocity ($\partial w/\partial z$) is explicitly calculated as the divergence.

TAPAS

G. Horizontal Dispersion

A Gaussian formulation is altered to include the effects of mass divergence (see ref. c) on horizontal dispersion. This effect is coupled with the values of σ_y presented by Turner for each stability class. Other more sophisticated forms of dispersion can be included.

H. Vertical Dispersion

σ_z is determined from Turner for each stability class. Other forms of dispersion can be included.

I. Chemistry/Reaction Mechanism

None

J. Physical Removal

None

K. Background

Can be removed, if know, from the calculated total allowable emission.

L. Boundary Conditions

No upper bound on vertical diffusion within each cell although the wind is calculated assuming a lid, a specified distance above the topography.

M. Emission and Meteorological Correlation

None

N. Validation/Calibration

The wind model has undergone various tests of accuracy and its' parameters have been adjusted accordingly. The diffusion-wind combination has not been validated.

TAPAS

0. Output

A matrix of the allowable emissions within each grid cell is output for each individual ambient air quality standard, i.e. 1 hr. CO, 8 hr. CO, 24 hr. TSP, or for any other preselected level of air quality, i.e. for 24 hr. TSP $\psi = 100$, $\chi_s = 75\ \mu g/m^3$ or $\psi = 8$, $\chi_s = 75\ \mu g/m^3$ (class I) or $\psi = 17$, $\chi_s = 75\ \mu g/m^3$ (class II).

The model is able to accomodate selection of different values of ψ at different grid points so that class I, II and III areas can be analysed together.

3.6.2 Validation Data on the VALLEY Model

Submitted by Herschel H. Slater, post-conference

Valley Model: Comparisons of Observed and Estimated Concentrations and Related Observations

The Valley Model was initially used to estimate the impact of emissions from single sources on elevated terrain. There are few data available to evaluate this or any other model or analytical routine in rough terrain situations, because: (1) it is difficult to locate and operate monitoring equipment in complex terrain; (2) the representativeness of meteorological data is often uncertain; and (3) some short-term standards are addressed to rare events. Sensing the rare event may require a very highly reliable, continuously operating monitoring program.

The dramatic example of the latter is provided by data collected by the Kennecott Copper Corporation at two of their sampling sites on January 20, 1976. The bearings from the main stack to the monitors were within 5° of each other (about 250° True). One monitor was about 2.7 miles (4.5 km) from and 300 feet (100 m) above the stack top. It measured a 24-hour SO_2 concentration of 2.71 ppm. The second monitor was about 3.0 miles (5 km) from and 1100 feet (350 m) above the stack top. It measured 0.02 ppm for the same 24-hour period. The maximum concentrations at monitors with elevations near or below the base of the stacks were at most 10-22% of the highest concentrations measured on the hillside. (It is probable the concentrations at the monitors near the elevations of the stack bases were caused by sources other than the pollutants emitted from the stacks.) It is quite apparent that the effluents from the stacks were contained in or below an inversion and lay along the hillside above the base and below the crest.

Comparisons of estimated and observed 24-hour sulfur dioxide concentrations measured at sites located at elevations greater than the stack top of a nearby source are shown in Table A-1. In five cases, the emission rate was well documented. To make the concentration estimates it was assumed that stable conditions (F) and light wind speeds (2.5 mps) described the dispersion conditions.

Quantitative comparisons have been made which digress from the original purposes and applications of the Valley Model; e.g., comparisons made for 1-hour averaging times. Also, observations exist which can be only qualitatively related to the plume impingement concept of the Valley Model. Some examples which may provide some useful insights follow.

Lantz, Hoffnagle and Pahwa[5] developed 1-hour estimates from the Valley Model and compared estimated and observed concentrations from the Navajo Generating Plant Study. Using 4 sets of meteorological inputs they developed 12 data-pairs. The ratio of estimated to observed maximum 1-hour concentrations ranged from 0.7 to 2.4.

Slowik and Pica[6] used the Valley Model to estimate concentrations at a sampling site on Laurel Ridge, Pa., near the Conemaugh Generating Station. Comparisons were made with one year of 1-hour sulfur dioxide concentrations. The data were screened on the basis of wind directions collected at a wind sensing site on Chestnut Ridge, 14 km from the monitoring site. The study presumes that the wind observation on Chestnut Ridge defines the plume trajectory in all cases. If this

TABLE A-1 Comparisons Between Estimated Maximum and Second Highest and Observed 24-Hour SO_2 Concentrations. Estimated Concentrations Are Based On Valley Model Assuming F Stability and 2.5 mps Wind Speed.

Location	Source	Period	24-Hour Concentration[a] Estimated	Observed Max	Observed 2nd High	Ratio Est/Obs Max	Ratio Est/Obs 2nd High
Crusher[1]	Garfield Smelter	4/15/73-1/31/74	2480	2564	2473	1.0	1.0
		2/01/74-1/31/75	2480	6130	3130	0.4	0.8
Lower Lake[2]	Garfield Smelter	3/08-12/16/75	1.18 ppm	2.66 ppm	1.20 ppm	0.4	1.0
		1/1-25/76	1.18 ppm[b]	2.71 ppm[c]	2.14 ppm[c]	0.4	0.6
Site 106[3]	Navajo P. P.	10/1/74-2/17/75	36	32	19	1.1	1.9
Site 107[3]	Navajo P. P.	10/1/74-2/17/75	25	30	15	0.8	1.7
C-Hill[1,4]	Anaconda Smelter	Although some data have been acquired at C-Hill near the Anaconda smelter, unresolved uncertainties with the data make it inadvisable to apply them for validation purposes.					
Phelps Mine[1]	Morenci Smelter	1975	15490[b]	2547	2416	6.1	6.4
Jones Ranch[1]	Miami Smelter	1974	8610[b]	2042	1760	4.2	4.9
		1975	8610[b]	2642	1548	3.3	5.6

(a) Micrograms per cubic meter except where otherwise indicated.

(b) Emission rates not well-documented.

(c) Reliability of air quality data not ascertained.

very tenuous assumption is accepted, then the ratio of estimated to observed 1-hour concentrations was 40 for the maximum hourly, 65 for the second highest and 30 for the 90th percentile concentration.

Keen observers of plume configuration have long noted that plumes from the stacks of sources located in hilly terrain usually have greatest impact on higher terrain. Studies of the plume travel of the Clifty Creek power plant and observations near the Widow's Creek facility confirm this observation in a qualitative sense. (The Navajo study provides quantitative confirmation.) Observers do not agree that a particular plume configuration such as high-wind fumigation, inversion break-up fumigation or impingement is associated with greatest ground level concentrations. The critical configuration is influenced by the characteristics of the source, its site, the frequency of weather events, the location and orientation of nearby terrain features, and the operating schedule of the facility.

Scorer(7) has described several circumstances which support qualitatively the assumptions on which the Valley Model is based; namely, in hilly terrain the highest 24-hour concentrations caused by pollutants emitted from a stack whose top is lower than the elevation of nearby terrain features occur under light wind stable conditions. Scorer describes plume characteristics of a number of sources. He states that in Bohemia (p. 36): "The gases from large power stations drift with very little dilution above the height at which they were emitted, but below the mountain tops, until they impinge on the hillsides and damage the pine trees...." He describes a situation in New Zealand where, due to steeply sloping nearby mountains, air pollutants are trapped in calm weather and often impinge on the hillsides. Further, on page 46, he cites the coastal area of Lebanon where "...the plumes from the factory chimneys at the coast impinge on the rich fruit-growing fields which slope up steeply inland..."

The classic Trail, B.C. study of Hewson and Gill[8] suggests that, on occasion, higher concentrations occurred on the slopes of the Columbia River Valley, above the valley floor but below the crests of the surrounding hills, than elsewhere.

An oft cited tracer study by Start, Dickson, and Wendell[9] was conducted in Huntington Canyon, Arizona. Based upon the single line-of-best-fit through observed vs. estimated concentrations from the four 1-hour valid tracer tests conducted during stable conditions, within a 48-hour period, the authors conclude that the dilution in the Canyon was 15 times that to be expected over flat terrain. Estimates were made by the bivariate Gaussian formulation, using the flat-terrain Pasquill-Gifford diffusion parameters corresponding to the stability observed in the Canyon. However, when the same data are expressed as the ratio of the estimated concentration to the study-period maximum observed concentration at each of the four sampling arcs (at distances about 2.2, 2.8, 4.2, and 6.2 km), we obtain values of 0.95, 1.1, 2.6, and 1.0, respectively. Relative to many modeling results, this is an excellent relationship. It is interesting to note that each maximum occurred at an end sampler of the respective arc. How adequately this set of data represents the dispersion conditions when the highest concentrations of the year occur has not been resolved.

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2a. Heaney, R.J.: Statement on Behalf of Kennecott Copper Corporation, December 16, 1975.

-b. Kennecott Copper Corporation: Air Pollution Emergency Episode, January 21 through 24, 1976. KCC Technical Report (undated).

3. Rockwell International;Meteorology Research, Inc.; and Systems Applications, Inc.: Navajo Generating Station Sulfur Dioxide Field Monitoring Program. Vol. IV: Ground-Level SO_2 Measurements. September 1975.

4. Anaconda Copper Company Observational data.

5. Lantz, R.B., G.F. Hoffnagle, and S.B. Pahwa: Diffusion Model Comparisons to Measured Data in Complex Terrain. Third Symposium On Atmospheric Turbulence, Diffusion, and Air Quality. AMS, Raleigh, N.C., p. 476, October 1976.

6. Slowik, A.A. and G. N. Pica: A field comparison of the EPA "Valley" Model, "Half-Height" Model and a suggested new model in complex terrain under stable atmospheric conditions. Interim Report No. 1, Pennsylvania Electric Co., August 31, 1976.

7. Scorer, R.S.: Pollution in the Air - Problems, Policies and Priorities. Rutledge & Kegan Paul, London and Boston, 1973.

8. Hewson, E.W. and G.C. Gill: Part III - Meteorological Investigations in the Columbia River Valley, near Trail, B.C. Report Submitted to the Trail Smelter Arbitral Tribunal (by R.S. Dean and R. E. Swain) U.S. Bureau of Mines, Bulletin 453, 1944.

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3.6.3 Comments by D. Henderson

Submitted after the conference

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION VIII
1860 LINCOLN STREET
DENVER, COLORADO 80203

March 23, 1977

REF: 8AH-A

Mr. Albert E. Smith
Energy and Environmental Systems Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Dear Al:

As a follow-up to our recent telephone conversation concerning comments on the EPA Modeling Guideline Working Group II-3, I am submitting the following suggestions. My first suggestions are related to use of the EPA Valley Model in complex terrain. These are followed by suggestions on the written statements prepared by Bruce Eagan, Douglas Fox, and Sumner Barr.

As I indicated in the workshop I have used the Valley Model differently than presented by Herschel Slater at the workgroup. I have attempted to use local meteorological conditions which would take into consideration the frequency of occurrance of the particular stability, wind direction and wind speed frequency distribution. This allows more versatility in applying the model, but requires consideration of persistance of the prescribed meteorological condition.

Several suggested changes to the Valley Model User's Guide were given by me to Herschel Slater and Ed Burt on the telephone. I suggested that in the introduction a statement similar to that given below be included.

"The EPA Valley Model is a modified Gaussian technique designed for making ground concentration estimates for plumes emitted from area sources and elevated point sources. Experience indicates that maximum 24-hour ground level concentrations frequently occur in elevated terrain when plumes are contained in a stable layer below the height of the terrain with the flow blocked under light wind conditions. This condition was given primary consideration in the Valley Model development for short term estimates."

The following comments pertain to the submission referred to at the beginning of this letter.

On page 11 at the end of section (ii), the statement is made that the box model approach is a conservative screening method. Without specifying averaging times, and how the top of the box is defined one cannot generally conclude that a box model is conservative. The results of the box model are very sensitive to the designation of the top boundary.

At the bottom of page 11 and also in one of Dr. Eagan's sections, physical modeling is proposed as a useable technique for source impact analysis in complex terrain. The guidelines should point out that the frequency of ocurrance and persistance of meteorological conditions are not determined in physical modeling techniques.

Several other suggestions were given to you on the telephone, but I believe the above covers those items I agreed to write you about. I hope these suggestions will be helpful to you.

Sincerely yours,

Don

Donald Henderson
Regional Meteorologist

3.6.4 Comments by M. Williams

Submitted after the conference.

On the occasions of which I am aware, the use of a plume half height correction would have produced drastically lower values than those observed or those predicted by Valley. These cases involve stable flow toward terrain as high as the approximate plume height.

With respect to the use of the principle of conservation of mass to consider what flow situations may be possible, it is very important that overly simplistic models not be used. There is a tendency on the part of some to use very simple models which assume that the wind is approximately uniform in direction the over than lower 2000 feet of the atmosphere. Under stable conditions this assumption is frequently false. Furthermore, the use of this assumption may suggest restrictions on plume behavior which do not, in fact, exist. We have found cases where a stable plume reached a distant ridge top (55 km) with little or no standoff distance. The ridge was approximately a two dimensional feature oriented at 45° to the direction of travel. Winds were approximately 3.5 m/sec.

With respect to alteration of diffusion rates we have found that terrain elements do not appear to influence the diffusion of stable plumes unless they are at full plume height. As long as there is no intervening terrain between an object and the source, it seems that no alteration in diffusion rates is justified for elevated plumes during stable conditions.

3.7 GROUP II-4

3.7.1 Comments on the Group II-4 Discussion of the Pasquill-Gifford σ_z Curves

Submitted by M. Williams after the conference.

Unfortunately I was not a party to the discussion which produced these conclusions so I do not know what basis was used to produce the stated conclusions. However, I have reviewed data which does relate to the question at hand. First, the Central Electricity Generating Board has reported on measurements near to power plants with stacks of 137 meters and 183 meters in height.[1] The calculational technique was that of the Pasquill H_{min} method which is similar to the Turner method except that the σ_z's are a little smaller in the Pasquill technique and the plume rise is calculated differently. The plume heights calculated through the H_{min} method are significantly smaller than those calculated through Brigg's plume rise used in CRSTER. Measurements near (1.4 km) the plant with the taller stack generally gave values comparable to those predicted, the exception being that during A stability with winds of 2.9 m/sec a 3-minute concentration of 58 pphm was predicted while the measured value was only 32 pphm and the highest measured value was only 36 pphm. Using a Brigg's plume rise with Turner dispersion parameters the calculated value is 40 pphm which appears to be in good agreement. Thus this evidence indicates that farily good agreement is obtain_d if the Turner values are taken as 3-10 minute values. The same document suggests that the maximum one-hour values are from half to three-quarters of the 3 minute values. Thus the Pasquill curves may overpredict by 33 to 100% if used as one-hour values at distances of about 1.4 km. This would suggest that the corrections should be applied to σ_y not σ_z. In addition to the ground-level measurements there are measurements of actual plume dimensions. These indicate that vertical spreads will be well in excess (more than twice) of those expected for Class B occurred even though the wind speeds were too high (5.8 m/sec) for Category A. This data does not seem to support either the replacement of Category A by Category B or the linear extrapolation technique. Both of these procedures would lead to dramatic underpredictions for low wind speed, near plant cases.

The measurements do suggest some underprediction at 5 km. Furthermore some of σ_z for categories B-D were greater than given by Turner curves.

In addition to the English work there is work in eastern Montana which suggests that the Turner σ_z curves are appropriate.[2] These data are based on work with a silver iodide tracer. I have enclosed Figures 5 and 6 from this work.

Finally, the Lappes study also suggests the importance of looping type situations.[3] The work shows that the highest ground level concentrations encountered occurred close in. There were two occasions where it looked as though the plume was undergoing classic looping type behavior near the Keystone plant.[2] In both cases peak values were comparable to those predicted with a Brigg's plume rise-Turner dispersion parameters combination. Furmore, repeated instances of high concentrations were found at 11:00 a.m.

These data suggest that while the computational procedures may require some revision it would be imprudent to change the σ_z curves without much more careful analyses. With the existing data as strong an argument can be made for changing the σ_y curves as can be made for changing the σ_z curves. The suggested changes for A stability might very well lead to dramatic underpredictions.

The recommended changes for the other categories also appear to be unsupportable. Certainly the measurements of dispersion during stable conditions in the Southwest show a much different behavior. TVA experience also indicates behavior similar to that found in the Southwest. Experiments reported by Slade also are inconsistent with the proposed changes.

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3. F. Pooler, Jr and L.E. Niemeyer, "Dispersion From Tall Stacks: An Evaluation", in Proceedings of the Second International Clean Air Congress edited by Englund & Beery, p1049-1056, 1971.

4. Francis A. Schiermeier and Lawrence E. Niemeyer, "Large Power Plant Effluent Study (LAPPES) Volume I-Instrumentation, Procedures, and Data Tabulations (1968)", U. S. Dept. of H. E. W., June 1970 pp 235&248.

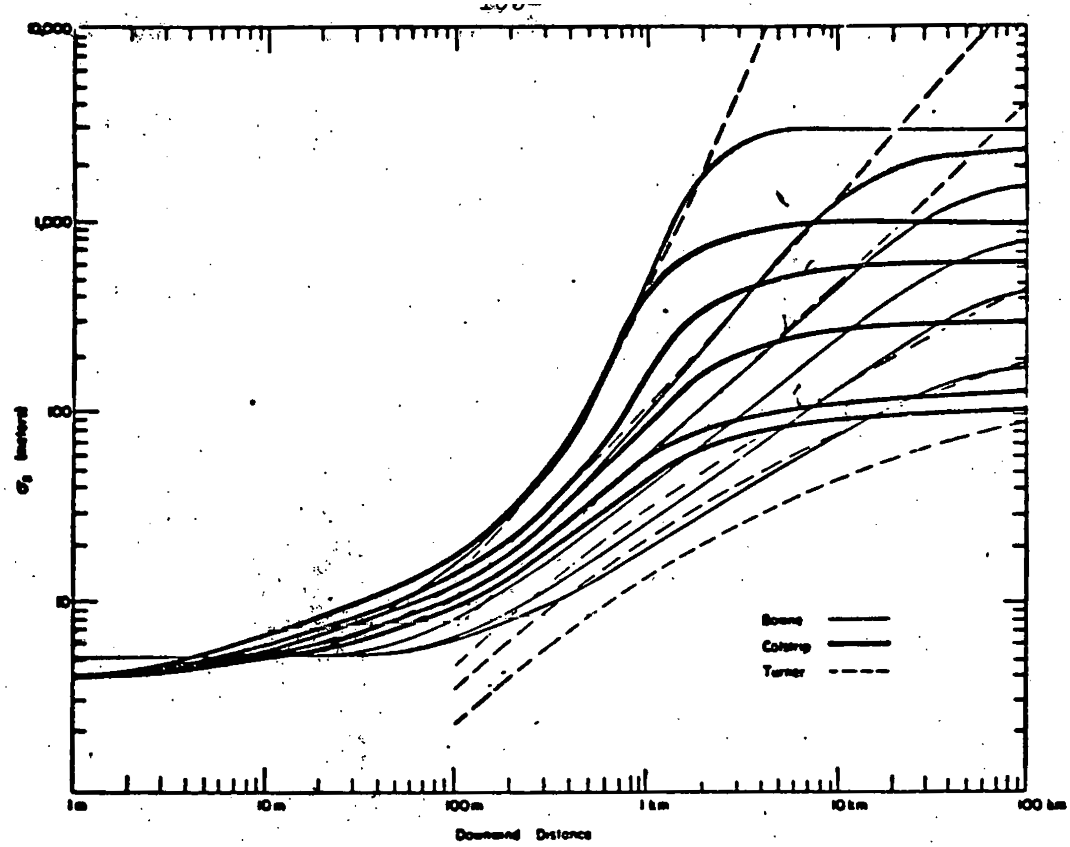

Figure 5. Comparison of the Colstrip vertical diffusion coefficients to those of Turner and Bowne's urban curves.

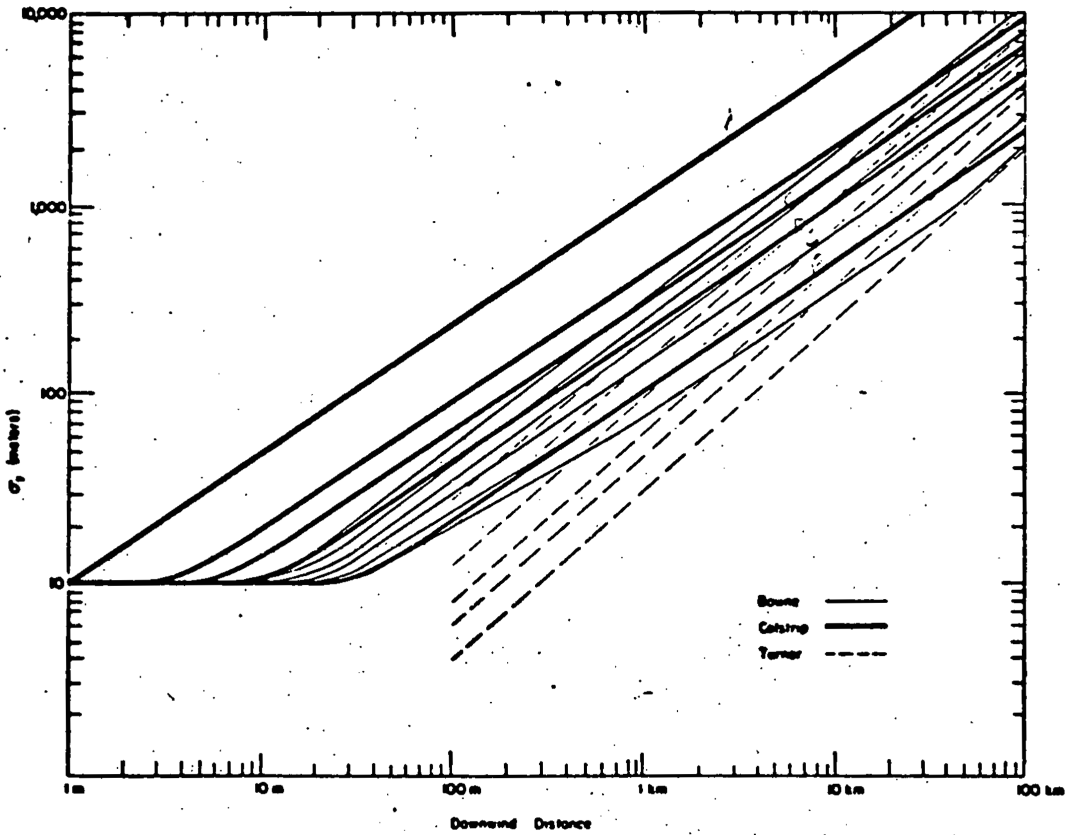

Figure 6. Comparison of the Colstrip horizontal diffusion coefficients to those of Turner and Bowne's suburban curves.

3.7.2 *Supplementary Comments on Discussion Topics of Working Group II-4*

Submitted by H. Cramer after the conference adjourned.

