ROYAL METEOROLOGICAL SOCIETY

POLICY STATEMENT

ATMOSPHERIC DISPERSION MODELLING:

GUIDELINES ON THE JUSTIFICATION OF CHOICE AND USE OF MODELS, AND THE COMMUNICATION AND REPORTING OF RESULTS

PUBLISHED IN COLLABORATION WITH THE DEPARTMENT OF THE ENVIRONMENT

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A POLICY STATEMENT ISSUED BY THE COUNCIL OF THE ROYAL METEOROLOGICAL SOCIETY

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EXECUTIVE SUMMARY

These guidelines seek to promote the use of *best practice* in the use of mathematical models of atmospheric dispersion, emphasising the principle of *fitness for purpose* in the selection of modelling procedures, and the importance of effective communication in the documentation of reported results. The underlying objectives are to ensure the efficient use of resources, especially in the context of assessments conducted for purposes of demonstrating compliance with regulatory obligations. The guidelines comprise considerations organised under the following ten headings:

1. Statement of Context and Objectives - to explain the situation being modelled and the purpose of the dispersion calculations, giving a clear account of the relationship between the objectives and the modelling procedures adopted to achieve them;

2. Justification of Choice of Modelling Procedure - to demonstrate the *fitness for purpose* of the modelling procedure;

3. Use of Software Implementations of Modelling Procedures - to provide a fully documented account of the details of the model and its conversion into valid software;

4. Input Data - to show how the data requirements of the model have been met, and to explore the implications on the assessment in cases where there are deficiencies in the available data;

5. Presentation of Results and Conclusions - to ensure that the findings of the exercise are successfully communicated;

6. Explicit Quantification - to ensure that best use is made of the opportunity to express results in quantitative terms;

7. Sensitivity Analysis - to expose how the results depend on choices and assumptions made in respect of variables whose values may be debatable;

8. Uncertainty and Variability - to ensure that these issues are addressed in respect of uncertainties in model parameters, the inherent variability of dispersion behaviour, and variations that are likely to be displayed between the results of one model and another;

9. Quality Assurance of Models - to demonstrate that the model used has been subjected to an evaluation procedure establishing its suitability for a specified range of tasks;

10. Auditability - to ensure that there is a clear and transparent account of the exercise for inspection by interested parties.

The assessment of environmental impacts of discharges to the atmosphere is a topic of importance to a wide range of individuals and organisations. The guidelines are accordingly addressed to such interested parties, including operators of industrial processes, environmental consultants, researchers in the academic institutions and national research bodies, commercial software houses, public interest groups, regulators, and enforcing authorities. The issues raised also have a wider application in other scientifically-based fields where technical advice is sought and used in support of practical decision-making.

INTRODUCTION

The need to conduct dispersion modelling exercises and to present the results for use as part of a decision making process arises in several contexts. Such modelling may relate to the design of a plant, the setting of operating conditions, the assessment of siting options, and the estimation of exposures as part of the assessment of the environmental impacts of releases. The results of the work may remain within a limited community of specialists, or they may be required to be presented to a much wider group for discussion and assessment as part of a regulatory procedure. Examples of such applications as part of a regulatory procedure include the following:

assessing Environmental Impacts of projects at the Land Use Planning stage, under the requirements of the EC directive 85/337/EEC on the Assessment of the Effects of Certain Public and Private Projects on the Environment, and the associated implementing regulations SI 1988 No. 1199, The Town and Country Planning (Assessment of Environmental Effects) Regulations 1988;

assessing the effects on the environment of releases in normal operation for substances and processes falling within the scope of the Environmental Protection Act 1990, as detailed in SI 1991 No. 507, The Environmental Protection (Applications, Appeals and Registers) Regulations 1991;

assessing the effects of accidental releases of substances in the Major Hazards sector, under the requirements of EC directive 82/501/EEC on the Major Accident Hazards of Certain Industrial Activities (as amended by Directives 87/216/EEC and 88/610/EEC) and the associated implementing regulations SI 1984 No. 1902, The Control of Industrial Major Accident Hazards Regulations 1984 (as amended by SI 1988 No. 1462 and SI 1990 No. 2325).