1. VERTICAL PROFILES OF WIND SPEED

I am in agreement with the working group's statement that the representation of the increase of wind speed with height employed in the EPA models by means of a power law with the exponent varying according to stability categories is satisfactory. However, this statement of the working group should not be interpreted to mean that the values of the power-law exponents now used by EPA are fixed and not subject to change. For example, wind-profile exponents are known to vary not only with stability category but also with wind speed and surface roughness. Specifically, it may prove desirable to vary the present values of the power-law exponents for the C and D stability categories with moderate and high wind speeds and with large changes in surface roughness parameters.

2. CONFLICTS AMONG SYSTEMS FOR ESTIMATING STABILITY CATEGORIES

In my experience the STAR program incorporating Turner's system using hourly surface observations to assign Pasquill stability categories is very satisfactory provided it is recognized that other meteorological parameters such as the mixing height, vertical gradient of potential temperature and wind-profile exponent must additionally be specified for each of the various combinations of wind-speed and stability categories. Of these parameters, the mixing height is by far the most variable and should not be considered fixed for any stability category, especially neutral. (One of the basic deficiencies of the Pasquill-Gifford σ_z curves is that they contain implicit mixing heights -- see comments below under Topic 3.) In my view, the opinion expressed by the working group that the STAR program tended to predict unrealistically high frequencies of occurrence of neutral stability reflects a lack of understanding of the importance of taking the mixing height into consideration when considering the behavior of tall-stack plumes during neutral stability. The STAR program output yields a stability classification that strictly applies in the first 10 meters or so above the surface. If the plume stabilization height is in a stable layer above the surface layer, which is frequently the case for tall stack plumes, the plume behavior does not and should not correlate with the behavior expected on the basis of the stability category assigned to the surface layer. The STAR program stability classification must be supplemented by detailed specification of the wind and temperature profiles along the vertical from the ground surface beyond the height attained by the upper edge of the plume as it travels downwind. As shown in Figure 1, the meteorological inputs required for application of the Gaussian plume model to tall stacks are thus directly related to vertical profiles of wind velocity and temperature (and in some cases to the vertical profiles of humidity and turbulent intensity as well) representative of a large reference air volume. This reference volume, which includes the source and the points on the ground at which concentrations are to be calculated, extends vertically to the top of the mixing layer and has horizontal dimensions large enough to contain significant ground-level concentrations.

I would like to register my complete and irrevocable opposition to the ΔT method for determining stability categories. Even if one ignores the very considerable and insurmountable practical difficulties in measuring and interpreting small vertical temperature differences of the order of 0.1^{o} C, the ΔT observations are strictly applicable only over the measurement height interval which is generally 100m or less. In working with tower ΔT measurements and following the AEC (ERDA) guidelines relating ΔT to stability categories, I have never been able to obtain results that appear to be reasonable on the basis of any conventional criteria. On the other hand, use of the Turner and STAR program procedures yields results that appear to be consistent with the wind measurements made on the towers and other conventional criteria.

$z_h = H_m =$ Depth of surface mixing layer $\approx$ 1 kilometer

$y_h = x_h =$ Maximum downwind distances $\approx$ 100 kilometers

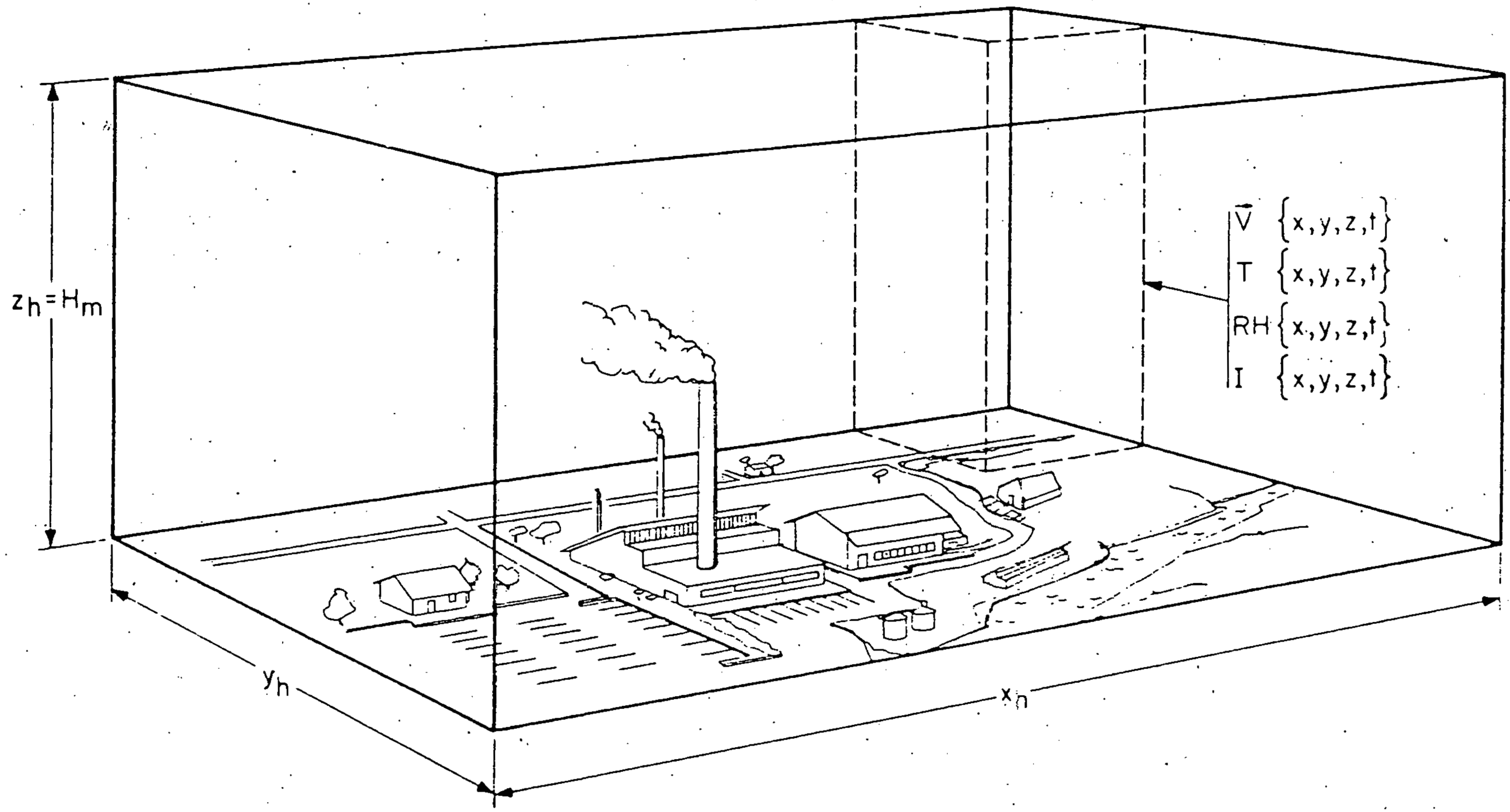

Figure 1. Schematic representation of the reference air volume.

3. VERTICAL DISPERSION ESTIMATES

As we have discussed over the telephone, the first sentence on page 7 of the 2 March First Round Report of Working Group II-4 was typed incorrectly and should be changed to read:

> "In their present form, the Pasquill-Gifford σ_z curves are unsuitable for calculating the ground-level concentrations produced by tall stack emissions. Specifically, the σ_z curve for A stability results in large overestimates of the short-term maximum ground-level concentrations (1-hour to 24-hour averages) and in large underestimates of the distances to the maximum concentration compared with observations."

There are two basic deficiencies in the Pasquill-Gifford σ_z curves that make them inherently unsuitable for describing the vertical dispersion of tall stack plumes:

- They refer specifically to the vertical dispersion of plumes from sources located at or near ground level and thus contain the effects of the large vertical gradients of atmospheric density (temperature gradients) and turbulence near the air-ground interface

- They are principally based on measurements of vertical plume dispersion made at distances less than 1 km from the source; the portions of the curves extending beyond 1 km are extrapolations and were originally intended only to serve as rough approximations to vertical dispersion from ground sources at these longer distances

The light lines in Figure 2 show the Pasquill-Gifford curves for the A, B, C, D, E, and F stability categories. The strong curvature of the A, D, E and F

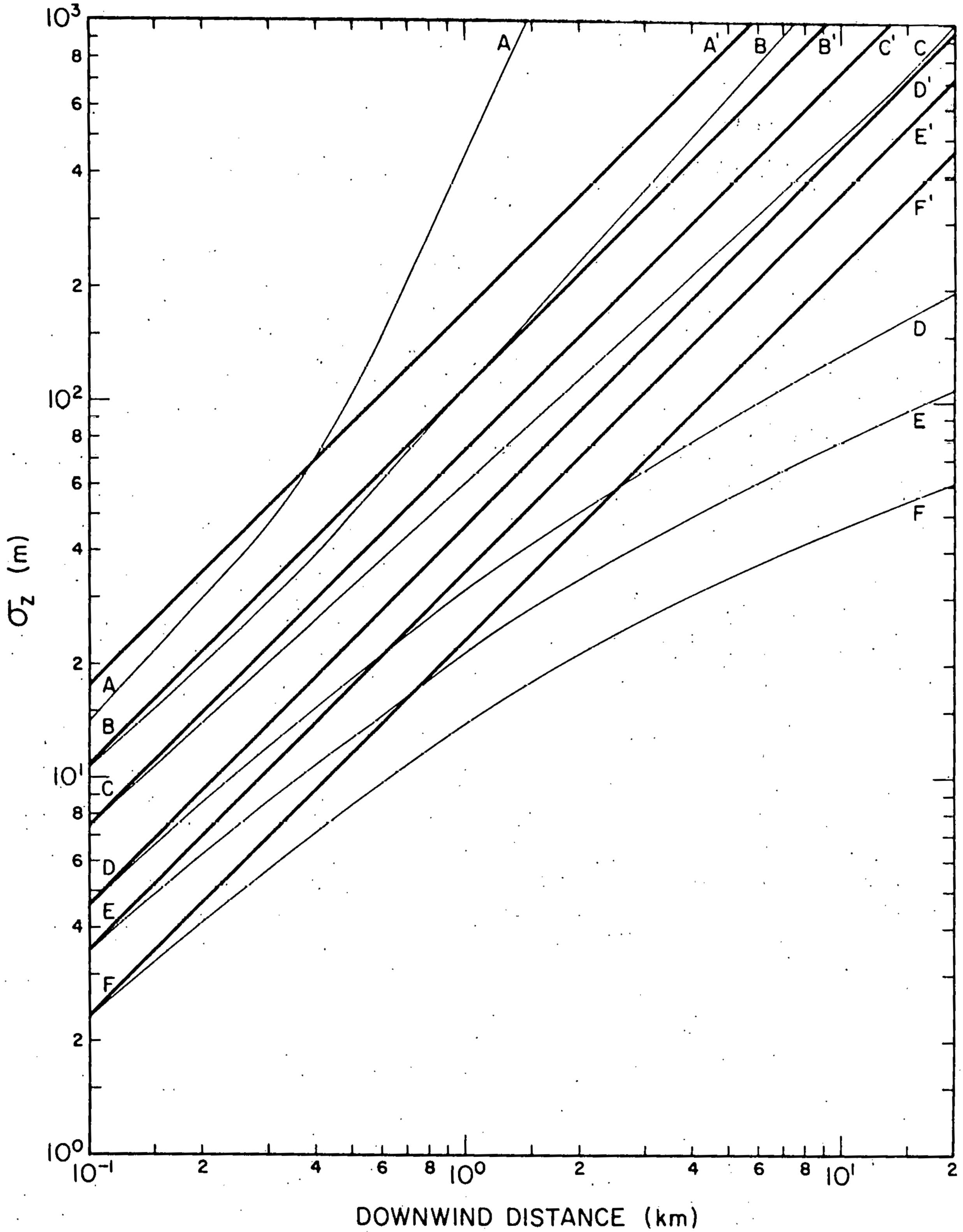

FIGURE 2. Pasquill-Gifford σ_z curves (light lines) and suggested modifications (heavy lines).

curves reflects the influence of the vertical gradients of temperature and turbulence in the air layers close to the ground on the upward vertical dispersion of plumes under very unstable conditions (A stability) and under neutral or slightly stable to stable conditions (D, E and F stability). Both measurements and theoretical reasoning indicate that the downward dispersion of plumes from elevated sources toward the ground surface is characterized by σ_z curves that plot as straight rather than curved lines on double logarithmic paper (i.e., $\sigma_z \propto x$) as shown by the heavy lines in Figure 2 labeled A' through F'. The upward dispersion of plumes from elevated sources depends on the vertical temperature gradients and turbulence in the air layers above the plume stabilization height.

In the absence of elevated temperature inversions that restrict upward plume growth, there appears to be an approximate linear relationship between vertical plume dispersion and σ_z. For example, Pasquill (1974, p. 202) cites experiments by Högstrom (1964) in which smoke puffs were released at a height of 50 m with the result that σ_z encreased linearly with travel distance out to about 300 m in all stabilities; at longer distances, σ_z tended to increase less rapidly with distance possibly because of a restriction on further upward expansion by an elevated stable layer at the top of the mixing layer. Pasquill (1974, p. 200) aslo cites experiments by Hay and Pasquill (1957) involving continuous tracer releases at a height of 150 m which showed a linear relationship between vertical spread (σ_z) and the travel time to downwind distances of 500 meters, the maximum distance at which measurements were made. Briggs (1975, p. 36) notes that recent studies of tall stack plumes show σ_z approximately linear with distance in the most unstable categories.

The strongest evidence of the inapplicability of the Pasquill-Gifford σ_z curves to tall stack plumes comes from comparisons of observations of plume behavior and measurements of ground-level concentration with model predictions. The approximate relationship between σ_z and the maximum hourly ground-level concentration for a tall stack plume is given by

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

where H is the plume stabilization height and both σ_z and σ_y are evaluated at the distance x_{max} of the maximum ground-level concentration. Assuming all parameters to be fixed except σ_z and σ_y at x_{max}, the predicted χ_{max} is directly proportional to the ratio $(\sigma_z/\sigma_y)_{x_{max}}$. Also, the distance at which χ_{max} occurs is the distance at which $\sigma_z = H/\sqrt{2}$ or 0.707 H. For simplicity, we assume a plume stabilization height of 500 m for A stability and a plume stabilization height of 300 m for D stability. By means of the two relationships given above and reference to the σ_z curves in Figure 2 and the Pasquill-Gifford σ_y curves, we obtain the results given in Table 1. As might be expected, the P. G. σ_z curve for A

TABLE 1

RESULTS OF EXAMPLE CALCULATIONS

	A Stability		D Stability
H	500 m		300 m
$(\sigma_z)_{x_{max}}$	354 m		212 m
x_{max}	P. G.	900 m	21,000 m
	Mod. P. G.	2,000 m	4,500 m
$(\sigma_y)_{x_{max}}$	P. G.	200 m	1,000 m
	Mod. P. G.	390 m	270 m
$(\sigma_z/\sigma_y)_{x_{max}}$	P. G.	1.8	0.2
	Mod. P. G.	0.9	0.8

stability places the maximum ground-level concentration about twice as close to the stack as the modified σ_z curve and yields a maximum concentration twice as large as the modified σ_z curve. Similarly, the P. G. σ_z curve for D stability places the maximum ground-level concentration about five times farther from the stack than the modified σ_z curve and yields a maximum concentration four times smaller than the modified σ_z curve.

Table 2 shows the σ_z/σ_y ratios for all the Pasquill-Gifford curves at distances from 0.1 to 10 kilometers. Note that the σ_z/σ_y ratios for C stability are approximately constant with increasing distance (which reflects the condition that $\sigma_z \propto x$) while the ratios for other stability categories either increase with distance (A and B stability) or decrease with distance (D, E and F stability). Assuming that the vertical dispersion of tall stack plumes toward the ground when the plumes are contained in the surface mixing layer requires that $\sigma_z \propto x$ (following the modified P. G. curves shown in Figure 2 and the P. G. curve for C stability), departures of the σ_z/σ_y ratios in Table 2 from a nominal value of about 0.6* provide a relative measure of the overestimation ($\sigma_z/\sigma_y > 0.6$) or underestimation ($\sigma_z/\sigma_y < 0.6$) of the maximum hourly ground-level concentration. It follows that the P. G. σ_z curves lead to large overestimates of the maximum ground-level concentrations for A and B stability and to large underestimates for D, E and F stability. Similarly, the P. G. σ_z curves lead to large underestimates of the distance to the maximum ground-level concentration in A and B stability and to very large overestimates of the distance to the maximum ground-level concentration for D, E and F stability. The degree of overestimation or underestimation in a particular stability category is directly related to the plume stabilization height. The minimum plume stabilization heights by stability category at which these effects become significant are approxi-

*Weil and Hoult (1973) in a study of SO_2 observations from the Keystone plant found that a value of $\sigma_z/\sigma_y = 0.6$ correlated best with hourly maximum ground-level concentrations during unstable conditions.

TABLE 2

RATIOS OF σ_z/σ_y FROM THE PASQUILL-GIFFORD CURVES

Distance (km)	Stability Category	A	B	C	D	E	F
0.1		0.53	0.54	0.59	0.60	0.60	0.57
0.2		0.57	0.57	0.60	0.56	0.56	0.54
0.5		0.96	0.63	0.58	0.50	0.49	0.47
0.7		1.32	0.66	0.58	0.47	0.46	0.44
1.0		1.97	0.69	0.58	0.44	0.42	0.40
1.5		3.39	0.74	0.58	0.41	0.38	0.36
2.0		5.05	0.79	0.58	0.38	0.35	0.33
3.0		8.49	0.85	0.59	0.35	0.31	0.28
4.0			0.91	0.59	0.33	0.28	0.26
5.0			0.96	0.59	0.30	0.26	0.23
6.0			1.00	0.59	0.29	0.24	0.21
8.0			1.07	0.60	0.27	0.22	0.19
10.0			1.14	0.60	0.26	0.20	0.17

mately 100 m (A stability), 300 m (B stability), 45 m (D stability), 22 m (E stability) and 11 m (F stability).

Confirmation of the effects described above is readily found in the results of model validation studies sponsored by EPA. For example, Lee, et al. (1975) describe a validation study of the EPA CRSTER Model (which uses the Pasquill-Gifford curves) that involved the application of the model to four power plants. In each case, there was no significant positive correlation between concurrent calculated and observed hourly and 24-hour average SO_2 concentrations. For a year of data, the CRSTER Model tended to overpredict the maximum observed hourly SO_2 concentrations and to underpredict to maximum observed 24-hour average concentrations. The poorest model performance was at the Canal Plant, which is located near Cape Cod Bay and consequently has a much greater frequency of occurrence of D, E and F stability than the other plants studied. Table 3 shows a comparison of hourly SO_2 concentrations observed at monitor stations in Tacoma, Washington downwind from the 172-meter stack of the ASARCO copper smelter with two sets of concurrent calculated concentrations. One set of calculated concentrations was made by means of the short-term Gaussian plume model described by Cramer, et al. (1975) which, except for the use of σ_z curves similar to those shown by the heavy lines in Figure 2, is practically identical to the EPA CRSTER Model. The second set of calculated concentrations (Pasquill-Gifford) was made by means of the same short-term model except that the Pasquill-Gifford curves were used. Differences in the two sets of calculated values in Table 3 are essentially due to the differences in the σ_z curves because the same source and meteorological inputs were used for both sets. For all the cases shown in Table 3, the average ratio of calculated and observed concentrations is 0.11 for the model calculations using the Pasquill-Gifford curves and approximately unity for the model calculations using the modified curves. The principal explanation is that the Pasquill-Gifford curves for D and E stability do not allow the plume to come to the ground at the distances of the monitors. This is the same result found by Lee, et al. (1975) at the Canal Plant. The modeling

TABLE 3

COMPARISON OF CALCULATED AND OBSERVED HOURLY SO_2 CONCENTRATIONS

Case No.	Monitor	Observed Concentration (ppm)*	Calculated Concentration (ppm)*		Ratios of Calculated and Observed Concentrations**		Pasquill Stability Category
			Pasquill-Gifford	Cramer, et al. (1975)	Pasquill-Gifford	Cramer, et al. (1975)	
2	N26th and Pearl	(1.23)	0.03	0.88	(0.02)	(0.72)	D
	Reservoir	0.27	0.00	0.04	0.00	0.15	D
	Highlands	0.73	0.06	0.44	0.08	0.60	D
3	N26th and Pearl	0.40 (0.46)	0.12	0.25	0.30 (0.26)	0.63 (0.54)	C
4	N26th and Pearl	0.56 (0.68)	0.00	0.61	0.00 (0.00)	1.09 (0.90)	E
	Reservoir	0.62	0.00	0.64	0.00	1.03	E
6	N26th and Pearl	0.30 (0.22)	0.04	0.30	0.13 (0.18)	1.00 (1.36)	D
	N26th and Pearl	0.26 (0.26)	0.01	0.23	0.04 (0.04)	0.88 (0.88)	D
7	N26th and Pearl	0.60 (0.46)	0.00	0.26	0.00 (0.00)	0.43 (0.57)	D
8	N26th and Pearl	0.32 (0.21)	0.00	0.44	0.00 (0.00)	1.38 (2.10)	E
	Reservoir	0.37	0.00	0.39	0.00	1.05	E

*Numbers enclosed by parentheses are concentrations measured by the ASARCO SO_2 monitor at N26th and Pearl.

**Numbers enclosed by parentheses are ratios of calculated and observed concentrations for the ASARCO SO_2 monitor at N26th and Pearl.

TABLE 3 (Continued)

Case No.	Monitor	Observed Concentration (ppm)*	Calculated Concentration (ppm)*		Ratios of Calculated and Observed Concentrations**		Pasquill Stability Category
			Pasquill-Gifford	Cramer, et al. (1975)	Pasquill-Gifford	Cramer, et al. (1975)	
9	N26th and Pearl	0.37 (0.67)	0.00	0.64	0.00 (0.00)	1.73 (0.96)	D
	N26th and Pearl	0.31 (0.21)	0.06	0.11	0.19 (0.29)	0.35 (0.52)	A
	N26th and Pearl	0.25 (0.25)	0.00	0.31	0.00 (0.00)	1.36 (1.36)	E
12	McMicken Heights	0.50	0.25	0.52	0.50	1.04	D
13	Meeker	0.28	0.04	0.28	0.14	1.00	D
	Meeker-Brown	0.31	0.06	0.35	0.19	1.13	D
	Meeker	0.38	0.06	0.42	0.16	1.11	D
	Meeker-Brown	0.42	0.07	0.50	0.17	1.19	D
	Meeker	0.59	0.06	0.56	0.10	0.95	D
	Meeker-Brown	0.49	0.05	0.53	0.10	1.08	D
14	McMicken Heights	0.30	0.06	0.09	0.20	0.33	C
	Tukwila	0.41	0.06	0.10	0.15	0.24	C
19	N26th and Pearl	0.42 (0.35)	0.00	0.87	0.00 (0.00)	2.07 (2.49)	E
	Reservoir	0.50	0.00	1.00	0.00	2.00	E
	N26th and Pearl	0.27 (0.17)	0.07	0.10	0.26 (0.44)	0.37 (0.59)	B
				Mean Ratios	0.11 (0.12)	0.97 (1.00)	

*Numbers enclosed by parentheses are concentrations measured by the ASARCO SO_2 monitor at N26th and Pearl.