In these regulatory applications the results may very well become a matter of public record by their inclusion in a legal document such as an Environmental Statement, or an Application for Authorisation. The results may be subject to detailed scrutiny and exposition as part of a public inquiry, particularly at the land use planning stage. Additionally, documents containing the results of such exercises are circulated to a wide range of statutory consultees and other interested parties, and are thereby subject to scrutiny by nominated representatives of those bodies.

Regulatory bodies have powers enabling them to obtain additional information from applicants where judged necessary. It is desirable that the documented account of the assessment carried out by or on behalf of the applicant should be adequate in a number of respects, as it may be required to serve several functions.

As material on which the applicant relies in seeking regulatory permission, it needs to satisfy the regulator's requirements for information to enable a sound decision to be made; any inadequacy that results in a request for more information introduces delay in the conduct of the regulatory procedure, and makes the deployment of regulatory effort less efficient than it could be.

As a record of matters on which regulatory decisions are made, the documented account is one of the instruments whereby civil administration is open to a process of independent audit, on which the legitimacy of the system depends; such scrutiny may be conducted at an informal level by interested individuals, or more extensively by organisations such as Non-Governmental Organisations, the operators of plants, and internal review bodies of the regulators themselves. In some cases there may be Judicial Review, requiring the availability of a full audit trail.

In all of these applications there is an essential need to achieve the twofold objective of (i) conducting a technically competent modelling exercise using appropriate methods, and (ii) communicating the results and conclusions successfully to the various interested parties. In the contexts outlined above the range of interested parties is such that it cannot be assumed that the normally accepted means and styles of communication used within the technical community will be successful in this latter respect, and it may well be that an exercise of even the best technical quality fails overall because it is not successfully communicated. Appropriate documentation is critical to the success of the assessment procedures.

Examination of documented accounts of dispersion modelling exercises conducted within the scope described above reveals a wide variety of practice as to the nature, level, and completeness of such documentation. Furthermore, there are numerous examples of misapplication of models to circumstances beyond those for which the model was designed. It is therefore considered appropriate for the Royal Meteorological Society, as a body representing dispersion modelling expertise within its membership, to put forward guidelines for the conduct and documentation of dispersion modelling exercises carried out with the intention of reporting the results to other interested parties, whether for regulatory purposes or otherwise. It should be emphasised that these guidelines are focused on the promotion of best practice in the conduct of dispersion modelling work using predictive mathematical procedures, including the justification of the choice of model, and the associated reporting functions. They do not address issues in the use of physical modelling procedures such as those conducted in wind tunnels. Guidelines for this class of modelling have been produced by Snyder(1981). Neither do they address the issue of which models should be used, a topic requiring the detailed examination of model performance, comparisons between models, sensitivity and benchmark studies, and validation of models against data bases of dispersion behaviour. Such assessments involve the deployment of very substantial resources, and are the subject of sustained exercises described as model evaluation studies, of which several examples are reported in the literature; a current exercise of this type is reported in a series of workshops on the Intercomparison of Advanced Practical Short-Range Atmospheric Dispersion Models (Olesen, 1993). The guidelines presented here are not in any sense a substitute for such sustained evaluation exercises, the objectives of which are fully endorsed by the working group.

REFERENCES

Snyder, W.H.
Guidelines for fluid modelling of atmospheric diffusion, USEPA report no. EPA-600/8-81-009, 1981.

Olesen, H.R.
(i) Review of earlier model evaluation work; and
(ii) Summary of model evaluation discussions in Manno: proceedings of workshop on *Intercomparison of advanced practical short-range atmospheric dispersion models*, Manno, Switzerland, Aug 29 - Sept 3, 1993.