**Numbers enclosed by parentheses are ratios of calculated and observed concentrations for the ASARCO SO_2 monitor at N26th and Pearl.

techniques, emissions data, meteorological data and the air quality observations referenced in Table 3 are described in detail in the report prepared for EPA by Cramer, et al. (1976).

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Pasquill, F., 1974: Atmospheric Diffusion (Second Edition). Ellis Horwood Limited, Sussex, England, 429.

Weil, J. C. and D. P. Hoult, 1973: A correlation of ground-level concentrations of sulfur dioxide downwind of the Keystone stacks. Atmospheric Environment, 7, 707-721.

3.7.3 *Comments on Report of Working Group II-4*

Submitted by D. Bruce Turner and L. E. Niemeyer after the conference.

Group II-4 expressed concern with the adequacy of the Pasquill-Gifford vertical dispersion coefficients for unstable conditons when applied to sources with tall stacks. Nevertheless, this distinguished group did not see fit to make a recommendation for changes at this time. The Pasquill-Gifford curves have stood the test of over a decades' use. The prudent course of action is to continue to use the time-tested factors until such time as the data which are now becoming available as sampling data from the vicinity of facilities with tall stacks are organized, until they are subjected to full scientific review and scrutiny and until the scientific community agrees that current values for the vertical dispersion parameters result in wholly unsatisfactory estimates. It is our current task to encourage, enhance and aid a prompt scientific analysis and review of this matter. To our knowledge such activities are underway by several atmospheric scientists and by professional scientific societies.

3.8 GROUP II-5

No Supplementary Materials

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3.9 *GENERAL SUPPLEMENTARY MATERIALS*

3.9.1 *Use and Formulation of the Hanna-Gifford Model*

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL RESEARCH LABORATORIES
Post Office Box E
Oak Ridge, Tennessee 37830

February 25, 1977

Mr. Kenneth Brubaker
Energy and Environmental Systems Division
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60439

Dear Mr. Brubaker:

I've had a chance to review the section on my model on pages 2.18 through 2.21 of your report "Descriptions of Air Quality Models and Abstracts of Reference Materials." There are a few corrections that should be made. I suppose these problems are basically my fault, since we have published our model in a series of articles, rather than in a comprehensive user's guide.

You and the EPA break up our model into a short-term and a long-term model. In reality, we never intended such a division and believe the model is equally applicable to averages from 20 or 30 minutes on up. Historically, we began in late 1969 with the equation

$$\chi = \sqrt{\frac{2}{\pi}}\frac{1}{U}\frac{(\Delta x/2)^{1-b}}{a(1-b)}\left\{Q_0 + \sum_{i=1}^{N} Q_i \left[(2i+1)^{1-b} - (2i-1)^{1-b}\right]\right\} \qquad (1)$$

where $\sigma_z = ax^b$. After applying this equation to several gridded urban areas, we discovered that the formula

$$\chi = C(Q_o/U) \qquad (2)$$

works just fine for most areas, where

$$C = \sqrt{\frac{2}{\pi}}\left(\frac{2N+1}{2}\Delta x\right)^{1-b}\frac{1}{a(1-b)} \qquad (3)$$

The "constant" C theoretically equals about 600, 200, and 50 for stable, neutral, and unstable conditions, respectively. So, you see we do have theoretical expression for C, in contrast to the statement made in your review. Further, we always caution that (1) should be used in place of (2) whenever the local emission Q_o is much less than the Q's of neighboring grid blocks. Also, it has always been recommended as part of our model that strong point sources (there are usually 10 or 20 in an urban area) be treated separately using the standard plume model.

Of course, whenever good observations of concentrations are available, the constant C in equation (3) or the expression $\sqrt{2/\pi}(\Delta x/2)^{1-b}/(a(1-b))$ in equation (1) should be replaced by a calibrated value. The diurnal variation of C has always been questionable, but through the analysis of much CO data from several states I have recently developed a diurnal curve for C. This will be reported in the open literature during the next few months.

We have also found from studying observed pollutant concentrations that the calibrated C varies with the pollutant, being highest for CO, lowest for SO_2, and intermediate for suspended particles. There are several hand waving arguments for these differences. Other modelers at the Nordic Hills workshop reported exactly the same behavior with their models.

In 1973 I extended this model to include the photochemical pollutants NO, NO_2, and oxidants. The seven-step reaction mechanism proposed by Friedlander and Seinfeld was used, although any kinetic mechanism could be plugged into the model. Predictions of this model were compared with predictions of other models in the Los Angeles basin, showing that our model was just as good as the others. In this case as well as in the other reprints that I have enclosed, we test or validate our model extensively. Because of the ease with which our model is applied, I can confidently state that it has been validated in the open literature much more often than any other urban dispersion model. Whenever a new set of observations comes out, we test it.

The following outline is my suggestion for a revision to pages 2.18-2.21 of your report:

References: 1) Hanna, S. R. A Simple Method of Calculating Dispersion from Urban Area Sources. J. Air Poll. Cont. Assoc., 12, 774-777 (Dec. 1971).
2) Gifford, F. A. and S. R. Hanna. Modeling Urban Air Pollution. Atmos. Environ., 7, 131-136 (1973).
3) Hanna, S. R. A Simple Dispersion Model for the Analysis of Chemically Reactive Pollutants. Atmos. Environ., 7, 803-817 (1973).

Abstract: This is basically an area source model that can be applied to any size grid square. It can be used in conjunction with the Gaussian plume model, which is used to treat the largest point sources in the region. Chemical reactions and physical removal mechanisms can also be incorporated into the area source model.

Equations: For grid squares in which the local area sources emissions are much less than those in neighboring grid squares:

$$\chi = \sqrt{\frac{2}{\pi}}\,\frac{1}{U}\,\frac{(\Delta x/2)^{1-b}}{a(1-b)}\left\{Q_0 + \sum_{i=1}^{N} Q_i \left[(2i+1)^{1-b} - (2i-1)^{1-b}\right]\right\}$$

for area sources across which emissions are nearly uniform

$$\chi = C(Q/U)$$

where

$$C = \sqrt{\frac{2}{\pi}}\left(\frac{2N+1}{2}\,\Delta x\right)^{1-b}\frac{1}{a(1-b)}$$

If good data on χ, Q, and U are available, C can be estimated or "calibrated" with these data.

A. Source-receptor relationship
   Uniform grid squares defined by user.
   Receptors and area sources at ground level.
   Receptor at center of grid square.
   Point sources at any location.

B. Emission rate
   User-specified for each grid square or point source, emissions not time-varying over the period of interest.

C. Chemical composition
   Define the normalized concentration

$$\chi_i^* = \chi_i U/CQ_i \qquad (4)$$

   When chemical reactions are not important, then according to eq. (3), $\chi^* = 1.0$.
   Assume that $C = \Delta x/Z$, where Δx is the width of the region and Z is the height of vertical dispersion. For illustration, use the Friedlander-Seinfeld (1969) seven step photochemical kinetic mechanism. Then

$$[O_3] = \beta \frac{[NO2]}{[NO]} \qquad \beta \text{ a constant} \tag{5}$$

$$\frac{\partial}{\partial t^*} \ln [NO]^* = \frac{1}{[NO]^*} - 1 - [NO_2]^* [RH]^* \left(\alpha\, Q_{NO_2}\, Q_{RH} \frac{\Delta x^3}{U^3 Z^2}\right) \tag{6}$$

$$\frac{\partial}{\partial t^*} \ln [NO_2]^* = \frac{1}{[NO_2]^*} - 1 + [NO]^* [RH]^* \left(\alpha\, Q_{NO}\, Q_{RH} \frac{\Delta x^3}{U^3 Z^2}\right) - [NO_2]^* [RH]^* \left(\lambda\, Q_{NO_2}\, Q_{RH} \frac{\Delta x^3}{U^3 Z^2}\right) \tag{7}$$

$$\frac{\partial}{\partial t^*} \ln [RH]^* = \frac{1}{[RH]^*} - 1 - [NO_2]^* \left(\theta\, Q_{NO_2} \frac{\Delta x^2}{U^2 Z}\right) - ([NO_2]^*/[NO]^*) \left(\mu (Q_{NO_2}/Q_{NO}) \frac{\Delta x}{U}\right). \tag{8}$$

where $t^* = tU/\Delta x$ and α, λ, θ, and μ are rate constants. These equations can be rewritten, using the reference, for any kinetic mechanism.

D. Plume behavior
   Gaussian plume model with Briggs' plume rise for point sources.

E. Horizontal wind field
   User-supplied wind speed and direction over a 16 point wind rose.
   No variation of wind with height.
   Constant winds for each calculation.

F. Vertical wind speed
   Assumed equal to zero.

G. Horizontal dispersion
   Narrow plume approximation for area sources.
   Power law $\sigma_y = ax^b$ for point sources.

H. Vertical dispersion
   $\sigma_z = ax^b$ assumption used, with a and b from Smith (1968) or Briggs (1973).

I. Chemistry and Reaction Mechanism
Friedlander and Seinfeld (1969).
Any mechanism could be input, however.

J. Physical removal
$1/(1 + C(v_d/u))$ factor applied to concentration prediction, where v_d is the deposition speed.

K. Background
Use whatever is appropriate for the local background.

L. Boundary conditions
Lower boundary: perfect reflection unless wet or dry deposition is occurring.
Upper boundary: mixing height limited.

M. Emission rates and meteorological parameters are all input

N. Validation/Calibration
Extensive validation has been done in the references.

O. Output
Concentration over the appropriate averaging time at each receptor.
The chemical model has a time varying output, however.

I hope that these comments will aid in the preparation of your report.

Sincerely,

Steve Hanna

Steven R. Hanna
Research Meteorologist
Atmospheric Turbulence
and Diffusion Laboratory

SRH:mja

cc: D. B. Turner
Herschel Slater

3.9.2 *Recommended Changes in Draft Guidelines*

Submitted by Michael D. Williams

On page 6

I believe that the second highest of all estimated concentrations should be used. Thus on page 6 the relevant sentence would read:

"Thus, emission limits which are to be based on an averaging time of 24 hours or less shall be based on the second highest of all estimated concentrations (plus a background concentration which can reasonably be assumed to occur with that concentration; see section on background concentrations)."

This is consistent with the protocol between EPA and Salt River Project with respect to the measurement program for the Navajo Generating Station Sulfur Dioxide Field Monitoring Program.

I note that if the highest, second highest concept is to be used, then meteorological data equivalent to the life of the facility should be used rather than for a five-year period. It seems likely that the second highest at an individual point in a year will increase as the number of years tested.

Page 19

Under item (4), with respect to an area with meteorological or topographic complexities, I believe this item should read:

"(4) If the meteorological or topographic complexities of the region are such that the use of any available air quality model is precluded, then the model used for control strategy evaluation may be limited to a rollback model[30], if a dense monitoring network is in place and has been operating for at least two years. In this context a dense monitoring network would be one in which all points expected to receive high concentrations on the basis of models applicable to the terrain are well covered."

I believe this change is justified because a rollback model based on a limited sampling network which does not address the points of controversy is likely to be much worse than best estimates based on existing models.

Page 29

The last sentence in the first paragraph should read:

"The receptor grid must allow sufficient spatial detail and resolution so that the location of the maximum or highest, second highest concentration is identified for all areas."

The phrase "which are generally accessible to the public" could, under some interpretations, be limited to roadside areas. The mountain climber struggling with a difficult pitch probably needs clear air too. Furthermore, the intent of the standards is to protect more than just human life. Finally, the health of vegetation on a steep slope not generally accessible to the public may be very important for esthetic or soil holding purposes.

Page 30

After the second sentence in the second paragraph, insert the following sentences:

"In cases where the impact of elevated sources on high terrain during stable conditions is to be considered the relevant winds are those measured at expected plume height rather than ground level or near ground level. In cases where the frequency of A stability conditions is important, methods should be used to either make direct measurement of the frequency through the use of a bivane or adjust the frequency given by the Turner categorization scheme to provide a better estimate of the actual frequency."

During stable conditions the ground level inferences of stability, wind speed and wind direction are likely to be so poor as to make their use unacceptable. Table I reports all days of stable conditions (at plume height) reported in Schiermeier's "Large Power Plant Effluent Study (LAPPES) Volume III. Instrumentation, Procedures and Data Tabulations (1970)" January, 1972.

TABLE I

Date	Time	Height	Speed (mps)	Direction	Direction Difference 50 m - Sfc	Direction Difference 400 - 50 m
April 20	0708	Sfc	2.2	140.°	5.8°	--
		50 m	4.3	145.8	--	48.2°
		400 m	12.0	194.	--	--
April 22	0700	Sfc	0.0	--	--	--
		50 m	2.6	217.	--	63.
		400 m	12.1	280.	--	--
April 27	0635	Sfc	0.0	-	--	--
		50 m	70.5	3.4	--	150.
		400 m	220.	4.4	--	--
April 28	0800	Sfc	0.0	--	--	--
		50 m	1.1	124.	--	81.
		400 m	4.4	205.	--	--
April 30	0830	Sfc	0.0	--	--	--
		50 m	4.8	146.	--	32.
		400 m	5.6	178.	--	--
May 5	0700	Sfc	.8	215.	2.	--
		50 m	3.2	213.	--	39.
		400	7.0	252.	--	--
May 8	0800	Sfc	.8	195.	33.	--
		50 m	4.	228.	--	35.
		400	17.4	263.	--	--
May 9	0700	Sfc	.8	230.	3.	--
		50 m	3.6	233.	--	36.
		400 m	14.3	269.	--	--
May 11	0630	Sfc	0.0	--	--	--
		50 m	4.8	216.	--	39.
		400 m	7.5	255.	--	--
May 15	0830	Sfc	1.3	225.	-87.	--
		50 m	4.6	138.	--	27.
		400 m	9.5	165.	--	--
Oct. 14	0800	Sfc	0.0	--	--	--
		50 m	1.3	211.	--	-16.
		400 m	8.6	195.	--	--
Nov. 9	0900	Sfc	4.4	110.	20.	--
		50 m	4.7	130.	--	27.
		400 m	13.2	157.	--	--

Exhibit #1 also shows that surface winds tend to be poor predictors.

With respect to the second line work by Luna and Church "A Comparison of Turbulance Intensity and Stability Rates Measurements to Pasquall Stability Classes," Journal of Applied Meteorology, Volume 11, June, 1972; pp. 663-669, illustrates the large discrepancy between stability as indicated by fluctuations in the vertical component of the wind and by Turner stability categories.

Finally I have difficulties with both CRSTER and Valley. The principal defects in CRSTER are that fumigation is not considered and that reduced plume rise with a capping inversion is not considered. I note that a group (Dames and Moore) modeling for utilities in the Southwest has suggested that the plume rise may be restricted to 2/3 of its normal value. There is a case in the Lapse study in which the plume rise was about one-half of its expected values (May 4, 1970, near Homer City). I believe some changes could be incorporated into CRSTER which would permit better predictions in the case of limited mixing situations.

With respect to Valley, I believe a number of modifications are reasonable which would improve its prediction capabilities. These can be drawn from experience at the Navajo Plant plus aircraft measurements of stable flow dispersion in the Navajo region, Four Corners region and the TVA. For more distant travel I recommend that time of travel be considered. The principal elements of the model changes are described below.

Modifications to CRSTER

Schiermeir's LAPPES study carries a case where the mixing layer clearly inhibited plume rise. On May 4, 1970, ground level concentrations were consistently about 0.5 ppm at 3 km downwind between 10:30 and 10:45 (p. 80). Helicopter temperature profiles gave a strong inversion at 765 meters (p. 218); pilot balloons indicated an average wind speed between stack top and 750 meters of 2.2 to 2.5 m/sec (p. 244). Plant operational parameters (pp. 287-288) gave one unit at 2126 gm/sec, VS = 21.3, T = 149° C, DT = 137° C, while the other unit was at 2556 gm/sec, VS = 21.3, T = 158, DT = 106. With a stack height of 244 meters and stack radius of 3.65 meters, the expected stack height will be 1380-1535 meters. Under these circumstances CRSTER would give a zero concentration because the expected height would be greater than the height of the mixing layer. A B stability calculation using the actual height 765 meters would give x = 1376 ug/m^3 as opposed to a measured maximum of 1493 ug/m^3. The predicted maximum would occur at 4.5 km. On the other hand, an A stability calculation would give 3742 at 1.2 km. Thus, for A stability one would have to use an assumption that one-half of the plume penetrated the stable layer and was trapped. On this basis I suggest that

$$He = L \text{ if } L \geq Hs + .5\,\Delta hc$$

however, for A stability

$$(1) \quad Qe = \frac{Q}{2} + Q\,\frac{(L - Hs - .5\,\Delta h)}{\Delta hc}\,, \qquad Hs + .5\,\Delta hc \leq L \leq Hs + \Delta hc$$

Replacement for Valley

The results of the Navajo study indicated that the maximum 3-hour concentration could be represented by:

$$(2) \qquad \chi = \frac{Q\, e^{-\frac{1}{2}\left(\frac{H - H_c}{\sigma_z}\right)^2}}{2\pi u\, \sigma_y\, \sigma_z}$$

with the values considered as 10-minute averages and extrapolated to 3 hours via a technique:

$$\chi_T = \left(T/\tfrac{1}{6}\right)^{-.2} \chi_{10\ \text{minute}}\,; \quad T \text{ in hours}$$

Note that the equation for χ does not use plume reflection. The parameters σy and σz are Turner values for E stability. However, aircraft data in TVA, Four Corners and the Navajo area suggest that the distance dependence is incorrect. Instead a form:

$$\sigma_y\, \sigma_z \propto x^{-.75}$$

is suggested. Thus I recommend

$$\sigma y = 140.6\, x^{.55} \quad \sigma z = 68.0\, x^{.21}$$

σy, σz in meters
x in kilometers

Finally, I believe time of flight should be considered. Thus the model would calculate the concentration expected at the receptor at x and then examine the wind directions for the time x/u. If the wind direction were reasonably consistent during that time the calculated concentrations would be presumed to have occurred at the receptor. Otherwise, they would not. Work by Start, et al. in Utah suggests similar relations apply to unstable and neutral conditions.

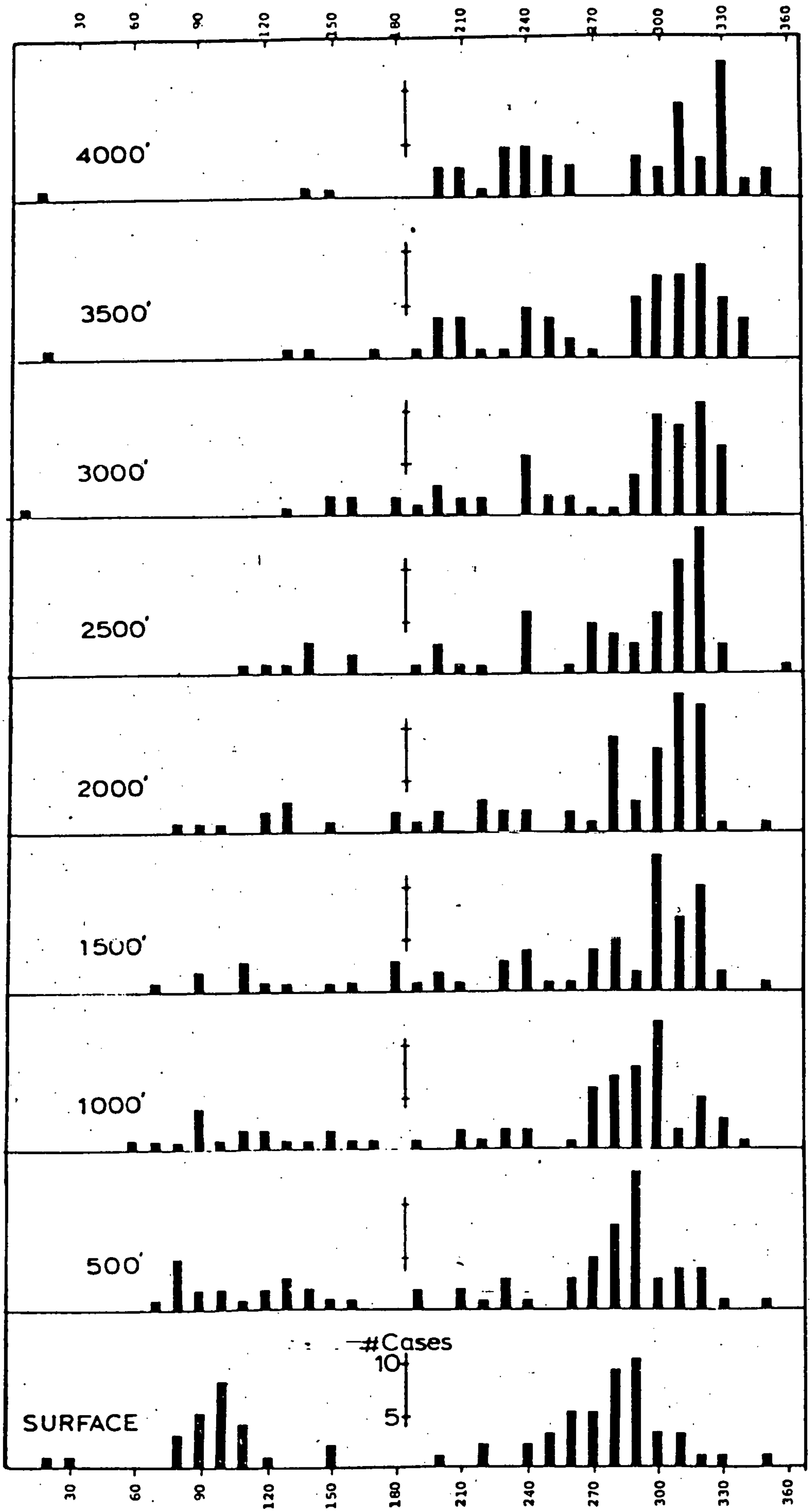

Figure 6. The arrays of direction by height for 70 pilot balloon runs from surface to 4000 feet above San Juan Plant Site, March 15-23, 1972.

3.9.3 Comments on the RAM Urban Model

Smith-Singer Meteorologists, Inc. DATE: February 4, 1977

TO: (MES) Model Study File (Maynard E. Smith)

FROM: JRM

RE: The RAM Urban Model

Howard Ellis made many points in his study of the RAM Model, a few of which deserve comment in regard to the Argonne Conference.

RAM is an urban model designed to calculate maximum 24-hour concentrations on a grid using a year's worth of data. It could be used for 1-hour and 3-hour predictions. Criticisms of it follow:

1. The model has not been validated. An extensive validation study must be done before the predicted results can be considered realistic.

2. σ_z values are excessively high for Pasquill A and B (they are equal for these two classes). The σ_z curve for Pasquill A and B is not as extreme as the CRSTER Model. However, the effect would be a doubling or tripling of the predicted maximum concentration compared to our modeling of tall stacks for 1-hour periods under very unstable <u>and</u> unstable conditions.

3. These σ_z values were developed from the St. Louis tests in the mid-60's, using low-level tracer releases and do not appear to be applicable to even low-level sources, let alone elevated sources. In brief, σ_z is considered inversely proportional to the crosswind integrated concentrations observed in these tests. Ellis documents several studies showing that the urban plume centerline is lifted by a mean upward wind component, leading to very low surface CIC and the resulting inflated σ_z values used in RAM.

4. What the proper urban σ_z values ought to be is uncertain. Ellis thinks they ought to be about 1.4 times the corresponding Pasquill-Gifford rural σ_z. I disagree with this conclusion for the σ_z corresponding to "A" stability. Those values are already far too high as was pointed out at Muskingum.

   Some evidence does exist to support a "1.4" factor for the other stability classes, though it is not conclusive. But there is no doubt that the RAM σ_z's corresponding to "A" and "B" stability are much too high.

   I have prepared some plots comparing Smith-Singer, Pasquill-Gifford and RAM σ curves. All systems agree rather well on σ_y values.

5. The EPA assumption of constant full load operation of sources in urban areas is absurd.

JRM:rg

3.9.4 Comments Regarding EPA Models

ENVIROPLAN, INC.
An Environmental Planning Company
47 ORIENT WAY, RUTHERFORD, N. J. 07070
201 935-5098

February 16, 1977

Mr. Maynard E. Smith
Smith-Singer Meterologists, Inc.
134 Broadway
Amityville, New York 11701

Dear Maynard:

Concerning your 1/29/77 letter, I would like to stress the following points concerning the E.P.A. Models now in use.

1. RAM Model (Urban Version). This model was used for the first time in E.P.A. regulation setting in Ohio and has seven serious problems. The enclosed evaluation adequately describes our concerns as well as recommendations for a Revised RAM Model for urban areas. I and many of the electric utilities in Ohio with plants in urban areas will be very grateful if you would read the enclosed critical evaluation, perhaps discuss it with me prior to the meeting, and then forcefully present the criticisms you concur with at the 2/22 meeting. Perhaps the most serious problem with Urban RAM is the use of vertical dispersion rates that are greatly in excess of Pasquill-Gifford vertical dispersion rates and that lead to predicted maximum short-term concentrations from power plants that are two to four times previous predictions using Pasquill-Gifford dispersion rates. I consider the use of Urban RAM as presently constituted to be the single most serious problem with present E.P.A. models for urban areas.

2. Use of Pasquill Stability Class A as the Most Extreme Vertical Dispersion Rate. My concerns with this issue and the necessity of using a less extreme vertical dispersion rate under the most unstable meteorological conditions are presented in the appendix to the Muskingum River Plant report prepared by Enviroplan in late 1976. Your office has a copy of this report.

3. Prediction Modeling in Complex Terrain. Two issues are of special importance here: 1) the assumed point of closest approach of the plume centerline to ground-level as the terrain rises, and 2) the enhancement of the turbulence and dispersion as the plume approaches elevated terrain. The Egan approach to issue 1) of reducing the effective stack height by half the

Mr. Maynard E. Smith
February 16, 1977
Page 2

increase in ground elevation seems more reasonable than using the E.P.A. CRSTER Model's full ground displacement procedure of subtracting the entire difference in ground elevation between receptor and stack base from the effective stack height. Progress on this issue and issue 2) would be helpful in eliminating some of the very major conservatisms in E.P.A. prediction modeling with CRSTER.

4. <u>Proposed Use of Five Years of Meteorology in the Prediction Modeling</u>. If E.P.A. adopts this procedure of using five individual years of meteorology in modeling, it is important some measure of actual operating rates rather than constant maximum possible operating rates be used. One excuse for using constant maximum operating rates is that only a single year of meteorology is being used for analysis. If the number of years of meteorology increases, some adjustment in the assumption on operating rates is needed to produce reasonable predicted concentrations.

Finally, I would certainly welcome any future opportunities there may be to participate directly in future meetings of this type.

Sincerely,

ENVIROPLAN, INC.

Dr. Howard M. Ellis
President

HME/pl
Enc.

3.9.5 Descriptions of C.E.G.B. Air Quality Models

Central Electricity Research Laboratories

Description of C.E.G.B. Air Quality Models

References   Papers by Moore D.J. listed in EPA-600/4-76 030a, also:

Scriven, R.A. and Fisher B.E.A. and Fisher B.E.A. 1975 Atms Env. 9 49 and 59 and 1063.

Fisher B.E.A. and Maul P.R. and Moore D.J. 1976 Proceedings of Symposium 'Systems and Models in Air and water Pollution' Institute of Measurement and Control, London.

Moore, D.J. 1975 Proc. Inst. Mech Eng. 189, 33. and 1976 Atmospheric Pollution 51-30 Ed. M. Benarie, Elsvier.

Abstract

The C.E.G.B. models include

(i) Gaussian models for predicting maximum g.l.c.s. from single sources, the vertical spread being related to an average vertical diffusivity, conservation of emitted material assumed.

(ii) Diffusivity profile models for calculating medium and long range effects including wet and dry deposition and chemical reactions.

Gaussian Model

A. Source-Receptor Relationship

Point source only, twin stacks assumed separate for plume height calculation single source for g.l.c. calculation. Multi-flue stacks as single sources. Receptor measuring points usually at 2 m above surface.

B. Emission Rate

Take from station load and fuel data.

C. Plume Behaviour

Plume rise calculated form C.E.G.B. plume rise equations. Growth due to relative motion taken into account in calculating location of maximum g.l.c. but not its magnitude.

D. Horizontal Wind Field

Wind speed and direction measurements made to about 2 stack heights on adjacent tall towers. Value of B based on measurements of crosswind spread and fluctuations in measured wind direction.

E. Vertical Dispersion $\sigma_z^2 = LX$.

L is a function of:

Height of source and/or height of mixing layer	(H,h) (m)
Free stream wind speed	(U) (ms^{-1})
Lapse rate above stack top	($\partial\theta/\partial z$) ($Km^{-1}$)
Sensible heat flux due to (i) solar heating of ground.	(E_o) (Wm^{-2})
or (ii) advection effects or cooling of cloud-tops	(E_1) (Wm^{-2})
Surface roughness length	(Z_o) (m)
Coriolis parameter	(f) (s^{-1})

Assumed independent of sampling the T for T > 3 min.

F. Lateral Dispersion $\sigma_y^2 = LX + B^2 X^2$.

B is a function of free stream wind speed and sampling time T(s) (for given source location and wind direction).

G. Emission and Meteorological Correlations

The calculations give ensemble mean values of maximum g.l.c. under a restricted range of meteorological conditions and emission rates when plume material remains within the mixing layer. Vertical wind effects and interaction with the top of the mixing layer cause variations about the ensemble mean and lead to a scatter with values falling within a range 0 to 2 times the ensemble mean value.

Terrain effects are not included as the sites studied are mostly flat.

Calculations refer to SO_2 but could be applied to any other conservative emission with negligible fall velocity.

Background is estimated from observations. The model may be used to make estimates of concentration out to about 3 times the distance of maximum g.l.c.

Sampling periods from 3 minutes to 1 year.

H. Validation/Calibration

Comparison with 3000 hours of observations at 2 power stations. r.m.s. residuals $\sim$ 12 per cent for ensemble means of grouped data (27 principal meteorological categories.)

I. Output

Maximum g.l.c., distance of maximum, for specified sampling period. Can give spatial distribution if required.

K-Profile Model

A. Source-Receptor Network

Individual large sources treated as point sources as in a gaussian model. Lower level emissions averaged over 10 km squares.

Long range model All emissions estimated over 127 km squares.

Chemical Composition - Normally SO_2.

B. Horizontal Wind Field

Average wind direction calculated using available meteorological data (wind or pressure field).

C. Vertical Wind Speed - None.

D. Vertical Dispersion

K profile, K proportional to height in layer of depth Z_1, constant from Z, to h, zero above h. Constant value of h consistent with values of L in gaussian model ($K_1 = \frac{UL}{2}$ where L and K are both independent of z).

E. Crosswind Dispersion

Based on gaussian model for hourly average and wind rose or distribution of wind trajectories for annual average.

F. Surface Deposition

Use is made of effective deposition velocity ($\bar{V}_g$) at the top of the surface layer, which is accurate for long range transport.

$$\bar{V}_g = \frac{V_g}{\left(1 + \frac{V_g Z_1}{K_1} \ln Z_1/Z_o\right)}$$

For near and middle distance transport exact K model uses V_g at ground.

G. Removal by Precipitation

Can be included by suitable decay constant for hourly or daily average. Precipitation included statistically with constant expected duration of dry and wet periods for annual average.

H. Chemical reactions

Conversion of SO_2 to SO_4 included.

Background: Man-made contribution may be calculated if source inventory available.

I. Validation/Calibration

Flux of SO_2 leaving U.K. compared with aircraft measurements of vertical profiles for middle distance transport.

Dry and wet deposition of S over W. Europe compared with OECD network. Observations of concentrations of SO_2 and SO_4 at distances up to 80 km from groups of power stations compared with aircraft cross-sections.

G.l.c. of SO_2 and SO_4 at distances up to 150 km from urban complex.

J. Output

Variable to suit requirement - e.g. surface deposition pattern, g.l.c. pattern, SO_2 flux.

3.9.6 *Description of the Air Quality Short Term Model*

Reference: "Air Quality Short Term Model," Illinois Environmental Protection Agency, Springfield, Illinois, January 1976.

Abstract: The Air Quality Short Term Model (AQSTM) is a steady state Gaussian plume model for estimating concentrations of relatively stable pollutants for averaging times from an hour to a day from multiple point sources in level or complex terrain. Concentrations can be computed to simulate inversion break-up fumigation, lake shore fumigation, and atmospheric trapping.

Equations:

1) Contribution from each upwind point source

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z U} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

2) Trapping

$$\chi = \frac{Q}{\sqrt{2\pi}\, \sigma_y L u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

3) Fumigation

$$\chi = \frac{Q}{\sqrt{2\pi}\, U \sigma_{yf} h_i} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yf}}\right)^2\right]$$

where: h_i: $H + 2\sigma_z$
σ_{yf}: $\sigma_y + H/8$

4) Continuous Lake Shore Fumigation

a) $$\bar{\chi} = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

b) $$\chi = \frac{Q}{\sqrt{2\pi}\, \sigma_{yf} u L} \left[\int_{-\infty}^{P} \sqrt{2\pi} \exp\left(-\frac{p^2}{2}\right) dp\right] \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yf}}\right)^2\right]$$

where: $P = \frac{L-H}{\sigma_z}$; $\sigma_{yf} = \sigma_y + H/8$

c) $$\chi = \frac{Q}{\sqrt{2\pi}\, \sigma_{yu} L u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yu}}\right)^2\right]$$

where: $\sigma_{yu} = \sigma_y$ corresponding to distance from virtual point so[urce] which yields σ_{yf} at X_2.

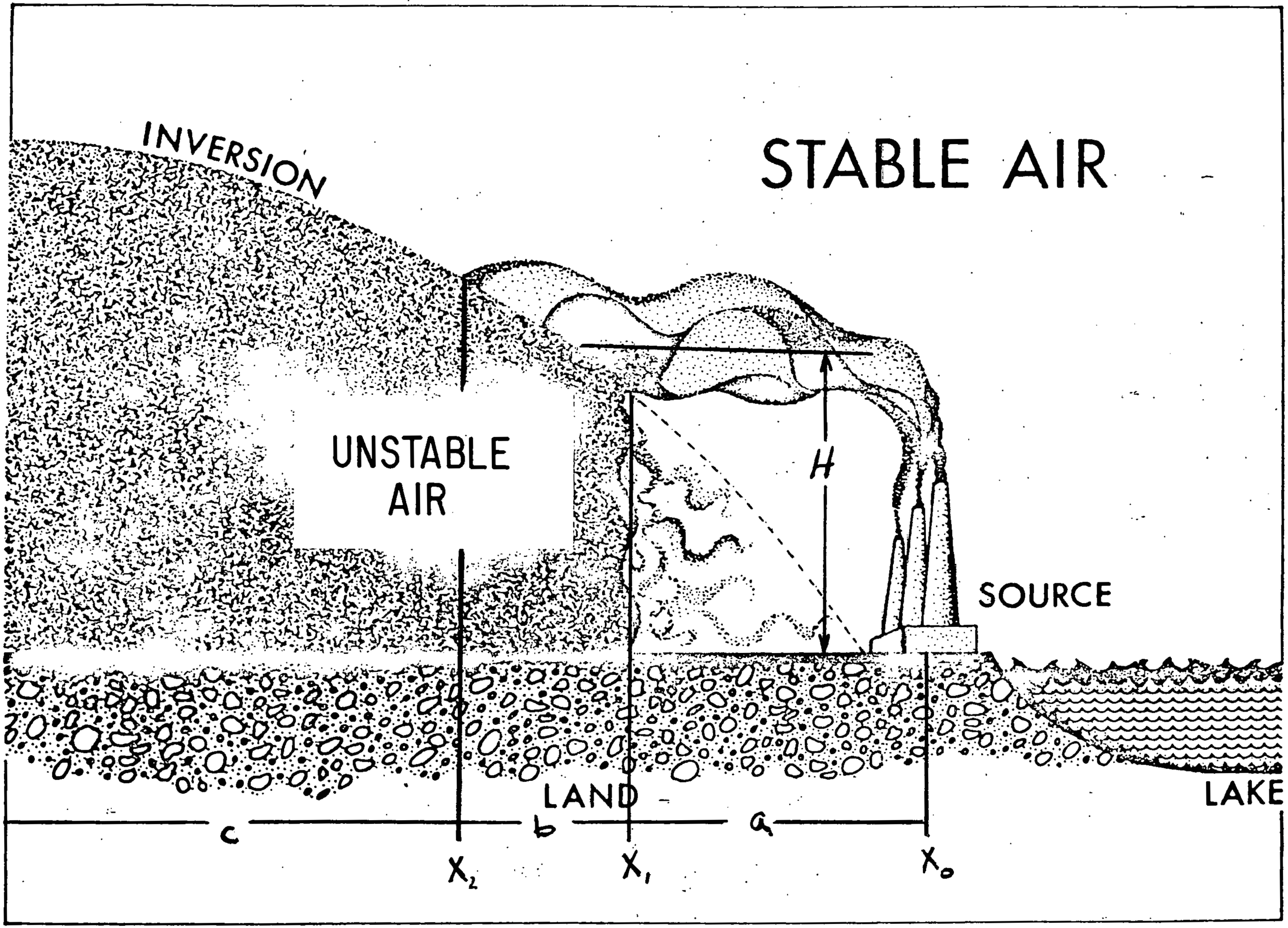

Figure 2. Lake Shore Fumigation.

A. <u>Source - Receptor Relationship</u>

Arbitrary location for a maximum of 200 point sources
Up to 900 receptors located on uniform rectangular grid
Unique release height for each point source
Unique separation for each source-receptor pair
Unique topographic elevation for each receptor and source
Receptors must be at ground level

B. <u>Emission Rate</u>

Unique constant emission rate for each source

C. <u>Chemical Composition</u>

Treats one or two pollutants simultaneously

D. <u>Plume Behavior</u>

Briggs (1971, 1972) final plume rise formulae
Does not treat downwash. If plume height exceeds mixing height, maximum plume height is limited to the mixing height. Treats fumigation by: (a) user specifying specific height of limiting lid and averaging time, or (b) user specifying <u>rate of rise</u> of inversion breakup (mixing height) and starti height.

E. <u>Horizontal Wind Field</u>

User specifies hourly wind speed and direction
Wind speed corrected for release height based on power law variation.
Constant, uniform (steady-state) wind assumed. In complex terrain, plume allowed to rise ½ the distance between the base of the stack and the height of a ground-based receptor. Plume assumed to remain at constant height abov ground following initial rise.

F. <u>Vertical Wind Speed</u>

Assumed equal to zero

G. <u>Horizontal Dispersion</u>

Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness or travel time.
User-supplied hourly stability class
Averaging time adjustment according to Turner (1969)(to one hour).

H. <u>Vertical Dispersion</u>

Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness, averaging time or travel time
User-supplied hourly stability class

I. <u>Chemistry/Reaction Mechanism</u>

Not treated

J. Physical Removal

Not treated

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: user-input mixing height used; perfect reflection assumed
Permits user to input continuous non-horizontal boundary layer or rising boundary layer.

M. Emission and Meteorological Correlations

N/A

N. Validation/Calibration

No calibration option provided
Direct application of Turner (1969) procedures

O. Output

Average concentration, source contributions at each receptor for total period of interest
Individual point culpability list for 5 maximum receptors

P. Computer Time Requirements

14 sources with 800 receptors requires 8 seconds CPU time (IBM 370/168)

3.9.7 *Application of Air Quality Models Under the Ontario Environmental Protection Act*

Submitted by A. E. Boyer: post-conference.

The design of pollution control equipment and the administration of environmental protection legislation are both complicated by the wide variability of air quality resulting from the interaction of pollution source characteristics and limiting meteorological variables.

From the point of view of source design, it is often desirable to design facilities to operate under whatever range of meteorological and operating conditions are likely to occur during the life of the source. An evaluation of limiting meteorological conditions, however, often shows that these limiting conditions occur a small fraction of this time; to design facilities to operate under all conditions, including these infrequent happenings, may result in greatly increased design costs.

The development of environmental legislation requires resolution of the need for laws which are easily understood and enforced and at the same time, cover a wide range of complex possibilities. These two ends are not easily resolved.

The development of several air quality simulation models provides tools for the analysis of the interaction of important source and meteorological conditions. The problem then is how to apply these models within the legal and engineering limitations noted above.

The Ontario Environmental Protection Act provides the framework for agencies and pollution sources to function within a simply enforced law based on a point source model. This Act also allows for redefinition of these simple controls in the event subsequent ambient air quality does not meet desired goals.

An example of the application of both simple point source and complex urban air quality simulation models within Ontario legislation is illustrated by Boyer and Shenfeld in, "Atmospheric Impact of Coal Firing", Power Magazine, March 1975. The question of converting an urban power generating station to an all coal-fired operation is examined. In this example, the Ontario Ministry of the Environment applied a multi-source urban model to the question of air quality impact under the assumption of the interruption of natural gas consumption by industrial and commercial users, limiting meteorological conditions and conversion of a large power generating station to an all coal-fired operation.

The conclusions of the above study are less important here than the methodology and the division of responsibility between the individual sources and the control agency, in this case, the Ontario Ministry of the Environment.

Each of the sources contributing to the SO_2 levels under study had previously been required to meet short-term (30-minute) air quality criteria for various pollutants. Compliance with this regulation can be satisfied by estimates of impingement concentrations based on a simple point source model. Certain frequently occurring meteorological conditions are specified for the basis of this estimate.

The responsibility of the control agency is then to estimate the combined effects of multiple sources under a wide spectrum of weather and operating conditions. This is accomplished in a variety of ways, including the application of urban air quality simulation models. [1,2]

If after application of the urban model, the control agency decides that the combined effect of multiple sources all meeting the regulation for a single source is unacceptable, then the single source limits may be changed by the issuance of new guidelines for the application of single source models. Other options may be included in the amended guidelines as, for example, the use of supplementary control systems.

Working within this framework, each source is assured that so long as ambient air quality objectives are met, the single source requirements with which they are forced to comply, will not be made more stringent.

The advantage of the guideline described above is that it allows for enforcement based on a simple straightforward point source model, while at the same time, allowing for a more detailed assessment of complex multi-source model applications by the control agency. In addition, while the various evaluations are in progress, it is in the interest of both the agency and the various sources that ambient air quality goals are met.

The procedure suggested above is similar to the use of emissions offset regulations used by the Environmental Protection Agency. They are different in that the Ontario guidelines make allowances for not only emission offsets to achieve desired air quality, but also variations in stack design, emission temperature and velocity, and in some cases, may include options for supplemental controls under limiting meteorological conditions.

1. Boyer, A.E. and Shenfeld, L. "Atmospheric Impact of Coal Firing", Power, March 1975.

2. P.S. Wong, K. Heidorn and D. Yap, "Modeling Sulphur Dioxide Levels in the Sarnia Area", Water, Air and Soil Pollution (1976) 407-414.

3.9.8 *Comments Regarding CRSTER*

Smith-Singer Meteorologists, Inc.

134 BROADWAY, AMITYVILLE, N. Y. 11701 TEL: 516-691-3395

March 21, 1977

Dr. John J. Roberts
Deputy Division Director
Energy and Environmental Systems
Argonne National Laboratory
9700 South Cass Avenue
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Dear Dr. Roberts:

Your letter of March 4 about the Specialist Conference on the EPA Modeling Guideline suggested that individual letters be submitted for the Appendix where participants have comments which are pertinent to the sessions, but were not actually a part of proceedings.

In Session II-4 the randomizer system used in the CRSTER model was discussed, and the working group decided that the method should be studied to see whether wind direction variability is adequately represented. This letter is a partial response to that suggestion.

The CRSTER model provides for a random adjustment to the wind directions which are typically reported only in 10^{o} intervals by the National Weather Service. This procedure is supposed to simulate the real wind fluctuation from hour to hour.

The effect of the system on calculated ground-level concentrations has been evaluated. Table 1 shows the concentrations directly downwind of the three-hourly mean wind under three conditions; (a) with no direction fluctuation, (b) with a $\pm 1^{o}$ shift, and (c) with a $+4^{o}$, -5^{o} shift. The latter is the maximum variability possible in the existing CRSTER system. Only with the maximum fluctuation is the mean ground-level concentrations reduced appreciably.

Most modeling systems based on real data use a method sumulating a more rapid lateral plume diffusion than allowed by CRSTER. TVA uses σ_y values which are larger than Pasquill-Gifford; both Smith-Singer and the state of Maryland use wind shear terms; Cramer assumes more rapid diffusion while the plume is rising after release.

Smith-Singer Meteorologists, Inc.

Dr. John J. Roberts

March 21, 1977

Two studies are suggested to EPA to define a better randomizer system:

1. Study real hourly mean wind direction fluctuations to determine the typical fluctuations over 3-hourly and 24-hourly periods.

2. Examine the σ_y values implied by the TVA, Maryland and Smith-Singer systems. These data should show how the randomizer might be improved.

Sincerely yours,

Maynard E. Smith
Mark L. Kramer
John R. Martin

MES:la
Enclosure

EFFECT OF WIND DIRECTION RANDOMIZATION ON GROUND-LEVEL CONCENTRATIONS

(Hypothetical 300-meter stack)

Wind Speed (m/sec)	Stability	Distance (km)	Three-Hour Concentrations Along 180° Radial (ug/m^3): Fixed Direction	Minimum Variation	Maximum Variation
6	Unstable	2	97	96	84
		5	769	761	649
		10	453	448	371
		15	261	258	209
6	Neutral	5	3	3	1.5
		10	264	212	116
		15	535	497	219

Wind Categories:	1st Hour	2nd Hour	3rd Hour
Fixed Direction	360°	360°	360°
Minimum Variation	360°	359°	001°
Maximim Variation	360°	355°	004°

3.9.9 *Comments On the Need for Model Accuracy*

Post Conference Contribution by J. L. Shapiro

In several different parts of the report, references are made to the required accuracy for uniformity of validity of models. For example, the Preface refers to an implicit "level of accuracy desirable." In Section 2.5.4 "the group generally agreed this assumption is not uniformly valid." There are other references to this subject, both explicit and implicit.