ASPECTS THAT SHOULD BE ADDRESSED

The following considerations are judged to be essential in conducting the modelling exercise and reporting the results:

1 STATEMENT OF CONTEXT AND OBJECTIVES

The documentation should include a clear statement of the context and objectives of the exercise, enabling the reader to form a proper understanding of the purpose of the study. Such a statement should describe the particular circumstances being modelled, identify the key issues and impacts of concern, specify the salient features of the regulatory requirement that the assessment is designed to address, and specify in some detail the objectives of the calculations in terms of receptors, locations and types of exposure, and the features of the exposure that are associated with various levels of impact. Overall, the statement should provide a definition of the scope of the exercise such that the stated objectives are related in a clear manner to the modelling procedures adopted.

2 JUSTIFICATION OF CHOICE OF MODELLING PROCEDURE

The type of modelling procedure chosen should be described and justified in relation to the objectives. This should include consideration of criteria for the neglect or inclusion of factors that may determine the type of model that is appropriate. It may be necessary to consider, for example, the neglect or inclusion of non-passive dispersion behaviour, the influence of topography, surface conditions, and the presence of buildings on dispersion and source behaviour, the influence of coastal meteorology, and whether the setting is urban or rural. Consideration of the suitability of a model will need to be related to the specific characteristics of the site of interest. The fact that a particular mechanism is not included in a model that is available, or that it would be difficult or expensive to address, should not be regarded as an adequate criterion for exclusion from the assessment if there is a case for its inclusion on technical grounds. The guiding principle in the justification of the chosen procedures is the demonstration of fitness for purpose. Although in many cases there will be a need to use software implementations of models, there may also be aspects where the use of scoping calculations is all that is needed. For example, where such calculations reliably show that the upper limit of a numerical quantity is so far below an appropriate reference level of concern that more detailed estimation is not merited, it would be a waste of resources to apply more involved methods.

3 USE OF SOFTWARE IMPLEMENTATIONS OF MODELLING PROCEDURES

In order that the recipient of the report on the exercise can assess the appropriateness of the models used it is essential that full documentation of the modelling procedures should be available. Preferably this should be in the public domain, but it is recognised that this may not always be practicable for a number of reasons, such as the need to protect the commercial investment in software development. In such cases an acceptable alternative would be for the relevant documentation to be made available to parties with a legitimate interest. The documentation should include a general account of the model, separate from the report of the particular application. It will often be helpful to include copies of these general supporting documents with the account of the particular exercise.

Where computational methods are employed, a minimum level of documentation of the model itself should include i) an account of the mechanisms that are addressed, together with a description of the mathematical relationships by which these mechanisms are represented, ii) a description of how the mathematical model has been converted to a form suitable for incorporation into software, including the algorithms used, the structure of the computer code, and a summary of the tests that the software has undergone, and iii) a user's guide which includes detailed instructions on how the model is to be used, and examples of model runs showing both input data and sets of results. Data files used in the modelling, both for specific properties of substances, and for modelling parameters such as dispersion coefficients, should be documented. It is strongly recommended that models for which such documentation is not available should not be used for the types of exercises discussed here.

4 INPUT DATA

The models used, of whatever type, will require input data of various categories. UK practice has been characterised by a tendency to accept that site-specific data are often unavailable. It is recommended that a more pro-active approach needs to be adopted, particularly where the planning timescales of projects are sufficiently long to permit this. For some important factors direct measurements are always to be preferred to estimates of those factors derived from other measured quantities. Where dispersion will be affected by the local terrain, for example in areas close to coasts or where there are significant topographical features, it is recommended that measurements of relevant quantities should be made at the site for a reasonable period, such as one year. These measurements can then be related to data obtained over longer periods at the most representative nearby site having such records. Where a decision is made, for reasons of economy or time, not to collect on-site data, information must nonetheless be provided in order that the assessment can proceed. In such cases the assessment may make use of meteorological data for nearby sites that are representative of the region, and as representative as possible of the site in question, with a view to examining how these differing inputs would affect the overall decision. Where such an approach is adopted careful consideration needs to be given to the question of the degree to which data from another site are representative of the location for which data are lacking. Geographic proximity alone is not a sufficient criterion in this respect, as differences in terrain may well make the comparison invalid. Sources of data should be specified in detail, and where data that are used are of such a type that it is necessary to select those to be used from a number of candidate options, the selection made should be justified. Assessments should examine the full range of climatology, including extremes where these are important to the nature of the impact, as well as more typical conditions. An account should be given in all cases of the quality and representativeness of the data used, so that the limitations imposed by the availability of suitable data are fully exposed.