While some attention was directed to this by Group II-5, with an indication that performance standards of models should be related to the "loftiness of performance goals," the overall tenor of the report does not adequately reflect this view. It appears that the validity of models as evaluated by the workshop participants is readily destroyed by citing instances where the models' predictions were exceeded. In general, the group is relatively satisfied with models that over-predict as compared to models that under-predict.

This traditional approach obviously is necessary in many applications but it is also obviously highly over-restrictive in some cases, particularly where PSD limits are on the border line of significance. In such cases, models should be adopted which are the best available and which most closely represent an "expected value" with the recognition that some cases will over-predict while others will under-predict. As experience is gained and we learn more about the details, we would expect that such models will be refined to reduce the magnitude of the errors.

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3.10 POLICY ISSUE SUPPLEMENTARY MATERIALS

3.10.1 On the Use of Statistical Techniques for the Prediction of Second High 24 Hour Concentrations

Post Conference Contribution

Richard A. Porter, P.E.

Air pollution standards styled as levels "not to be exceeded more than one time per year" require a probalistic approach in modeling. However, models that are currently available (listed in the draft guideline) are not suitable for determining the second high value. Only the RAM model is available with a statistical post processor, but the RAM model contains no method for testing the model-generated data for goodness of fit to the proposed log-normal distribution. Predictions of values at the extreme end of the probability distribution function are very sensititive to the fit of the data to the proposed distribution. Order of magnitude errors may be encountered when the data is forced to fit the wrong distribution.

Many investigators have examined the frequency distribution of air pollution concentrations at air pollution monitoring facilities. A wide range of skewed frequency distributions have been fitted to the empirical data. The distributions proposed include Weibull (Barlow, 1971; Milokai, 1972) and negative-binomial distributions (Prinz and Stratman, 1966); but by far the most extensively fitted distributions are log-normal (Bencala, and Seinfeld, 1976; Knox and Pollack, 1974; Shoji and Tsukatani, 1973) in the multiple source urban environment and exponential (Gifford, 1959; Scriven, 1965; Gartreli, 1966) in an environment dominated by a single source. In the case of the urban environment the work of R. I. Larsen (Larsen, 1970; 1971) based on analysis of seven years of continuous monitoring data from USEPA monitors in urban areas is the most widely cited investigation of the log-normality of air pollution concentration. Studies by P. J. Barry (Barry, 1971; 1975) support the theory that receptors,dominated by a single source,record concentrations of pollutant that are exponentially distributed. The work by Barry is based on several years of data using ARGON-41 injected in the plume of a power plant. (Porter and Christiansen, 1976).

In the paper "Predictions of Annual Sulfur Dioxide Concentrations for Frankfurt An Main, Federal Republic of Germany, Aug., 1971 to July 1972 (Porter and Christiansen, 1976), a frequency distribution of concentrations was generated using the Texas Episodic Model for 242 receptor points in the Frankfurt area. Two methods were used to estimate the parameters of the log-normal distribution: 1) the graphical method of Larsen (Larsen, 1971), essentially the concept used in RAM; 2) the Delta- Log-normal distribution (Atchison and Brown, 1957), a three parameter log-normal distribution that accepts zero variates. Tests for log-normality using the Kolmogorov-Smirnov Statistic (Lillienfors, H. W., 1967) failed at 73 of the 242 receptors for one or both of the methods used to estimate the log-normal parameters.

All but two of the receptors that failed the test for log-normality were located on the edge of the urban area. Both theory and observed data suggest that the frequency distribution of concentrations at a receptor due to a single point source is exponential (Gifford, 1959; Barry, 1975). In theory, a receptor located in the center of a uniform area source will have a log-normal distribution of concentrations (Bencala, and Seinfeld, 1976). One can expect that receptors that are located in urban areas (away from the influence of a strong single source) will have log-normal distributions, and receptors that are influenced by a single source will have exponential distributions. However, the frequency distributions of concentrations at receptors that do not fit in one of the above categories are probably a mixture of the two distributions. The experience with the Frankfurt study cited above indicated that unreasonably large values for the second high concentration were predicted for non-urban receptors that had low predicted mean concentration. These receptors failed the test for log-normality. It is suggested that any model that uses statistically processed data to estimate concentrations should include a test of the data for goodness of fit to the proposed distribution.

Alternative Methods

The alternative to the statistical approach is to use the "worst case" estimate for the concentrations. The RAM model can be used to survey a specified period of meteorological record to determine the worst case condition in terms of predicted concentration. Or a short term model (such as the Texas Episodic Model) can be exercised on selected scenarios of meteorology that can be expected to result in the highest concentrations for the sources involved.

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3.10.2 *Methods for Estimating Levels Not to Be Exceeded or Not to Be Exceeded More Than Once Per Year*

Distributed at Conference

Richard A. Porter

The sound scientific approach to estimating compliance with standards styled "not to be exceeded more than *xxx* times per *xxx*" is a probabilistic approach. However, none of the models that are now widely available contain the statistical post processor necessary to make such a probability statement.[1] Therefore, some method must be stated for estimating compliance with such short-term standards without having the necessary statistical post processor. There are two possible methods: 1) survey of historic data; 2) estimation of worst case from meteorological and source considerations.

Survey of Historic Data

This is the method used by RAM. The question becomes: What period of record should be used? Using more than one year of data causes problems with computational time. Using only one year of data limits the number of meteorological conditions examined. Practical considerations can decree the period of record examined. Less than one year of data would be unacceptable.

Estimation of Worst Case

An experienced modeler can estimate the worst case conditions when only a few sources are being considered. Such an option is very economical and should be available as a tool for estimating worst case.

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[1]The paper *Predictions of Annual Sulfur Dioxide Concentrations for Frankfort Air Main Germany, Aug. 71 - July 72*. 7th Technical Meeting of the NATO/CCMS Committee. (Porter and Christiansen, 1976), discusses the problems associated with frequency distribution determination.

3.10.3 Position on Recently Proposed Amendments to the Clean Air Act

(Draft, prepared by the Committee on the Meteorological Aspects of Air Pollution of the American Meteorological Society and not yet approved as of the date of the conference by the American Meteorological Society Council.)

Distributed at Conference

Bruce A. Egan

The 94th Congress considered, at length, proposals to the Clean Air Act of 1964, as revised in 1970. Many issues were discussed and presented to Congress and its committees in consideration of these amendments; a joint House-Senate conference bill was also prepared. Congress adjourned without passing any amendments. The Committee on the Meteorological Aspects of Air Pollution of the American Meteorological Society feels it necessary to establish certain issues of policy regarding the use of meteorological knowledge in air pollution studies. Inasmuch as these policy issues were addressed in the Clean Air Act Amendments, we feel it is important to comment on areas where meteorological expertise is required.

Existing legislation and Environmental Protection Agency regulations have established National Ambient Air Quality Standards (NAAQS) designed to protect the health and welfare of the general public by not allowing air pollution levels to exceed certain values for different averaging times. Under these regulations, the establishment or continuation of any source of air pollution is allowed if it can be shown that pollution from that facility will not add to the pollution burden by an amount which would cause an excess of the NAAQS. A second type of regulation adopted by the Environmental Protection Agency addresses the emission of pollution from new industrial and other sources. New Source Performance Standards (NSPS) require that a facility must restrict emissions of certain criterion pollutants per unit of production using Best Available Control Technology (BACT). Thus there are in existence two types of standards, one which addresses ambient air quality, and a second which requires that each new source be controlled so as to limit, within prescribed amounts, its pollution emissions to the atmosphere.

The Supreme Court of the United States has determined (Sierra Club vs. Ruckelshaus) that the Clean Air Act Amendments of 1970 empower the Environmental Protection Agency to issue a third type of regulation to prevent the significant deterioration of air quality and in particular to preserve existing clean air regions. Regulations were promulgated by the Environmental Protection Agency in 1974 which provide for the classification of areas within the U.S. according to allowable increments of deterioration. In Class I (pristine areas) no significant deterioration of air quality would be allowed. Class II areas would allow very little deterioration and Class III regions would allow air quality to deteriorate to the NAAQS.

A number of methods or 'models' have been used historically by federal, state, and local agencies, by industrial sources and others for calculating the ambient air quality resulting from various configurations of air pollution sources. Mathematical models, when used responsibly with good meteorological data, have proven invaluable in analyzing the effects of new construction on ambient air quality.

This committee is particularly concerned that language in certain of the versions of the Clean Air Amendments proposed to the 94th Congress and in the Conference Report (House of Representatives Report No. 94-1742, September 30, 1976) included wording to the effect that a model or a group of models would be designated by the Administrator of the Environmental Protection Agency to evaluate the impact of new and existing sources of emissions on ambient air quality.

The term 'model', with respect to air quality considerations, has been taken to mean a relationship, analytical or empirical, which relates the ambient air quality as measured at a receptor to the emission of material from sources influencing that receptor. Such relationships can be established and have, in fact, been validated on many occasions, if meteorological conditions are adequately known. While there is much active research in progress to improve the current state-of-the-art of such models, the present models do not permit accurate predictions of ambient air quality when meteorological conditions are not known. Further, many meteorological phenomena which are responsible for threats to short averaging time standards are not amenable to simple mathematical treatment.

Our specific concern is with the concept that there should be currently established one particular model which will be capable of analyzing all conceivable situations. From a professional meteorological point of view, we feel this is not a tenable position to support. The scales of atmospheric motion which are responsible for dispersing pollutants vary from site to site and exhibit quite variable behavior. While meaningful averages can generally be calculated and established from data, there is no model currently available which has a proven reliability for a range of commonly encountered topographical and meteorological situations of importance. The diversity of meteorological, geographic, and site-specific conditions which exist is such that very careful choice of a model is important and attention must be given to whether a given modeling approach adequately handles the situation of concern. Models, after all, are simply an extension of professional opinion and abilities on the part of the model maker. To incautiously or casually apply a model to a specific situation without careful meteorological and other professional consideration is not appropriate for problems having significant economic and social implications. While it may be desirable from a legal point of view to adopt one uniform method for calculating air quality, it is a scientifically indefensible and unreasonable procedure, given the non-uniformity and complexity of the atmosphere, and the wide variability in meteorologically relevent geometric factors.

The above discussion has been implicitly considering the pollutants for which non-deterioration standards are presently being proposed, namely sulfur dioxide and particulates. When one considers the problems of modeling the transport and transformation of other pollutants of concern such as sulfates or oxidants which may involve atmospheric chemical reactions and other physical phenomena still not well understood (for example, dispersion of pollutants over long distances) then the arguments are even more compelling to not advocate the adoption of uniform modeling techniques. The state-of-the-art simply does not justify it.

The atmosphere is a large but finite resource. Used responsibly, it can provide a disposal mechanism for many of the pollutants of our modern society. Responsible use, however, includes continual consultation with professional meteorologists whose knowledge and experience will provide guidance on the best current methods for evaluating the effects of emissions on air quality, and who can provide even more reliable methods as our understanding of atmospheric phenomena increases.

3.10.4 *Consistency and Standardization*

Distributed at Conference

Bruce A. Egan

Considerable discussion at the conference centered on the issues of needs for consistency and standardization and the compromises inherent in adopting standardized models.

Standardization of approach was stated as a concept which would greatly relieve the work load presently within the various EPA regional offices and support facilities with respect to reviews of SIP revisions, New Source Reviews, PSD, etc. Standardization was also stated as an objective expressed to EPA by various industry groups who were concerned that different EPA regional offices had different approaches and this may result in variations in required emission limitations for what otherwise could be considered similar source situations. Therefore, differences resulted simply as a matter of location. A case where two regional offices disagreed on the methodologies for the same source affecting both regions was cited as indicative of the need for a consistent approach. It was stated that new sources needed to be assured that, after construction was started, the ground rules would not change so as to require still more stringent emission limitations. Section 318 of the September 30, 1976 House of Representatives Conference Report was cited as requiring that a modeling conference be held and that..."special attention shall be given to appropriate modeling necessary for carrying out subtitle C of Title I (relating to prevention of significant deterioration of air quality)."

Standardization of modeling approaches has the potential for creating other problems. The present state-of-the-art does not permit the identification of a single specific model which would be most appropriate for most sources. Site by site analyses which include room for professional judgment regarding choice of modeling techniques and meteorological parameters is generally required. They are especially appropriate for the analysis of siting and control alternatives of sources where large capital investments are involved. The problem with the use of a specific standard model is that if this model is non-conservative (that is, it is considered to be appropriate for a "most probable" concentration estimate) it can be expected to err sometimes by overpredicting and sometimes by underpredicting. Over predictions would suggest emission limitations which are beyond that called for in order to maintain ambient air quality standards and therefore not cost-effective; underpredictions would suggest emission limitations which would result in concentrations in excess of the standards — therefore not responsive to EPA regulations. Thus, a standardized approach if used to define emission limitations which would result in concentrations close to an air quality goal (NAAQS or PSD increments) has hidden costs associated with potential "overkill" and "underkill" on a site by site basis.

A second problem associated with standardization as discussed above is that it tends to discourage the advancement of our scientific understanding of air pollution phenomenon. A standardized approach would have resolved the debate of the two regional offices cited above but the resolution might not have satisfied either's concerns about the specific technical issues at hand. Science advances more responsively when technical differences are aired and a judgment passed on the basis of the technical arguments.

A solution proposed in these guidelines which meets the concerns outlined above is to move toward the adoption of standardized models for screening purposes. These models would be purposefully made to produce "conservative" estimates of ambient air quality levels. They would be used to identify and efficiently deal with "non-problems." If, for example, the conservative model indicated that a new source would not threaten air quality goals, a quick approval could be granted. If the model indicated a potential problem, then a refined modeling and analysis approach should be defined which would attempt to produce more realistic estimates of the actual impact. The required approach could involve the collection of more complete data, more applicable (site-specific) meteorological parameterization and model validation efforts. The guideline document can then provide guidance on the choice of generic models (basic model types) which are thought to be most appropriate for the various source types and for various combinations of source configuration, local meteorology, and local topography.

Discussion concluded in the topic of providing in the guideline document a strong statement regarding the rights of sources to choose alternative modeling approaches for the refined types of estimates. The predictions which result from the use of alternative models must be defensible in a scientific sense implying adherence to known physical principles and the presentation of model validation data. A corollary to this discussion was the recognition that if a new model were to prove superior to the screening model from an accuracy point of view (adjusting for the built-in conservatism of the screening model) then the new model might be a candidate for upgrading the standardized model at a future date. A conclusion was the recognition of the need to establish a very good data base in the public domain for purposes of evaluating alternative modeling approaches.

3.10.5 *Statistical Evaluation of Compliance*

Distributed at Conference

Noel de Nevers

In evaluating the modeling results to determine compliance with short-term AAQS (not to be exceeded more than once per year) or PSD (not to be exceeded), the test shall consist of computing the predicted concentration at the worst receptor point, for each applicable period (1 hr., 3 hr., or 24 hr. where applicable) for a period of not less than __ years and longer if data are available and using the most probable modeling techniques. The resulting computed values shall be fitted by a suitable cumulative frequency distribution function. The distribution shall be considered to demonstrate compliance if the cumulative distribution function indicates that the second high short term standard will not be exceeded twice in a calendar year, more than one year in each __ years, and that the PSD increments will not be exceeded more than once per __ years.

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*This version should be regarded as a draft version. The final form is incorporated in Section 2.2.5.

3.10.6 Statistical Evaluation of Compliance (Revised) *

Distributed at conference by Noel de Nevers

In evaluating the modeling results to determine compliance with short-term AAQS (not to be exceeded more than once per year) or PSD (not to be exceeded), the test shall consist of computing the predicted concentration at the worst receptor point, for each applicable period (1 hr., 3 hr. or 24 hr. where applicable) for a period of not less than 1 year and longer if data are available (but generally not more than 5 years) and using the most probable modeling techniques. The resulting computed values shall be fitted by a suitable cumulative frequency distribution function. The distribution shall be considered to demonstrate compliance if the cumulative distribution function indicates that the (second high) short term ambient air quality standard will not be exceeded twice in a calendar year, more than one year in each xx years, and that the PSD increments will not be exceeded more than once per y years.

(The above assumes we MUST use the same format (second high) as is used in the definition of the AAQS. We understand that the format was chosen to correspond to the realities of ambient air quality sampling. The realities of modeling are different. Thus for modeled compliance - we would prefer the appropriate section of the final sentence to read ". . . indicates that the short term ambient air quality standard will not be exceeded, on the average, more than once per calendar year, and that the PSD . . . .")

We have purposely left the x and y in the above paragraphs undefined. We believe that a thorough study of the consequences of possible choices of those values should be made before values are assigned.

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*This version should be regarded as a draft version. The final form is incorporated in Section 2.2.5.

3.10.7 Comment on Statistical Guide for Compliance Distributed at Conference

W. A. Perkins

It is common engineering practice to use statistically computed criteria for structural design to meet extreme meteorological conditions. Drainage as flood control improves and wind loads on structures are two examples. Appropriate meteorological parameters are treated by special statistical procedures to estimate conditions for specified return periods ranging from 10 to 100 years (10% to 1% of the distribution function). These estimates often exceed the period of record by a factor of two or more.

Meteorological conditions required for atmospheric transport models are very different from those used in the above examples. However, the concept of using a statistical approach to determine compliance is analogous to established practice.

3.10.8 *Validity of Hour-by-Hour Estimates of Air Quality (The Use of the Nowcast in Pollution Potential Forecasting)*

Distributed at Conference

A. E. Boyer

A practice developed in pollution potential forecasting has been to analyze current conditions so as to prepare a consistent picture of air quality and meteorological data in map format. This process is very similar to the meteorological exercise called "map analysis." In the case of the weather map, selected reports of pressure, temperature, wind, precipitation, and other variables are used to estimate the continuous initial distribution of air mass and frontal characteristics.

In the case of pollution potential forecasting, an exercise referred to as the "nowcast" consists of analyzing initial values of wind velocity and shear, continuous temperature gradients, stabilities, along with measured and simulated air quality values to estimate the continuous initial state of velocity and thermal structure of the atmosphere.

The nowcast is an attempt to use a limited amount of air quality and meteorological data in the vicinity of a pollution source to present a snapshot or analysis of the continuous distribution of air quality and meteorology in three dimensions. It is based on the concept that if one is given the height of an elephant at eye level, it is likely that one could estimate other dimensions of the elephant. In a similar fashion, given a limited number of meteorological, source, and air quality measurements, a skilled meteorologist using mathematical simulation models can fill in the gaps between the reporting points. This initial state analysis is then the basis of decisions for the need for environmental control in the coming hours. It is a corollary of meteorological predictions that no prediction can be more detailed or more accurate than the initial state analysis upon which it is based. It is for this reason that the concept of the nowcast or of the initial state analysis of air quality and meteorology is so important.

3.10.9 *A Comment Concerning the Use of Unverified Models as "Relative Predictions"*

Post-conference contribution submitted by Philip M. Roth

Oftentimes there is doubt as to the accuracy of a particular model as an "absolute predictor" due to shortcomings in its formulation. On occasion such models are used instead to estimate differences in concentration between a base case and a case of interest. Insofar as we can see, there is no evidence to support the hypothesis that a model whose absolute predictive capability is in doubt will, in general, perform more reliably when used as a relative predictor. Hence, those notes of caution raised concerning the use of models as absolute predictors, i.e., the need for model evaluation and verification for a variety of relevant conditions, should apply when these models are used as relative predictors as well.

3.10.10 Comments on Various Issues

Smith-Singer Meteorologists, Inc.

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March 25, 1977

Dr. John J. Roberts
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Dear Dr. Roberts:

This letter summarizes several ideas which we consider pertinent to the issues raised at the recent Specialist's Conference on the EPA Modeling Guidelines. We would like to have it included in the Appendix.

1. Screening Procedures

Over the past decade the effort required for the approval of any facility emitting pollutants has grown enormously. Much of this effort is good because it represents genuine concern about environmental problems, but some is totally unnecessary paperwork and computation. We strongly favor the use of screening techniques to simplify approval procedures.

As recommended by Working Group I-2, it should often be possible to reach a "yes-no" decision about a new facility from a limited set of calculated hourly mean concentrations. These should cover a wide range of hypothetical wind and stability conditions, but need not involve any site data. If none of these test calculations exceed a specified concentration level, the facility could be accepted without further study.

To apply such a system one should know how hourly values are related to 3-hourly and 24-hourly concentrations. The recent paper by Martin and Reeves* should be helpful to EPA in developing such a screening procedure. They show the following ratios apply for a typical group of power plants:

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* Martin, J. R. and Reeves, R. W., Relationships Among Observed Short-Term Maximum Sulfur Dioxide Concentrations Near Coal-Fired Power Plants, 1977 Annual APCA Meeting (in press).

$$\frac{\text{Maximum 3-Hour Concentration}}{\text{Maximum 1-Hour Concentration}} = 0.77$$

$$\frac{\text{Maximum 24-Hour Concentration}}{\text{Maximum 1-Hour Concentration}} = 0.28$$

$$\frac{\text{Maximum 24-Hour Concentration}}{\text{Maximum 3-Hour Concentration}} = 0.37$$

2. Air Quality Standards

Although we understand why EPA is reluctant to revise the established air quality standards, a number of the Conference participants favored a change in expressing the standards so that more reasonable and reliable statistics could be employed. Revising the air quality standards so that maximum values are not involved would be a great improvement for the following reasons:

a. The maximum or second maximum, whether computed or observed, is an inherently controversial quantity. One can always argue that the examination of a longer period of record or a more adverse set of assumptions would reveal a higher concentration than had been discovered to date.

b. A standard based on extreme values tends to involve spurious data. Improper recorder operation, computer errors or even one untenable assumption may suggest an apparent violation where none exists.

c. Protecting against an absolute maximum is not a realistic objective. All human activity involves risk and it is reasonable to balance the severity of the event against the probability of occurrence. Total elimination of risk is an unreasonable objective.

There is no technical reason why the short-term standards cannot be redefined so that the limiting values fall within the normal statistical population. Careful choice of new limiting values would still prevent the existing maximums from being exceeded very often, but it would eliminate the controversial "never" concept.

For example, one might specify in a new 3-hourly SO_2 standard that a concentration of 200 $\mu g/m^3$ should not be exceeded in more than 1% of the cases. Based on typical probability distributions this would insure that a 1,300 $\mu g/m^3$ level would seldom be exceeded.

3. Alternative Models or Algorithms

The participants emphasized the basic conflict between the need for more consistent regulatory treatment and the need to retain flexibility. In striving for consistency, EPA Guidelines should not stifle alternative approaches to solving air quality and emission problems. If they do, certain situations would be treated unreasonably, and both research and imaginative review would be discouraged.