5 PRESENTATION OF RESULTS AND CONCLUSIONS

Presentation of results should make good use of quantitatively labelled graphical summaries (such as maps overlaid with concentration contour plots) wherever possible, and should not rely solely on tables of numbers. In any case, all numerical quantities should be clearly labelled with the appropriate units. Conclusions should be expressed in a manner that bears a clear relationship to the stated objectives and to the results obtained from the modelling procedure. All conclusions should be made explicit, and should not have to be inferred by the reader.

6 EXPLICIT QUANTIFICATION

Results should always be fully quoted as numerical values in any discussion of their significance. Inferences and conclusions should be substantiated by explicit reference to the numerical quantities on which the argument is based; the discussion should not contain unsubstantiated assertions. For example, if it is argued that a quantity is of negligible importance in relation to some reference level, both should be explicitly quoted so that the quantitative interpretation of negligibility is clearly expressed. Quantitative descriptions should be used wherever possible in order to avoid ambiguity. For example, different parameter values may well be required for winds blowing from the sea to the land as compared with the reverse case. The wind directions for which this is the case should be specified, since the meaning of on-shore and off-shore directions will only be unambiguous in the idealised case of the long straight coast line.

7 SENSITIVITY ANALYSIS

Model sensitivity to user selected variables may be important in determining the results of the assessment. Where the assessment depends on the results obtained using choices of variables that may be debatable, sensitivity analysis should be conducted, and the results expressed. A summary of the cases considered in the analysis, presented in the form of a table or matrix of parameters examined and the associated effects on salient outputs, will often provide an effective means of communicating the results. Unsubstantiated assertions as to the insensitivity of the results to certain factors should not be made, but instead the argument should be demonstrated by reference to quantitative examples.

8 UNCERTAINTY AND VARIABILITY

The estimation of atmospheric dispersion behaviour is subject to numerous sources of uncertainty. These include ones arising from the approximation represented by the model itself, those attributable to the range of choice available in relation to the user-defined parameters, and the incompleteness of our knowledge of dispersion behaviour. Additionally, the dispersion process is inherently variable, so that the exposures resulting from a sequence of release episodes occurring in conditions that are apparently identical in terms of observed meteorology will inevitably differ. Since models produce concentration estimates that are averaged in various ways, it is to be expected that these averaged quantities will differ from those observed in a single dispersion episode. The model user should give some estimate of the uncertainty that attaches to the results, and should address the issue of variability. If this is done much of the apparent disagreement between models, and between measured values and those estimated by models, may be encompassed within the ranges of uncertainty. Failure to address these issues is likely to result in loss of credibility in the use of dispersion modelling as an aid in decision making where, for example, unresolved differences consume a disproportionate amount of time in a public inquiry. Modellers and model users have a responsibility to ensure that these issues are addressed so that they do not become sources of confusion in the decision-making process. Where this happens the result is often that the dispersion modelling exercise as a whole is discredited, and the potential usefulness of the information is lost.

9 QUALITY ASSURANCE OF MODELS

Quality assurance of models depends largely on the model evaluation procedures referred to earlier. Evaluation of a model includes the distinct procedures of verification, validation, and (where appropriate) scientific assessment. At the very least, a computer model should not be used unless it has been verified, that is, shown by a detailed examination to be a true version of the mathematical model which it incorporates. Such verification should be carried out independently of the personnel who constructed the model. Model verification is a painstaking task of checking that the coding faithfully reproduces the mathematical model approximations incorporated in the algorithms, and as such is one of the easier parts of the evaluation procedure. Additionally, a model should be subjected to a process of validation, that is, its results should be compared with an independent dataset, and the accuracy and reliability of the model assessed. This is a much more difficult task, and the degree to which a model can be said to be validated, and in what respects, is more open to debate. It is recommended that users should give an explicit account of the range of conditions for which the model has been validated, and where the scope of the assessment necessitates use outside of this range, specific mention should be made of this fact, and some assessment should be given of the degree to which extrapolation has been taken. The data set used for validation should be independent of any data set incorporated in the model. Validation should be carried out against experimentally determined values, preferably measured in the environment to which the model is being applied. It is strongly recommended that a model that has not undergone such a validation process should only be used if there is no alternative, for example if it were the only model of its kind at an early stage in the development of modelling capability in a particular field. In such cases attention should be drawn to the speculative nature of the procedure.