On the other hand, capricious acceptance or rejection of alternatives at the state and regional levels could destroy regulatory consistency, a primary objective of the Guideline.

We recommend a review procedure for alternative algorithms in which the systems would be evaluated by the EPA technical staff in Raleigh. Once an alternative system has been approved, it would no longer be necessary to justify its use for each subsequent application in any region, other than to assure that the system is appropriate for a particular problem.

The term "equivalent" should not have the same stringent limitations as would be true of air quality measurements. Diffusion modeling is much less precise, and there is no certainty that a given EPA algorithm is significantly better than some other alternatives. The limits of acceptability should therefore be correspondingly broad.

4. Rollback

The initial reaction of most of the Conference participants was to reject rollback entirely as a modeling technique. It seems to us, however, that rollback still has a place in control strategy. It is appropriate when applied to a large group of very similar sources which cannot be modeled or controlled in any other way. Residential heating and automobiles are good examples of this type of source.

Rollback should not be used as a substitute for a more erudite analysis merely because the problem is complex, the modeling is difficult, or because it is time-consuming. Application in these circumstances is precisely what has given rollback a bad name.

5. Background Concentrations

The definition of background concentrations is still an unsettled problem. However, there are serious flaws in two methods which are frequently proposed.

a. For an isolated source, or closely-packed group of sources, the proposed background is the maximum concentration at a nearby air quality station determined when the source cannot affect it. This definition suffers from the same drawbacks as the maximum in an air quality standard. Instrument problems and very unusual meteorological circumstances may be responsible for this single value.

   It is erroneous and overly conservative to assume that this maximum background exists throughout the region and on all time scales. A significantly lower value should be selected.

b. The draft Guideline suggests an optional method to determine background when no monitors are near the source. This method consists of using as background an average monitored concentration from sites in similar topographic and climatological settings. The flaw in this technique is that the average monitored concentration at one location is influenced by its own local sources. It does not represent background even at the point of measurement. Transferring this concentration from one location and calling it the background at another site compounds errors.

6. Use of Measured Air Quality Data

Accurate air quality data, regardless of the agency responsible for measurement, must play a more important role in assessing compliance with standards and in model validation.

As mentioned earlier, the frequency distributions of air quality data are more valuable than isolated maximums. They provide a more complete picture of the impact of a pollutant on the area. Distribution curves will reflect the effect of emission changes more faithfully than maximum values, since they are much less sensitive to minor variations in meteorology or measurements.

Another important use for the data distributions is in the validation of diffusion models. Comparing the predicted and observed concentration distributions is more effective than relying upon matching the observed and predicted maximums, especially for short-time scales.

Sincerely yours,

Maynard E. Smith

Mark L. Kramer

John R. Martin

MES/MLK/JRM:rg

ERT

3.10.11 Comments on the Use of Proprietary Models and Some Examples

Post conference submission by B. Egan

ENVIRONMENTAL RESEARCH & TECHNOLOGY, INC.
CONCORD, MASS. • CHICAGO • LOS ANGELES • WASHINGTON, D.C.

REF: AQSD-1428

25 April 1977

Dr. John J. Roberts
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Dear Dr. Roberts:

I would like to offer some supplementary material relating to the issue of proprietary models and the inclusion of descriptions of models in the Report of the Specialists Conference on the EPA Modeling Guideline.

ERT feels that it will be very important for EPA to clearly articulate its position regarding its intended exclusion of proprietary models in the Modeling Guideline recommendations. In particular, a clarification should be made regarding whether the intent is to discourage the use of proprietary models by EPA regional offices or whether the intent is more generally to not accept the results of analyses performed by anyone on the basis of proprietary model computations.

As a consulting firm with business in the areas of model development and application, ERT is concerned about the implications of the latter possible intention. We feel strongly that, just as patents and copyrights protect investments in other commercial areas, establishing a proprietary status to models or algorithms which have commercial value, provides a means of encouraging and protecting private investments in the development of advanced modeling techniques. Our company, for example, over the years has invested well over one-half million dollars in internal development projects relating to model development. We believe that private investments have historically contributed substantially to advancing the state-of-the-art of modeling and we, therefore, wish to discourage EPA from "legislating away" incentives for further advancing our capabilities in the area of modeling air pollution impacts. In our opinion, proprietary status does not at all preclude the possibility that a model (including computer code) can be reviewed and tested in detail by concerned parties.

Having stated our feelings about the principles involved, as a matter of practice we recognize the potential benefits of having a number of our models more widely appreciated. We are, therefore, offering for inclusion in the Report of the Specialists Conference, the enclosed descriptions of models which ERT currently utilizes in air quality studies. We have summarized the main features of four of the models in accordance with the format Argonne used in the referenced document: Descriptions of Air Quality Models and Abstracts of Reference Materials.

696 VIRGINIA ROAD CONCORD, MASSACHUSETTS 01742 (617) 369-8910 TELEX: 923 335 ENVIRORES CNCM CABLE: ERTCON

Versions of each of the models have been considered non-proprietary by ERT in the past. If it becomes a prerequisite for inclusion in the modeling guideline, ERT would offer the current versions as non-proprietary also.

I would suggest that the ERTAQ description be included in the section on multiple-source, set 1 pollutants*; the ARTSIM and LAPS models be included in the section on set 2 pollutants+ and EGAMA be included in the Long Range Transport and Loss Mechanism (II-1).#

For more general interest we have enclosed a tabular description of computer models utilized by ERT for a variety of applications. An important point is the recognition that a number of important environmental assessment problems require special models which include detailed treatment of effluents as a function of unique source configurations or thermodynamics (e.g. cooling towers, gas turbines). Other applications, such as SCS (Supplementary Control Systems) feasibility studies, require specialized programs which utilize system operational input data and provide output information which includes considerations of a variety of engineering and operational constraints.

I hope these materials will be of use to you in the final report.

Sincerely yours,

Bruce A. Egan
Manager
Air Quality Studies Division

/mk

Enclosures

*Section 3.1.4

+Sections 3.3.4 and 3.3.5

#Section 3.4.1

TABULAR SUMMARY OF SOME KEY ERT, INC. AIR QUALITY MODELS

Model	Key Elements/Features	Typical Applications
ERTAQ	• Gaussian Plume in Vertical • Sector Crosswind Averaging • Climatological Wind Rose Input • Briggs Final Plume Rise • Turner (Pasquill/Gifford) σ_z • Point, Line and Area Sources • Climatological Mixing Depth	• Regional Studies • "Background" AQ • Seasonal/Annual Averages • Arbitrary Source-Receptor Geometry • Level Terrain Only • Low Level Sources • Transportation Links
PSDM	• Double Gaussian Plume (ASME coefficients) • One or Two Point Source Sites Only (≤ 10 stacks per source) • Sector Centerline Concentrations Only • "Weather Condition" Inputs	• Designed for stack height determination • Isolated Source DEC Feasibility Studies • Identifications of "Worst Case" Meteorology • Identification of Maximum Ground Level Concentrations
EGAMA	• High Resolution Numerical Simulation Model based on Conservation of Mass Equation • Eddy Diffusivity (K Theory) vs. Gaussian Dispersion • Time and Spatially Variable Meteorological Inputs Allowed • Requires independent determination of flow fields (Done internally for Highway Applications) • Forward time-step "Marching" Computation Routine	• Highway Impact Studies (Especially well suited for near roadway AQ estimates) • Special Studies: Downwash Street Canyon Terrain Effects Fumigation • Research Tool Long range transport Chemical Transformation Sea/Lake Breeze Flows
ATRAJBOX	• Air Trajectory Transport Model with well-mixed BOX approach • Linear Chemistry and Deposition processes • Tracks transport of air from its origin to receptor for a specified time	• Regional Transport of SO_2 and SO_4 • Ideal for predicting daily mean concentrations at a receptor for an episode

TABULAR SUMMARY OF SOME KEY ERT, INC. AIR QUALITY MODELS continued

Model	Key Elements/Features	Typical Applications
COOLTOWR	• Based on Convective Rise of Cumulus Cloud Formations • Moisture Parametrization, Phase Change and Plume Merger Considerations • Meteorological Data Inputs	• Cooling Tower Studies: Visible Plume Length, Icing and Fogging Potentials
DEPOT	• Drift Deposition Model which Includes Consideration of Plume Dynamics, Droplet size and Mass Distributions, evaporation effects on drop fall velocity	• Cooling Tower Salt Deposition Predictions
PSDM-2	• PSDM modified to incorporate fall velocity and ground deposition rate	• Particulate AQ studies
FUMIG	• Based on EGAMA and Boundary Laver Parameterization	• Time dependent inversion breakup fumigation • Sea Breeze Fumigation
SULFA3D	• Three-Dimensional Advective-Diffusive Grid Model • Linear Deposition and Transformation processes with first order Chemistry	• Long range regional transport • Regional Sulfate Predictions
MONITOR	• Dispersion Model inputs used to rank usefullness of alternative monitoring locations	• Optimal Monitoring Site Location
PROBL	• Dispersion Model inputs used to generate statistics for probability analysis of exceeding standards	• SCS Feasibility Studies

TABULAR SUMMARY OF SOME KEY ERT, INC. AIR QUALITY MODELS continued

Model	Key Elements/Features	Typical Applications
RATE BOX	• One-Dimensional Sector/Square Model with well-mixed BOX Approach for Point/Urban Area Sources • Finite-Difference Numerical Solution • Includes Washout and Rainout	• Point or Urban Scale Sulfate Predictions • Ideal for local SO_2, SO_4 and H_2SO_4
DIFDEP (Diffusion/Deposition)	• Same as Plume with TWO Tracer Equations for SO_2 and SO_4 • Linear Chemistry and Removal Processes	• Point Source Sulfate Problems • Acid Rain Predictions
CRSVAL	• Modification of EPA CRSTER Models for Complex Terrain • Incorporates some features of EPA-Valley Model • Gaussian Plume concentration profile with Multiple Images	• Estimates of hourly ground level concentrations due to large point source in areas of complex terrain • National and State Ambient Air Quality Standards Studies
DIFKIN	• Finite Difference solutions based on mass conservation Eqn. • Chemical kinetics and the upward spread through a series of vertical cells • Vertical diffusion coefficients	• Regional maximum oxident concentrations • "Background" O_3 concentration • Transportation strategy evaluation of O_3 concentration
ASTEC	• Gridded Area Sources • Gifford/Hanna Concept • Computationally Inexpensive	• Regional Model (Flat Terrain) • Multiple Area Sources (Homogeneous Emission Geometry)
PLUME	• Rising Plume Deflected by Crosswind • Morton, Turner and Taylor Local Similarity Hypothesis • Conservation Equations and Entrainment Coefficients • Meteorological Sounding Data Inputs	• Gas Turbine Plume Studies • Unconventional Stack Geometry or Effluent Characteristics • Final Plume Rise Predictions

3.11 Descriptions of Air Quality Models

This section is an exact reproduction of Sections 1 and 2 of the notebook entitled "Descriptions of Air Quality Models and Abstracts of Reference Materials" prepared by ANL staff and distributed to the participants prior to the conference. A supplement to that notebook was prepared and distributed at the conference. It has also been reproduced here.

Section 3 of the notebook, which has not been reproduced here, contained abstracts of the references cited in the draft Guideline.

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SECTION 1

GENERAL

Introduction

This section contains two outlines, the first listing the aspects of atmospheric dispersion which simulation models must treat and the second providing a list of features defining applications to which models are applied.

The first outline of model characteristics provides the framework for the model descriptions in Section 2. It also provides a common basis for comparing and evaluating models.

The second outline of features of model applications is intended to aid in the identification of specific features characterizing situations related to various issues to be addressed.

Model Characteristics

I. General considerations
   A. Method as implemented
   B. Basis for parameterization

II. Specific elements
   A. Emission characteristics
      1. Source-receptor relationship
         a. Downwind distance
         b. Orientation
         c. Release height-elevation
         d. Horizontal location
         e. Ground level vs. elevated
      2. Emission rate
         a. Spatial variation
         b. Temporal variation
      3. Chemical composition of emissions
   B. Transport characteristics
      1. Plume behavior
         a. Plume rise
         b. Fumigation - inversion breakup
         c. Downwash
         d. Looping
         e. Trapping
      2. Horizontal wind field
         a. Shear (variation in speed and direction)
         b. Periodic variations (seasonal, diurnal)
         c. Terrain effects (e.g., channeling)
         d. Persistence
      3. Vertical wind speed
         a. Terrain effects
         b. Lake breeze
      4. Horizontal dispersion
         a. Stability
         b. Surface roughness
         c. Averaging time as compared to transport time
      5. Vertical dispersion
         a. Stability
         b. Surface roughness
         c. Mixing height
         d. Elevated vs. ground level sources
   C. Removal and transformation
      1. Chemistry and reaction mechanism
         a. Secondary production
         b. Chemical removal
      2. Physical removal
         a. Dry deposition
         b. Precipitation scavenging
         c. Resuspension

- D. Background
  - 1. Long term
  - 2. Short term
  - 3. Directional dependence
- E. Initial conditions
- F. Boundary conditions
  - 1. Ground
  - 2. Mixing height
  - 3. Sides in complex terrain
- G. Correlations
  - 1. Emissions
  - 2. Meteorological parameters

III. Validation
- A. Sensitivity analysis
- B. Field studies

IV. Calibration - confidence limits

V. Requirements for implementation
- A. Resource requirements
  - 1. Personnel
  - 2. Monetary
  - 3. Computer
- B. Data requirements

VI. Output
- A. Averaging time
- B. Spatial resolution
- C. Source culpability list
- D. Frequency distribution
- E. Special output (e.g., amount deposited

Features of Model Applications

I. Pollutant characteristics
   A. Production
      1. Primary
      2. Secondary
      3. Resuspension
   B. Removal
      1. None
      2. Chemical
      3. Physical
   C. Chemical identity
      1. Single substance
      2. Mixture

II. Averaging time
   A. Long-term: (month, season, year)
   B. Short-term: 1-24 hrs. (1, 3, 8, 24)

III. Source characteristics
   A. Number
      1. Single
      2. Multiple
   B. Geometry
      1. Point
      2. Area
      3. Line
      4. Combination
   C. Release height
      1. Ground level
      2. Elevated
   D. Temporal
      1. Constant
      2. Time-varying

IV. Transport characteristics
   A. Geography
      1. Simple terrain
      2. Complex terrain (rough terrain, lake breeze)
      3. Urban
      4. Rural
   B. Range
      1. Short
      2. Meso
      3. Long
   C. Transport time

V. Output
   A. Mean
      1. Specific location
      2. Arbitrary locations or isopleths
   B. Frequency distribution
      1. Specific location
      2. Arbitrary locations or isopleths
   C. Maximum at specific receptor or overall maximum

VI. Activity
   A. Overall planning
   B. Source-specific review

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SECTION 2

DESCRIPTIONS OF MODELS

Introduction

This section provides brief descriptions of the models suggested for use in the guidelines. Rollback has not been included. A brief discussion of the limitations of rollback is provided in Reference 30 in Section 3. The format of each description follows the outline of model characteristics given in Section 1. The descriptions are in alphabetical order.

APRAC-1A

Reference: Nos. 34, and 35 in the guideline.

Ludwig, F.L. and R.L. Mancuso. "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program." Prepared for Division of Meteorology, Environmental Protection Agency, under Contract CAPA-3-68(1-69) (NTIS PB 213091), Research Triangle Park, North Carolina 27711, September 1972.

Ludwig, F.L. and W.F. Dabberdt. "Evaluation of the APRAC-1A Urban Diffusion Model for Carbon Monoxide." Prepared for Division of Meteorology, Environmental Protection Agency, under Contract CAPA-3-68 (1-69) (NTIS PB 210819), Research Triangle Park, North Carolina 27711, February 1972.

Abstract: APRAC is a model which computes hourly average carbon monoxide concentrations for any urban location. The model calculates contributions from dispersion on various scales: extraurban, mainly from sources upwind of the city of interest; introurban, from freeway, arterial, and feeder street sources; and local, from dispersion within a street canyon. APRAC requires an extensive traffic inventory for the city of interest.

Equations:

Extraurban - $\chi_e = \frac{5.15 \times 10^{-11} F}{uL}$; F = annual fuel consumption within 22.5° sector extending from 32 km to 1000 km upwind of receptor.

Intraurban - $\chi_{ij} = \frac{0.8 Q_i}{u a_{ij}} \left(\frac{x_{i+1}^{1-b_{ij}} - x_i^{1-b_{ij}}}{1-b_{ij}} \right)$ until this expression equals

the "box model value" $\frac{Q_i}{uL} (x_{i+1} - x_i)$

Thereafter the box model formula is used.

i = upwind area segment label

j = stability class label

a_{ij} and b_{ij} from $(\sigma_z)_{ij} = a_{ij} x^{b_{ij}}$ for x within segment i

Street Canyon - Lee side $\chi_L = \frac{KQs}{(u+0.5)\left[(x^2+z^2)^{1/2} + L_o\right]}$

Windward side $\chi_W = \frac{KQs(H-z)}{(u+0.5)WH}$

Intermediate wind direction (less than ±30° from street direction) $\chi_I = \frac{1}{2}(\chi_L + \chi_W)$

In which

x = horizontal distance from traffic lane

z = height above pavement

K = constant $\simeq 7$

L_0 = vehicle size $\simeq 2m$

u = rooftop wind speed

Q_s = CO emission rate / meter

W = street width

H = average building height $\simeq$ 38.8 meter

APRAC-1A

A. Source-Receptor Relationship

User specifies set of traffic links (line sources) by providing link endpoints, road type, daily traffic volume
The traffic links may have arbitrary length and orientation
Off-link traffic allocated to 2 mi x 2 mi grid
Link traffic emissions are aggregated into a receptor oriented area source array
The boundaries of the area sources actually treated are 1) arcs at radial distances from the receptor which increase in geometric progression, 2) the sides of a 22.5^o sector oriented upwind for distances greater than 1000 m, and 3) the sides of a 45^o sector oriented upwind for distances less than 1000 m.
A similar area source array is established for each receptor
Sources assumed at ground level
Up to 10 receptors
Receptors at ground level
Receptor locations are arbitrary
Four internally defined receptor locations on each user-designated street are used in a special street canyon sub-model

B. Emission Rate

Daily traffic volume for each link and off-link grid square is input and modified by various factors to produce hour-by-hour emissions from each link
Link emissions aggregated as described above: sector area source contributions obtained analytically
Off-link traffic emissions on 2 mi grid are added into sector area sources
In street canyon sub-model, a separate hourly emission rate is provided by user for the link in question

C. Plume Behavior

Does not treat plume rise
Does not treat fumigation or downwash except in street canyon sub-model
In street canyon sub-model, a helical circulation pattern is assumed

D. Horizontal Wind Field

Hourly wind speed and direction in tens of degrees is input
No variation of wind speed or direction with height
Constant, uniform (steady-state) wind assumed within each hour

E. Vertical Wind Speed

Assumed equal to zero except in street canyon sub-model
Helical circulation assumed by street canyon sub-model

F. Horizontal Dispersion

Sector averaging uniform distribution within sectors
22.5° sectors beyond 1 km
45.0° sectors within 1 km

G. Vertical Dispersion

Semi-empirical/Gaussian plume
6 stability classes; stability class determined internally from user-supplied meteorological data [modified from Turner (1964)]
Dispersion coefficients from McElroy and Pooles (1968), modified using information in Leighton and Ditmar (1953)
No adjustments made for variations in surface roughness
Downwind distance variation of σ_z assumed to be ax^b for purposes of doing analytic integration
In street canyon sub-model, empirical function of wind speed and street width and direction is used

H. Chemistry/Reaction Mechanism

Not treated

I. Physical Removal

Not treated

J. Background

Box model used to estimate contribution from upwind sources beyond 32 km based on wind speed, mixing height, annual fuel consumption
In street canyon sub-model, contribution from other streets is included in background

K. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection; ignores effect until concentration equals that calculated using box model; uses box model (uniform vertical distribution) thereafter
Mixing height determined from morning radiosonde data as follows:
midnight to dawn: constant at pre-dawn value obtained using minimum urban temperature
dawn to sunset: afternoon maximum temperature used to obtain maximum height; hourly values obtained from surface temperature variations
sunset to midnight: linear interpolation with time

L. Emission and Meteorological Correlation

Emissions a function of hour of the day and day of the week
Meteorological parameters are functions of hour of the day

M. Validation/Calibration

No calibration option provided
Some documented validation experience available

N. Output

Hourly concentration values at each receptor
Frequency distribution based on hourly values can be obtained

AQDM

Reference: No. 26 in the guideline.

TRW Systems Group. "Air Quality Display Model." Prepared for National Air Pollution Control Administration under Contract No. PH-22-68-60 (NTIS PB 189194), DHEW, U.S. Public Health Service, Washington, D.C., November 1969.

Abstract: The Air Quality Display Model (AQDM) is a climatological steady state Gaussian plume model that estimates annual arithmetic average sulfur dioxide and particulate concentrations at ground level. A statistical model based on Larsen (1969) is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

For both point and area sources:

$$\chi = \sum_{k=1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{5} \phi_{k\ell m} \chi_{k\ell m}$$

with

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{2Q}{\sqrt{2\pi}\, \sigma_z u_\ell} \left(\frac{c-y}{c}\right) \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad \text{for } x \leq x_L$$

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{Q}{u_\ell L} \left(\frac{c-y}{c}\right) \quad \text{for } x \geq 2x_L$$

linear interpolation for $x_L < x < 2x_L$.

x_L defined by $\sigma_z(x_L) = 0.47\, L$

y = crosswind distance between receptor and sector k centerline
c = sector width at receptor location

$\sigma_z(x) = a x^b + c$; a, b, c = functions of stability class (m)
a, b, c for neutral conditions split into $x > 1000$ m case and $x \leq 1000$ m case.

AQDM

A. Source-Receptor Relationship

Arbitrary location for each point source
Arbitrary location and size for each area source
Up to 225 receptors located on uniform rectangular grid
Up to 12 user-specified receptor locations
Unique release height for each point, area source
Unique separation for each source-receptor pair
Receptors at ground level
No terrain differences between source and receptor

B. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
Each source treated by effective single point source approximation
No temporal variation allowed

C. Chemical Composition

Treats one or two pollutants simultaneously

D. Plume Behavior

Holland (1953) formula, with adjustment for stability
No plume rise calculated for area sources
Does not treat fumigation or downwash
If stack height plus plume rise is greater than mixing height, ground level concentration assumed equal to zero

E. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes
No variation in windspeed with height
Constant, uniform (steady-state) wind assumed

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Climatological approach
Linear interpolation between 22.5° sector centerlines; center value calculated by sector averaging procedure (narrow plume approximation)
Averaging time = 1 month - 1 year

H. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes (Turner, 1964)
Neutral stability split internally into 60% day, 40% night
Dispersion coefficients from Pasquill (1961) and Gifford (1961)
Neutral dispersion coefficients used for all neutral and stable classes
No provision for variations in surface roughness

I. Chemistry/Reaction Mechanism

No provision for treatment

J. Physical Removal

No provision for treatment

K. Background

Input single constant background value for each pollutant

L. Boundary Conditions

Lower boundary (ground): perfect reflection
Upper boundary (mixing ht): no effect until $\sigma_z \geq .47H$ (occurs at $x=x_L$)
for $x > 2x_L$ uniform mixing
in between-linear interpolation transition region used

M. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose
Emission rate - not correlated with any other factor
Non-sequential (climatological) limited correlation
Mixing height adjusted according to stability class:
- Class A - 1.5 x afternoon climatological value
- Class D (night, internally divided) average of 100 meters and afternoon climatological value
- Class E - assumes 100 meters

N. Validation/Calibration

Calibration option available
Substantial experience but limited documentation

O. Output

1 month - 1 year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen (1969) procedure
  (typically 1-24 hr)
  Assumes
    1) lognormal concentration distribution,
    2) power law dependence of median and maximum
       concentrations on averaging time
Up to 225 gridded receptor locations, 12 arbitrary locations
Individual point, area source culpability list for each receptor

CDM

Reference: No. 27 in the guideline.