It should be emphasised that comparison of the output of one model with the output of another model does not necessarily constitute validation; such a procedure constitutes a comparison only, although it may have merit as part of a validation procedure if the primary model has been well validated. This kind of comparison should be approached with considerable caution, and should be carefully justified for the cases considered. Scientific assessment involves examination of the validity of the description of the mechanisms that are modelled. This is of particular significance where it is necessary to investigate conditions that are outside the range within which the models have been validated. Application outside of the validated range will depend for its validity on the judgment made as to the robustness of these scientific descriptions in those circumstances. In such cases there should be an explicit statement of the conditions in which the model is judged to be applicable, and those in which it is not applicable. Responsibility in this matter falls on both model developers to provide the source of guidance, and on users to demonstrate that they properly appreciate the issues.

10 AUDITABILITY

An essential requirement in the documentation of a dispersion modelling exercise is that of auditability. The test in this respect is that the documentation should give a complete and transparent account of what has been done. Interested parties should be able to rely on the documentation in this respect, so that they can scrutinise, check, and if desired repeat what has been done without having to seek any further information. The audit procedure often proves to be the means whereby problems are first revealed. Auditability is enhanced by successful communication, and it is recommended that good use should be made of graphical and diagrammatic summaries, such as flow-charts representing the adopted calculation strategy.

CONCLUSIONS

These guidelines are intended to promote the achievement of best practice in the mathematical modelling of atmospheric dispersion, a technical field that is subject to frequent exposure as part of the advice presented to regulatory decision-making procedures involving the assessment of environmental effects of releases. The proliferation of software implementations of such models has made these techniques readily available to a very wide range of users who are not specialists in this field, and there is a need to ensure that such users have access to the expertise necessary to apply these techniques appropriately. Problems attributable to inappropriate use do occur. They can arise from poor selection of models due to inadequate communication from model originators to potential users concerning the scope and limits of applicability of models. Problems also occur as a result of poor selection and implementation of models by users who lack the relevant expertise. Expenditure of resources on inappropriate modelling is wasteful and inefficient for both the initiators of the exercise and those charged with assessing the implications of the results on the decision making process. It should be emphasised that these guidelines focus on the use of predictive mathematical models of dispersion, as distinct from physical modelling techniques utilising wind tunnel or water flume facilities. Further, these guidelines address only the need to achieve best practice in general terms, and therefore do not include consideration of which particular models should be used in given applications. In seeking to promote best practice the working group wish to draw attention to the responsibilities that fall upon the various bodies involved. These include:

the responsibility of regulatory authorities to insist on the achievement of standards such as those recommended here, and to encourage and actively support the development and use of appropriate models;

the responsibility of the providers of services to ensure that the commissioned task is conducted to an adequate standard;

the responsibility of users of such services to recognise that the small extra cost of sound advice represents money well spent;

the responsibility falling on all interested parties to ensure that successful communication is achieved in all aspects of the process.

It is recognised that there is always pressure on resources, and that any inefficiency in their use is to be avoided. The exercise that is conducted should be appropriate to the problem, and over-assessment is as much to be avoided as under-assessment. However, where there is failure to insist on the maintenance of adequate standards the cheapest assessment will prevail. The working group wish to emphasise the need to maintain adequate standards, and to ensure that dispersion modelling practice is neither discredited because of poor communication of its usefulness, nor accepted uncritically by end users. Although the issues addressed here relate to a particular technical field, the essence of the concern applies to a very wide range of topics where technical advice is sought and used, in meteorology as well as in other scientifically-based fields.