Busse, A.D. and J.R. Zimmerman. "User's Guide for the Climatological Dispersion Model." Publication No. EPA-RA-73-024 (NTIS PB 227346/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1973.

Abstract: The Climatological Dispersion Model (CDM) is a climatological steady-state Gaussian plume model for determining long-term (seasonal or annual) arithmetic average pollutant concentrations at any ground level receptor in an urban area.

A statistical model based on Larsen (1968) is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

$$\chi_{point} = \frac{16}{2\pi} \sum_{n=1}^{N} \sum_{k=1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{6} Q_n \phi_{k_n \ell m} S_{\ell m}(\rho_n) / \rho_n$$

$$\chi_{area} = \frac{16}{2\pi} \int \left[\sum_{k=1}^{16} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi_{k\ell m} S_{\ell m}(\rho) \right] d\rho$$

with $q_k(\rho) = \int_{\text{Sector } k} Q(\rho, \theta)\, d\theta$

$$S_{\ell m}(\rho) = \frac{2}{\sqrt{2\pi}\,\sigma_z u_\ell} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \exp\left[-\frac{0.692\,\rho}{u_\ell T_{1/2}}\right] \quad \text{for } \sigma_z \le 0.8L$$

$$S_{\ell m}(\rho) = \frac{1}{u_\ell L} \exp\left[-\frac{0.692\,\rho}{u_\ell T_{1/2}}\right] \quad \text{for } \sigma_z > 0.8L$$

$\sigma_z = ax^b$; a, b = functions of stability class (m) and downwind distance (ρ) - three ranges of distance used:

100-500 m

500-5000 m

5000-50000 m

CDM

A. Source-Receptor Relationship

Arbitrary location for each point source
Area sources equal uniform grid squares
Receptor location arbitrary
Arbitrary release hts for pt. and area sources
Unique separation for each source-receptor pair
Receptors are at ground level
No terrain differences between source/receptor

B. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
area integrations are done numerically one 22.5° sector at a time; sampling at discrete points defined by specific radial and angular intervals on a polar grid centered on the receptor
Day/night variations in emissions, same variation assumed for all sources.

C. Chemical Composition

Treats one or two pollutants simultaneously

D. Plume Behavior

Only Briggs (1971) neutral/unstable formula used.
If stack height + plume rise is greater than mixing height, ground level concentrations assumed equal to zero.
Alternative to Briggs - input value of plume rise times wind speed for each point source.
No plume rise calculated for area sources.
Does not treat fumigation or downwash

E. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes
Wind speed corrected for release height based on power law variation exponents from DeMarrais (1959)
Constant, uniform (steady-state) wind assumed

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Climatological
Uniform distribution within each of 16 sectors
(narrow-plume approximation)
Averaging time = 1 month to 1 year

H. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes as defined by Turner (1964)
Neutral stability split into day/night cases on input
Dispersion coefficients taken from Turner (1970)
Area sources - stability class is decreased by 1 category from
input values (to account for urban effects)
Neutral dispersion coefficients are used for all neutral
and stable classes.
No provision for variations in surface roughness

I. Chemistry/Reaction Mechanism

Exponential decay, user-input halflife

J. Physical Removal

Exponential decay, user-input halflife
Always applies the same rate constant

K. Background

Input single constant background value for each pollutant.

L. Boundary Conditions

Lower boundary (ground): assumes perfect reflection
Upper boundary (mixing height): no effect until dispersion
coefficient equals 0.8 of the mixing height, uniform vertical
mixing assumed beyond this point.

M. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose
Mixing height is adjusted according to stability class:
Class A - 1.5 x afternoon climatological value
Class D (night) - average of morning and afternoon climatological values
Class E - morning climatological value
Emission rates: day-night variation allowed; all sources vary
by same factor
Non-sequential (climatological) limited correlation

N. Validation/Calibration

Limited validation experience
Calibration option available

O. Output

One month to one-year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen (1969) procedure (typically 1-24 hr.)
Assumes
1) lognormal concentration distribution,
2) power law dependence of median and maximum concentrations on averaging time
Arbitrary number and location of receptors
Individual point, area source culpability list for each receptor
Point, area concentration rose for each receptor

CRSTER

Reference: No. 13 in guideline.

Environmental Protection Agency. "A User's Guide to the Single Source (CRSTER) Model." Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711, 1977. (In preparation)

Abstract: CRSTER is a steady state Gaussian plume technique applicable in uneven terrain. The purpose of the technique is to: 1) determine the maximum 24-hour concentration from a single point source of up to 19 stacks for one year, 2) to determine the meteorological conditions which cause the maximum concentrations, and 3) to store concentration information useful in calculating frequency distributions for various averaging times. The concentration for each hour of the year is calculated and midnight - to - midnight averages are determined for each 24-hour period.

Equations:

$$\chi = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_3 \qquad \text{for } \sigma_z \le 1.6L$$

$$\chi = \frac{Q}{\sqrt{2\pi}\, u L \sigma_y} g_1 \qquad \text{for } \sigma_z > 1.6L$$

$\chi = 0$ (stability class 7)

L = constant, independent of downwind distance

H = (stack height + plume rise) − (difference in elevation between receptor and base of stack)

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{2nL-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2nL+H}{\sigma_z}\right)^2\right]\right\}$$

CRSTER

A. Source-Receptor Relationship

Up to 19 point sources, no area sources
All point sources assumed at the same location
Unique stack height for each source
Receptor locations restricted to 36 azimuths (every 10^{o}) and 5 user-specified radial distances
Unique topographic elevation for each receptor; must be less than stack height
Receptors must be at ground level

B. Emission Rate

Unique average emission rate for each source
Monthly variation in emission rate allowed

C. Chemical Composition

N/A

D. Plume Behavior

Briggs (1971, 1972) final plume rise formulas
Does not treat fumigation or downwash
If plume height exceeds mixing height, concentrations further downwind assumed equal to zero

E. Horizontal Wind Field

Same as RAM

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Semi-empirical/Gaussian plume
7 stability classes used; Turner (1964), Pasquil (1961)
Class 7: extremely stable, elevated plume assumed not to touch the ground
Dispersion coefficients from Turner (1969); no further adjustments made for variations in surface roughness, transport or averaging time

H. Vertical Dispersion

Semi-empirical/Gaussian plume
7 stability classes
Dispersion coefficients from Turner (1969); no further adjustments made

I. Chemistry/Reaction Mechanism

Not treated

J. Physical Removal

Not treated

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection at the same height as the receptor
Upper boundary: perfect reflection
Multiple reflections handled by summation of series until σ_z= 1.6 x mixing height
Uniform vertical distribution thereafter
Mixing height is constant and follows topographic variations:
Taken from base of stack for determining whether plume punches through
Taken from receptor elevation for determining vertical concentration distribution
Hourly mixing height obtained from radiosonde data using same interpolation algorithm as RAM

M. Emission and Meteorological Correlation

Same as RAM
Monthly emission variation allows limited emission - meteorology correlation

N. Validation/Calibration

No calibration option provided
Comparison with observations around at least 5 separate power plants have been made
Additional work in progress

O. Output

Highest and second highest 1-hour and 24-hour concentrations at each receptor for the year plus the annual arithmetic average at each receptor
For each day in the year, the highest 1-hour and highest 24-hour concentration values found in the field of receptors
Hourly concentrations for each receptor are output onto magnetic tape for further processing, for example to obtain the frequency distribution

HANNA-GIFFORD

Reference: Numbers 28, 29 in guidelines.

Hanna, S.R. "A Simple Method of Calculating Dispersion from Urban Area Sources." J. Air Pollution Control Assn., Vol. 21, No. 12, pp. 774-777, December 1971.

Gifford, G.A., and S.R. Hanna. "Modeling Urban Air Pollution." Atmospheric Environment, Vol. 7, pp. 131-136, 1973. (also S.R. Hanna, private communication*)

Abstract: Two slightly different versions of the same model are described. The first is a purely deterministic version which does not require any local air quality data for its implementation. The form of the second version may be derived from the first on the assumption that area source emissions are uniform. For actual use however, it is recommended that local air quality data be used to, in essence, calibrate the model.

Equations:

Short term:

$$\chi = \sqrt{\frac{2}{\pi}}\,\frac{1}{u}\,\frac{(\Delta x/2)^{1-b}}{a(1-b)}\left\{Q_0 + \sum_{i=1}^{N} Q_i\left[(2i+1)^{1-b} - (2i-1)^{1-b}\right]\right\}$$

a, b defined by $\sigma_z = a x^b$

Long term:

$$\chi = C\frac{Q}{u}$$

*See also Section 3.9.1.

HANNA-GIFFORD (Short-Term)

A. Source-Receptor Relationship

Area sources only; uniform grid squares; user-defined grid
Sources assumed at ground level
Receptors assumed at ground level
Each receptor is assumed located at center of a grid square
Unique separation for each source-receptor pair

B. Emission Rate

Arbitrary user-specified emission rate for each grid square
Emission rates assumed constant

C. Chemical Composition

N/A

D. Plume Behavior

Plume rise not treated
Does not treat fumigation, downwash

E. Horizontal Wind Field

User-supplied hourly wind speed and direction
No variation of wind speed or direction with height
Constant, uniform (steady-state) wind assumed within each hour

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Narrow plume approximation; horizontal dispersion not treated explicitly

H. Vertical Dispersion

Semi-empirical/Gaussian plume
Dispersion coefficient assumed of the form $\sigma_z = ax^b$
Analytic integration of upwind area source contributions assuming each can be represented as an infinite crosswind strip of width equal to area grid spacing.
Dispersion coefficient parameters a, b modified from Smith (1968)
Stability classes modified from Smith (1968)
No adjustments made for variations in surface roughness

I. Chemistry and Reaction Mechanism

Not treated

J. Physical Removal

Not treated

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: mixing height assumed high enough to have no effect; treats only effects of lower boundary

M. Emission and Meteorological Correlations

Emission rates, meteorological parameters all input by user on hourly basis

N. Validation/Calibration

Calibration not used in previous applications. Some validation experience has been published
In nearly all applications, a single set of dispersion coefficient parameter values ($a = 0.15$, $b = 0.75$) has been used, corresponding to neutral stability

O. Output

Hour-by-hour average concentration values at each receptor

HANNA-GIFFORD (Long Term)

This model is intended for use in predicting an area-wide average pollutant concentration, and is expected to work best for long averaging times. The working equation is

$$X = CQ/u$$

in which

X = average concentration within a suitably defined region,

Q = average emission rate per unit area within the same region,

u = average wind speed in the polluted layer over the desired averaging time, and

C = proportionality constant to be determined empirically for each different region

Specific values of C for both SO_2 and TSP concentrations in a large number of U.S. cities have been presented by Gifford and Hanna (1973). It is recommended that local emission, meteorological and air quality data be used to determine the value of C appropriate for the region of interest. If such data is not available, an approximate average value of C = 225 has been recommended for use in evaluating the true area source effect in the absence of removal or decay processes.

HIWAY

Reference: No. 36 in guideline.

Zimmerman, J.R. and R.S. Thompson. "User's Guide for HIWAY: A Highway Air Pollution Model." Publication No. EPA-650/4-74-008 (NTIS PB 239944/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1975.

Abstract: HIWAY is a Gaussian plume model that computes the hourly concentrations of non-reactive pollutants downwind of roadways. It is applicable for uniform wind conditions and level terrain. Although best suited for at-grade highways, it can also be applied to depressed highways (cut sections).

Equations:

$$\chi = \frac{q}{u}\int_0^D f\,d\ell$$ integral along length of line segment, evaluated using trapezoidal rule

q = CO emission rate / unit length

for stable conditions or if mixing height $L \geq 5000$ m

$$f = \frac{1}{2\pi\sigma_y\sigma_z}\, g_1 g_2$$

for neutral or unstable conditions, $\sigma_z \leq 1.6L$

$$f = \frac{1}{2\pi\sigma_y\sigma_z}\, g_1 g_3$$

for neutral or unstable conditions, $\sigma_z > 1.6L$

$$f = \frac{1}{\sqrt{2\pi}\,\sigma_y L}\, g_1$$

with

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_2 = 2$$

$$g_3 = 2\sum_{n=-\infty}^{+\infty} \exp\left[-\frac{1}{2}\left(\frac{2nL}{\sigma_z}\right)^2\right]$$

HIWAY

A. Source-Receptor Relationship

Horizontal finite line, multiple line sources (up to 24 lines)
Straight lines, arbitrary orientation and length
One road or highway segment per run
Arbitrarily located receptors, downwind of the sources
Unique source-receptor distance defined
Arbitrary receptor heights
Arbitrary release heights
Cut section mode
  Receptors cannot be located in the cut
  Emissions treated as coming from 10 equal uniform line sources at the top of the cut
Flat terrain assumed
Line sources treated as sequence of point sources; the number used is such that convergence to within 2% is achieved

B. Emission Rate

Constant uniform emission rate for each lane

C. Chemical Composition

N/A

D. Plume Behavior

Not treated

E. Horizontal Wind Field

User specifies arbitrary wind speed and direction
No variation of wind speed and direction with height
Uniform, constant (steady-state) wind assumed

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Semi-empirical/Gaussian plume
User specifies which of 6 stability classes to be used; Turner (1964)
Dispersion coefficients from Turner (1969); for distances less than 100 m, dispersion coefficients from Zimmerman and Thompson (1975)
Level grade mode - initial value of dispersion coefficient equals 3 meters
Cut section mode - initial value of dispersion coefficient approximated as a function of wind speed
No further adjustments to dispersion coefficients are made

H. Vertical Dispersion

Semi-empirical/Gaussian plume
User specifies stability class
Dispersion coefficients from Turner (1969); for distances less than 100 m, dispersion coefficients from Zimmerman and Thompson (1975)
Level grade mode - initial σ_z = 1.5 meters
Cut section mode - initial σ_z = function of wind speed

I. Chemistry/Reaction Mechanism

Not treated

J. Physical Removal

Not treated

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection

i) Stable conditions or mixing height greater than 5000 m: assumes no effect, treats only reflection from ground

ii) Other stabilities with σ_z > 1.6 times mixing heights assumes uniform mixing

iii) Other neutral or unstable conditions: perfect reflection, multiple reflections treated by summation of series

M. Emission and Meteorological Correlation

N/A; user inputs all specific parameter values for hour in question

N. Validation/Calibration

Validation studies have been published

O. Output

1-hour average concentration at each receptor

PTDIS

Reference: Same as PTMTP.

Abstract: PTDIS is a steady-state Gaussian plume model that estimates short-term center-line concentrations directly downwind of a point source at distances specified by the user. The effect of limiting vertical dispersion by a mixing height can be included and gradual plume rise to the point of final rise is also considered. An option allows the calculation of isopleth half-widths for specific concentrations at each downwind distance.

Equations:

$$\chi(x,y,0;H) = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_3$$

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{2nL-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2nL+H}{\sigma_z}\right)^2\right]\right\}$$

$$\chi = 0 \quad \text{if } H > L$$

PTDIS

A. Source-Receptor Relationship

Single stack of arbitrary height
Up to 50 receptors specified by user; all receptors at ground level, below plume centerline, at user-specified downwind distances
Flat terrain assumed

B. Emission Rate

Single constant value

C. Chemical Composition

N/A

D. Plume Behavior

Briggs (1971, 1972) plume rise formulae
Alternatively, one user-supplied plume rise value can be used
Does not treat fumigation or downwash
If plume height exceeds mixing height, ground level concentration assumed equal to zero

E. Horizontal Wind Field

Wind directions implicit along source-receptor direction
Uses user-defined wind speed
No variation in wind speed with height
Constant, uniform (steady-state) wind assumed

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Semi-empirical/Gaussian plume
Calculations for a single user-specified stability class, Turner (1969)
Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness, averaging time or travel time

H. Vertical Dispersion

Semi-empirical/Gaussian plume
Calculations done for user-specified stability class
Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness

I. Chemistry/Reaction Mechanism

Not treated

J. Physical Removal

Not treated

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: user-input mixing height used; perfect reflection assumed
Multiple reflections numerically accounted for by summation of series

M. Emission and Meteorological Correlations

N/A

N. Validation/Calibration

No calibration option provided
Direct application of Turner (1969) procedures

O. Output

Centerline, ground-level values of concentration and normalized concentration (concentration x wind speed/emission rate) σ_y, σ_z and plume height at user-supplied downwind distances
Isopleth halfwidths of up to eight user-specified ground level concentrations, at same downwind distances as above

PTMAX

Reference: Same as PTMTP.

Abstract: PTMAX is a steady-state Gaussian plume model that performs an analysis of the maximum short-term concentrations from a single point source as a function of stability and wind speed. The final plume height is used for each computation. A separate analysis must be made for each individual stack; but the model cannot give the maximum concentrations of a combination of stacks.

Equations:

$$\chi(x,0,0;H) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

PTMAX

A. Source-Receptor Relationship

Single stack used
Determines downwind distance to ground-level maximum concentration
Flat terrain
Unique release height

B. Emission Rate

Single value

C. Chemical Composition

N/A

D. Plume Behavior

Briggs (1971, 1972) final plume rise formulae
Does not treat downwash or fumigation

E. Horizontal Wind Field

Wind direction implicit along source-receptor direction
Calculations done for fixed, internally defined set of wind speed values
No variation in wind speed with height
Constant, uniform (steady-state) wind assumed

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Semi-empirical/Gaussian plume
6 stability classes as defined by Turner (1964)
Calculations done for dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness, travel or averaging times

H. Vertical Dispersion

Semi-empirical/Gaussian plume
Calculations done for 6 stability classes
Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness

I. Chemistry/Reaction Mechanism

Not treated

J. Physical Removal

Not treated

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: mixing height assumed high enough to have no effect

M. Emission and Meteorological Correlation

N/A

N. Validation/Calibration

No calibration option provided
Direct application of Turner (1969) procedures

O. Output

Maximum ground level concentrations, distances to maximum values and final plume heights for all stability classes and wind speeds
Averaging time less than 1 hour (Turner, 1969)

PTMTP

Reference: No. 17 in the guideline.

Environmental Protection Agency. "User's Network for Applied Modeling of Air Pollution (UNAMAP). (Computer program on tape for point source models, HIWAY, Climatological Dispersion Model, and APRAC-1A), NTIS PB 229771, National Technical Information Service, Springfield, Virginia, 1974.

Abstract: PTMTP is a steady-state, Gaussian plume model that estimates for a number of arbitrarily located receptor points at or above ground-level, the concentration from a number of point sources. Plume rise is determined for each source. Downwind and crosswind distances are determined for each source-receptor pair. Concentrations at a receptor from various sources are assumed additive. Hour by hour calculations are made based on hourly meteorological data; both hourly concentrations and averages over any averaging time from one to 24 hours can be obtained.

Equations:

$$\chi(x,y,z;H) = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_3$$

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right]\right\}$$

$$\chi = 0 \quad \text{if} \quad H > L$$

PTMTP

A. Source-Receptor Relationship

Up to 25 arbitrarily located point sources
Up to 30 arbitrarily located receptors
Unique separation for each source-receptor pair
Unique release height for each source
Terrain assumed flat
Arbitrary height above ground for each receptor

B. Emission Rate

Unique constant emission rate for each source

C. Chemical Composition

N/A

D. Plume Behavior

Briggs (1971, 1972) plume rise formulae
Does not treat fumigation or downwash
If plume height exceeds mixing height, concentration at any receptor further downwind is assumed equal to zero

E. Horizontal Wind Field

Uses user-supplied hourly wind speed and direction
No variation in speed and direction with height
Constant, uniform (steady-state) wind assumed within each hour

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Semi-empirical/Gaussian plume
User-supplied hourly stability class, Turner (1969)
Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness, averaging time or travel time

H. Vertical Dispersion

Semi-empirical/Gaussian plume
User-supplied hourly stability class
Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness

I. Chemistry/Reaction Mechanism

Not treated

J. Physical Removal

Not treated

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: user-input mixing height used; perfect reflection assumed
Multiple reflections numerically accounted for by summation of series

M. Emission and Meteorological Correlation

User-supplied hourly values of wind speed, direction, stability class, mixing height, ambient temperature (used in plume rise calculations) are correlated

N. Validation/Calibration

No calibration option provided
Direct application of Turner (1969) procedures

O. Output

Hourly concentration, individual source contribution list at each receptor
Average concentration, source contributions at each receptor for total period of interest

RAM

Reference: No. 32 in guideline.

Hrenko, J. and D.B. Turner. "An Efficient Gaussian-Plume Multiple Source Air Quality Algorithm." Paper presented to the Annual Meeting of the Air Pollution Control Association, Boston, Mass., 1975. (Available upon request from EPA, OAQPS, Monitoring and Data Analysis Division, Research Triangle Park, North Carolina 27711)

Abstract: RAM is a steady state Gaussian plume model for estimating concentrations of relatively stable pollutants for averaging times from an hour to a day in urban areas from point and area sources. Level or gently rolling terrain is assumed. Calculations are performed for each hour.

Equations:

Contribution from single upwind area source $\chi_A = \frac{q}{u}\int_{x_1}^{x_2} f\,dx$ integral evaluated numerically

x_1, x_2 = points of intersection of ray from receptor through area source in question.

Stable conditions: $f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_2$

$$\chi_{point} = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_2$$

Neutral or unstable conditions, $\sigma_z \le 1.6\,L$

$$f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_3$$

$$\chi_{point} = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_3$$

Neutral or unstable conditions, $\sigma_z > 1.6\,L$

$$f = \frac{1}{L}$$

$$\chi_{point} = \frac{Q}{\sqrt{2\pi}\,u L \sigma_y} g_1$$

In which

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_2 = \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right]\right\},$$

RAM

A. Source-Receptor Relationship

Arbitrary location for point sources
Receptors may be
  1) arbitrarily located
  2) internally located near individual source maxima
  3) on a program-generated hexagonal grid to give good coverage to a user-specified portion of the region of interest
Receptors all at same height above (or at) ground
Flat terrain assumed
Unique stack height for each point source
User may specify up to three effective release heights for area sources, each assumed appropriate for a 5 m/sec wind speed. Value used for any given area source must be one of these three
Unique separation for each source-receptor pair

B. Emission Rate

Unique, constant emission rate for each point, area source
Area source treatment-
  Narrow plume approximation
  Area source used as input; not subdivided into uniform elements
  Arbitrary emission heights imput by user
  Areas must be squares; side lengths = integer multiples of a basic unit
  Effective emission height = that appropriate for 5 m/sec wind
  Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulae for contribution from area source with given effective release height.

C. Chemical Composition

N/A

D. Plume Behavior

Briggs (1971, 1972) plume rise formulas
Does not treat fumigations or downwash
If plume height exceed mixing height, ground level concentration assumed zero

E. Horizontal Wind Field

Uses user-supplied hourly wind speeds
Uses user-supplied hourly wind directions (nearest 10^{o}), internally modified by addition of a random integer value between -4^{o} and $+5^{o}$
Wind speeds corrected for release height based on power law variation, exponents from DeMarris (1959); different exponents for different stability classes, reference height = 10 meters
Constant, uniform (steady-state) wind assumed within each hour

F. Vertical Wind Speed

Assumed equal to zero

G. Horizontal Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally by Turner (1964) procedure
six classes used
Dispersion coefficients from McElroy and Pooler (1968) (urban) or Turner (1969) (rural). No further adjustments made for variations in surface roughness or transport time

H. Vertical Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally
Dispersion coefficients from McElroy and Pooler (1968) (urban) or Turner (1969) (rural). No further adjustments made for variations in surface roughness

I. Chemistry/Reaction Mechanism

Exponential decay, user-input halflife

J. Physical Removal

Exponential decay, user-input halflife

K. Background

Not treated

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection
Neutral and unstable conditions
Multiple reflections numerically accounted for by summation of series until σ_Z = 1.6 x mixing height
Uniform mixing assumed in vertical thereafter
Stable conditions: ignore effect of upper boundary
Mixing height for a given hour is obtained by suitable interpolation using data from soundings taken twice a day. Interpolation technique dependent on mode of operation (urban or rural) and calculated stability class for the hour in question as well as the stability classes for the hours just preceding sunrise and sunset. See attached description and figure

M. Emission and Meteorological Correlation

User supplies hourly values of wind speed, direction, mixing height and other meteorological variables required for determination of stability class and plume rise

N. Validation/Calibration

No calibration option provided
No documented validation or comparison with observational data

O. Output

Hourly and average (up to 24 hours) concentrations at each receptor
Limited individual source contribution list
Cumulative frequency distribution based on 24-hour averages and up to 1 year of data at a limited number of receptors can be obtained from special versions of RAM (RAMF, RAMFR)

Two different mixing heights are calculated by the preprocessor. One is for basically rural surroundings; the other is for urban locations. The user is given the option to specify which he wants to use. Hourly mixing heights are determined from maximum heights (MXDP) for yesterday (i-1), today (i) and tomorrow (i+1) and from minimum mixing heights (MNDP) for today (i) and tomorrow (i+1) (See Figure 1.)

For urban mixing height, between midnight and sunrise; if the stability is neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ ①, if stability is stable use $MNDP_i$ ②. For hours between sunrise and 1400, if the hour before sunrise was neutral, interpolate between $MXDP_{i-1}$ and $MXDP_i$ ③. For sunrise to 1400, if the hour before sunrise was stable, interpolate between $MNDP_i$ and $MXDP_i$ ④. For 1400 to sunset, use $MXDP_i$ ⑤. For hours between sunset and midnight; if stability is neutral interpolate between $MXDP_i$ and $MXDP_{i+1}$ ⑥, if stability is stable interpolate between $MXDP_i$ and $MNDP_{i+1}$ ⑦.

For rural mixing height between midnight and sunrise, interpolate between $MXDP_{i-1}$ and $MXDP_i$ ⑧ For hours between sunrise and 1400, if the hour before sunrise was neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ ⑨. For sunrise to 1400, if the hour before sunrise was stable, interpolate between 0 and $MXDP_i$ ⑩. For 1400 to sunset, use $MXDP_i$ ⑪. For sunset to midnight, interpolate between $MXDP_i$ and $MXDP_{i+1}$ ⑫. A listing and detailed description of input formats for the preprocessor are given in Appendix A.

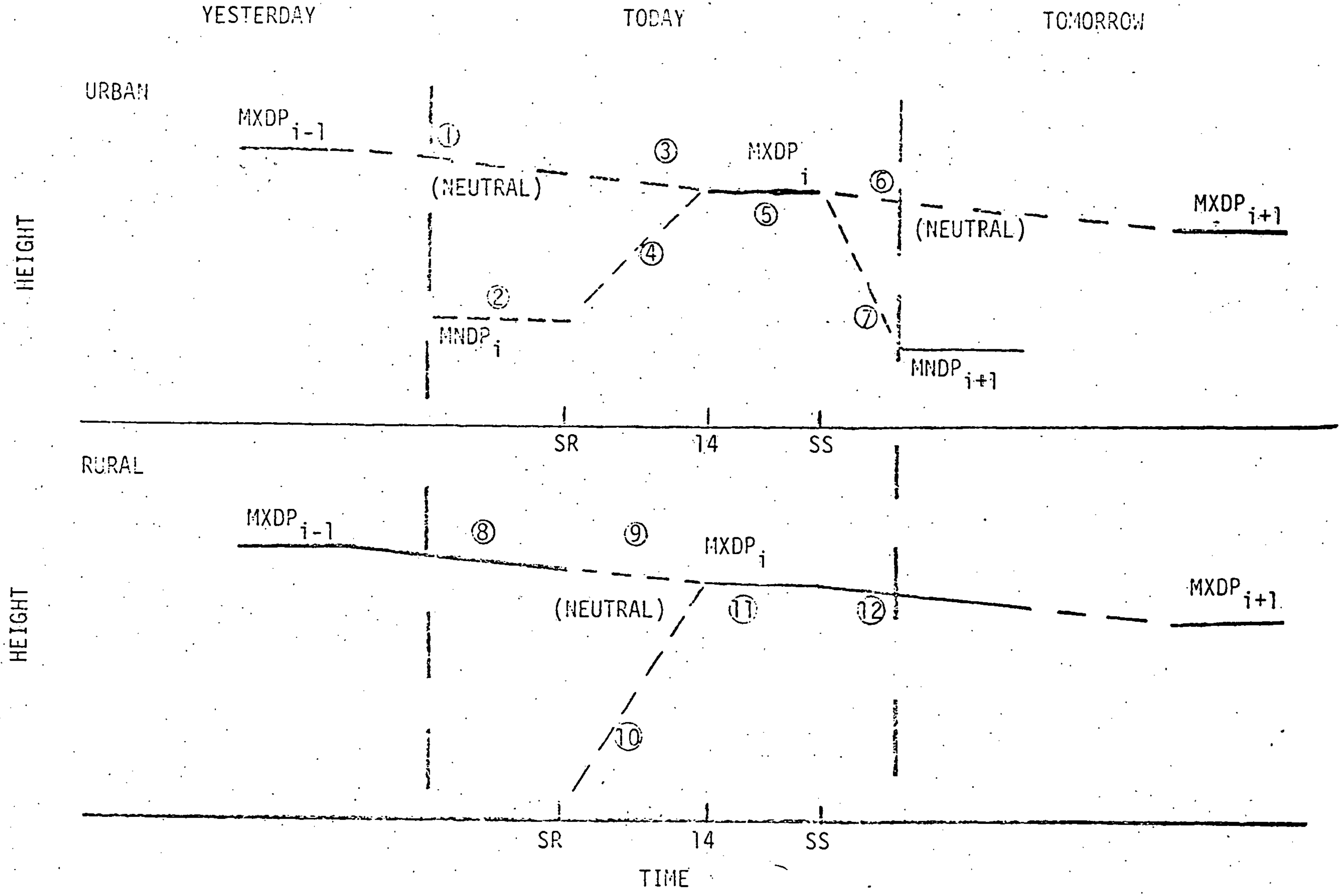

FIGURE 1. DETERMINATION OF MIXING HEIGHTS

VALLEY

Reference: No. 14 in guideline.

Environmental Protection Agency. "User's Guide to the Valley Model." Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711, 1977. (In preparation)

Abstract: VALLEY is intended for use in calculating annual and maximum 24-hour average SO_2 and TSP concentrations from single point sources in complex terrain. A climatological approach is used in calculating the annual average. The maximum 24-hour averages are calculated by assuming F stability and a wind speed of 2.5 m/sec and are intended to apply to the situation in which the plume impinges on a hill.

Equations:

$$\chi = \sum_{k=1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi_{k\ell m}\, \chi_{k\ell m} \quad \text{with } \chi_{k\ell m} \text{ as follows:}$$

Annual average:

neutral or unstable conditions -

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{Q}{\sqrt{2\pi}\, u_\ell\, \sigma_z} \cdot g_3 \cdot \exp\left[-\frac{0.692\, x}{u_\ell\, T_{1/2}}\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty} \left\{ \exp\left[-\frac{1}{2}\left(\frac{2nL-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2nL+H}{\sigma_z}\right)^2\right] \right\}$$

H = stack height + plume rise

$\chi = 0$ if $H > L$

stable conditions -

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{2Q}{\sqrt{2\pi}\, u_\ell\, \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \exp\left[-\frac{0.692\, x}{u_\ell\, T_{1/2}}\right]$$

define D = (stack height + plume rise) - receptor elevation

if $D \geq 10$ meters, set $H = D$

if $D < 10$ meters, set $H = 10$ meters and interpolate concentration linearly to zero at a height 400 meters above (stack height + plume rise).

$\chi_{k\ell m} = 0$ if $H > L$

Maximum 24-hour concentration:

$\chi = 0.25\,\chi_{klm}$ (stable) with $m = 6$ (F stability), l = such that $u = 2.5$ m/sec and k = appropriate sector for receptor of interest.

If $H > L$, set $H = L$.

VALLEY

A. Source-Receptor Relationship

Arbitrary location for each point source
Arbitrary location and size for each area source
112 receptors on radial grid, 16 directions; relative radial distances internally fixed, overall scale may be modified by user; location of grid center defined by user
Unique release height for each point, area source
Receptors at ground level; ground level elevations above mean sea level defined by user
Total number of sources less than or equal to 50

B. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
Each source treated by effective point source approximation
No temporal variation allowed

C. Chemical Composition

N/A

D. Plume Behavior

Briggs (1971, 1972) plume rise formula for both point/area sources
Alternatively, a single constant plume rise value may be input for any or all sources
Does not treat fumigation or downwash
If plume height exceeds mixing height:

A. for long-term calculations, ground level concentrations assumed equal to zero
B. for short-term calculations, maximum plume height is limited to the mixing height

E. Horizontal Wind Field

A. For long-term calculations
   Climatological approach
   16 wind directions
   6 wind speed classes
   No variation in windspeed with height
   Constant, uniform (steady-state) wind assumed
   User must specify wind speeds representative of each class; these are not internally defined

B. For short-term calculations, specifically to predict the second highest 24-hour concentration expected in 1 year:
   Class F stability and 2.5 m/sec wind speed assumed with user-defined direction. These conditions are assumed to exist for 25% of the 24-hour period; an internal adjustment is made for this

E. Horizontal Wind Field (Cont'd)

C. In stable conditions, in complex terrain, concentrations for receptors located above the point of impingement are obtained by linear interpolation between the value obtained at the point of impingement and a value of zero at a height of 400 meters above that point. The value at the point of impingement is taken to be equal to the value 10 meters below plume centerline. For receptors located below the point of impingement, the effective plume height is equal to the height of the plume above receptor elevation or 10 meters, whichever is larger. The plume is assumed to remain at a constant elevation following the initial rise

In neutral or unstable conditions, in complex terrain, the plume is assumed to remain at a constant height above topography, following the initial use

No variation of wind speed with height

Constant, uniform (steady-state) wind assumed

F. Vertical Wind Speed

In stable conditions, assumed equal to zero.
In neutral and unstable conditions, assumed such that the plume remains at a fixed height above terrain.

G. Horizontal Dispersion

Climatological approach
Sector averaging (narrow plume approximation) for calculating center values of each of 16 sectors; linear interpolation between centerlines as in AQDM
Averaging time 1 month to 1 year for long-term calculations.

H. Vertical Dispersion

Semi-empirical/Gaussian plume
Urban mode:
- 5 stability classes (Turner, 1964)
- Neutral stability split internally into 60% day; 40% night
- Dispersion coefficients from Pasquill (1961) and Gifford (1961)
- Neutral dispersion coefficients used for all neutral and stable classes
- No provision for variations in surface roughness
- Never considers stable cases, hence never deals with topographic effects

Rural mode:
- 6 stability classes; Turner (1964)
- Dispersion coefficients from Pasquill (1961) and Gifford (1961)
- Neutral stability split internally into 60% day; 40% night (has no effect on dispersion coefficients), long-term mode only
- No adjustments made for variation in surface roughness

I. Chemistry/Reaction Mechanism

Exponential decay, user-input halflife

J. Physical Removal

Exponential decay, user-input halflife

K. Background

Not treated in any mode

L. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection
  Neutral, unstable conditions - multiple reflections accounted for by summation of series
  Stable conditions - ignores effect of upper boundary, treats only reflection from lower boundary.

M. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose approach
Emission rate not correlated with any other parameter
Non-sequential; limited correlation
Mixing height adjusted according to stability class
  Urban, long term:
    Class A - 1.5 x afternoon climatological value
    Class D (night) - 0.5 x afternoon climatological value
    Class E - assumes morning climatological value
  Rural, long term:
    Class D (night) - 0.5 x afternoon climatological value
    Stable classes - ignores existence of any mixing height (assumes no limit)
  Short term calculations - input value is ignored, only F stability is considered

N. Validation/Calibration

No calibration option available.
Some validation experience, but limited documentation

O. Output

Long-term mode:
  Long-term arithmetic means, source contribution list for each receptor
Short-term mode:
  Second highest 24-hour concentration, source contribution list for each receptor

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Zimmerman, J.R. and Thompson, R.S. 1975. *User's Guide for HIWAY, a Highway Air Pollution Model.* EPA Publication No. EPA-650/4-74-008. National Environmental Research Center, EPA, Research Triangle Park, N.C.

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4 Materials Distributed to Participants Prior to the Conference

In order to prepare the invited participants for productive deliberations, a number of letters and documents were distributed at least two weeks prior to the conference. This section contains a listing of the documents and reproductions of the correspondence.

The distributed documents were:

1. A draft of the "Guideline on Air Quality Models and Associated Data Bases:, Source Receptor Analysis Branch, MDAD, OAQPS, U.S. EPA, January 1977.

2. "Descriptions of Air Quality Models and Abstracts of Reference Materials", a notebook prepared by K. Brubaker and A. Smith from EES/ANL with assistance from the staff of OAQPS/EPA, describing the technical details of the models suggested in the draft guideline, and abstracting the references cited therein.

3. "Turbulent Diffusion - Typing Schemes: A Review", F. A. Gifford, Nuclear Safety, Vol. 17, No. 1, Jan.-Feb. 1976.

4. "Atmospheric Dispersion Parameters In Gaussian Plume Modeling".

   Part I - "Review of Current Systems and Possible Future Developments", A. H. Weber, EPA-600/4-76-030a, July 1976.

   Part II -"Possible Requirements for Change in the Turner Workbook Values", F. Pasquill, EPA-600/4-76-030b, June 1976.

Reproductions of other correspondence follows:

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ARGONNE NATIONAL LABORATORY

We are pleased that you have agreed to participate in a workshop for the peer-review of modeling guidelines proposed by the U.S. Environmental Protection Agency. We realize that your schedule is full and appreciate your willingness to assist in this important task.

The EPA Office of Air Quality Planning and Standards has prepared these modeling guidelines for application in the review of new sources under federal regulations such as those governing prevention of significant deterioration and as an aid in the revision of State Implementation Plans. EPA as well as the States must fulfill these important review responsibilities now; therefore, our challenge is to advise on the best approach to modeling air quality impacts within the current state of the art and with consideration for required data and resources. As participants in the conference, we should view the forthcoming draft guidelines as a well-considered attempt by EPA to meet this challenge. Hopefully, our efforts will build upon their draft to produce the final version.

The conference will be held at Carson Inn/Nordic Hills near Chicago, Illinois, from February 22-25, 1977. A tentative conference schedule and brochures describing Nordic Hills are included. As you can see, our schedule is full but the accommodations are excellent.

Also enclosed is a registration and housing form and a return envelope. Please indicate the nights for which you will require lodging. Since the conference does not begin until noon on Tuesday, February 22, you may find it convenient to arrive in Chicago on Tuesday morning.

By February 8 you should have received a copy of the proposed guidelines and background information. Please contact Donald Rote [(312)739-7711 ext. 5266 or FTS 388-5266] or Albert Smith [(312)739-7711 ext. 3259, 3240 or FTS 388-3259, 3240] if you have not received the material by this date.

9700 South Cass Avenue, Argonne, Illinois 60439 · Telephone 312-739-7711 · TWX 910-258-3285 · WUX LB, Argonne, Illinois

The costs of rooms and scheduled meals will be paid directly by the sponsors. To cover the cost of meals outside the conference, per diem of up to $15/day will be paid to eligible participants. As government agencies, we cannot make cash advances. Forms for reimbursement of allowable expenses (air fares, ground transportation, and other conference related expenses) will be available at the conference. Please note that receipts are required and that government employees can be reimbursed only if their expenses are not covered by their agencies. If you wish us to purchase your airline tickets in advance, please fill out and return the attached "Request For Airline Ticket". We must receive these ticket requests before February 4.

In addition to the expenses noted above, you will be paid an honorarium of $150.00 per conference day.

A list of attendees has been included for your information.

Again, let me express my sincere appreciation for your attendance at the conference. With your support I feel sure that the conference will yield a workable set of guidelines.

Very truly yours,

John J. Roberts
Energy and Environmental Systems Division

JJR/blt
attachments

Dear

I wish to thank you for accepting an invitation to participate in the Modeling Workshop and helping us to develop more uniform and consistent modeling guidance.

The choice of analytical procedures to assess environmental impacts has become a significant, and often the paramount, issue in the administration of the new source, nonattainment, and prevention of significant deterioration policies. I believe that we have gathered a distinguished and balanced group of scientists to consider this important problem. Certainly the group represents a broad spectrum of interests and concerns. But more important, you and other participants are recognized not only for your scientific competence, but for your appreciation and depth of understanding of the nature of the problems that arise in administering a national environmental program.

I wish you success and have asked my staff and their associates at Argonne National Laboratory to do whatever is necessary to help you make the workshop a success.

Sincerely yours,

Walter C. Barber
Director
Office of Air Quality Planning
and Standards

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ARGONNE NATIONAL LABORATORY

February 3, 1977

TO: Conference Participants

FROM: John J. Roberts

SUBJECT: Background Material for Conference on EPA Modeling Guidelines

Enclosed please find some information which you will find of use in preparing for the upcoming Conference on EPA Modeling Guideline: a draft of the guideline itself; descriptions of the models suggested for use in the guideline; and excerpts from the references cited in the guideline. Several additional references will be sent under separate cover.

If you intend to propose alternate models or submodels for consideration by the conference, it would be most helpful if you could document your position in a format similar to that used in Sec. 2 of the enclosed Descriptions of Air Quality Models and Abstracts of Reference Materials. Thirty-five (35) copies should suffice for the conference participants; we will also have copying facilities available on the premises at the conference. In addition we will be able to make 8½ x 11 viewgraphs. An overhead projector for the viewgraphs and a 2 x 2 slide projector will also be available.

We look forward to meeting with you and to discussing your ideas for improving the guidelines.

JJR:tb

Enclosures

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ARGONNE NATIONAL LABORATORY

February 4, 1977

TO: Participants in the Specialist Conference on EPA Modeling Guideline

FROM: John J. Roberts

SUBJECT: Potential Conference Issues

We have some additional* information which may be of use to you in connection with the up-coming Specialist Conference on EPA Modeling Guideline. A number of issues and questions are likely to arise as you review the draft and discuss it with your colleagues. Without focusing attention on specifics and without the intention of biasing your thinking, we have prepared a list of potential issues. This list is certainly not complete and we welcome additions or other modifications. Furthermore, we do not expect to discuss each of these issues in detail unless the participants feel such discussion is warranted. The issues identified so far fall into three categories:

1) Policy Issues
2) Guideline Contents
3) Guideline Format or Structure

The major objective of the conference is, of course, not to simply identify issues but to reach consensus regarding the guideline itself. This consensus could presumably take one or more of the following forms as appropriate:

1) Statements regarding the adequacy of the guideline in terms of the issues (majority and minority opinions may evolve).
2) Recommendations of specific changes and additions or deletions to the guideline including both the content and format thereof.
3) Identification of issues which are regarded as important but which can not be adequately addressed at this time because of incomplete information or other constraints.

Again we look forward to meeting with you and to a fruitful conference.

JJR:tb

*A copy of the draft guideline along with other materials is being sent under separate cover.

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Potential Conference Issues

1. Policy issues

   1.1 What should be the limits of the discretionary powers of users?

   1.2 The guideline will be subject to a periodic review and updating process. What should be the form and period of review?

   1.3 Which concentration estimates should be used for specific policy questions? That is, which short term estimate (highest, 2nd highest, etc.) should be used for SIP and NSR?

   1.4 Should pragmatic considerations (computer and/or manpower cost and time) enter into model choice guidance?

2. Applications (or problems associated with specific applications)

   2.1 Features which are associated with specific applications (for general list of such features see the table in Sec. 1 of the notebook prepared by ANL)

   2.2 Importance of each of these features for specific applications and the requirements for accuracy of treatment by models.

   2.3 Criteria for deciding whether features such as downwash, complex terrain, anomalous meteorological conditions, etc., deserve special treatment.

3. Suitability of models specified in the guideline and criteria for selecting alternatives or updating

   3.1 Matching models to application requirements (qualitative considerations)

   3.2 Accuracy determination and specification

   - What measures of accuracy should be used. How should they be determined?
   - What constitutes acceptable validation? (purpose, procedures, documentation)
   - Calibration - What role should it play?
     What method(s) should be used?
     Criteria for use?

   3.3 Criteria for acceptability of alternatives to the proposed models or portions thereof?.

4. Specialized technical issues

4.1 Characterization of turbulent diffusion

4.1.1 Typology of regimes
4.1.2 Algorithms within each regime

4.2 Boundary conditions

4.3 Formation and loss mechanisms - guidance on when to worry and how to deal with

4.4 Estimation of short-term concentrations

4.4.1 Calculations of multi-hour concentrations
4.4.2 Statistics of 2nd highest value
4.4.3 Suitability of peak-to-mean ratio technique

4.5 Receptor points: density, location, grid or cell size

5. Data requirements - Representativeness (location, duration); Accuracy (sampling method, quality control)

5.1 Air quality data

- Background estimation
- Model validation
- Model calibration

5.2 Meteorological data

5.3 Emission data

- Temporal and spatial resolution, accuracy

6. Structure and content of guideline

6.1 Appendices - Summary and/or documentation of models?

6.2 Guidelines for modeling photochemical smog?

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