

## Summary of Work Funded by ADMLC

A report prepared for ADMLC by

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### ABSTRACT

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ADMLC and the earlier ADMWG have undertaken reviews of a large number of topics in atmospheric dispersion and deposition modelling. This document presents a review of the topics that have been covered by ADMLC and ADMWG. In some cases, different reviews have covered similar areas. The aim of this work was to identify whether there are any overlaps or gaps in those cases where similar topics have been tackled on different occasions.

This review concluded that there are no instances where reports contradict, rather than update, earlier reports. Gaps in the areas covered by the earlier studies were identified, and suggested topics for future work by ADMLC were proposed.

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The views expressed in this report are those of the authors, and do not necessarily represent the views of ADMLC or of any of the organisations represented on it

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## EXECUTIVE SUMMARY

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ADMLC and the Steering Committee which preceded it have produced a total of 30 reports. In some cases different reports relate to similar topics. ADMLC wanted a review of the work which has been carried out, intended to identify any contradictions between different reports and any gaps in the areas covered. The aim was not to provide a scientific critique of each report, nor to consider whether subsequent work elsewhere would support a possible review or revision of any of the earlier reports.

The 30 reports were divided into 12 groups where the reports referred to topics that were related; for example four reports related to aspects of dispersion from releases near buildings, and five reports related to aspects of the use of meteorological data. The main topics covered by each of the reports have been summarised, and the areas of overlap between reports or gaps in the areas covered have been identified. Many of the reports included recommendations for future work; these recommendations have also been summarised in this report.

There are several instances where different reports describe models for the same or very similar applications. In almost all such cases, the later report references the earlier one. In this case, the later report can be regarded as updating, rather than contradicting, the earlier report. In the few cases where the later report does not reference the earlier one, there are no instances of contradictions between the two reports. In all cases, the reports can be regarded as updating earlier documents or providing additional, complementary, information.

There are two instances where the authors of this report have reservations about the conclusions reached in ADMLC reports; these relate to the portability of met data and the use of "old" met data, i.e. whether concentrations predicted using data from a site over a period of years show a trend with time.

This review also identified a number of gaps, either in the coverage of a single report or between the coverage of different reports on related topics. This will provide a useful input into discussions within ADMLC on future work programmes. The main gaps are:

- a Models for dispersion of dense gases.
- b Modelling of chemical reactions in the atmosphere, either between different materials within a single plume or between material in a plume and the general background levels of other chemicals.
- c Modelling the dispersion and deposition of particles which are large enough that their settling under gravity should be considered.
- d Models for dispersion and plume growth over bodies of water.
- e Models for concentration indoors resulting from a plume outdoors or from a release within the building.
- f Dispersion of material released at high speed, or in directions other than vertically upwards.
- g Dispersion of material released in an explosion.

This list was derived simply from the comments on the coverage of the previous reports for ADMLC, and so reflects gaps in the areas which are similar to those considered in previous work. It does not include possible topics which are completely outside the range of previous work undertaken for ADMLC.

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# 1 INTRODUCTION

The Atmospheric Dispersion Modelling Liaison Committee (ADMLC) was established in 1995, replacing an earlier (less formal) Steering Committee and its Working Group (ADMWG) which was established in December 1977.

This document presents a review of the work undertaken by ADMWG and ADMLC. It is intended to assist ADMLC in choosing topics to fund in future years, by identifying the topics that have been covered so far. The aim of this work is to identify the topics that have been covered in earlier work, and whether there are any overlaps or gaps in those cases where similar topics have been tackled on different occasions. Therefore this document does not present a summary of the scientific content of the various reports, nor does it attempt to identify whether reports should be updated because relevant work has been undertaken since they were originally published.

ADMWG published seven reports with one report including sections on four different topics. Four organisations on the Steering Committee funded a review on the preparation for a complex dispersion model to replace R91. This report was not published at the time, but has now been included on the ADMLC web site, and is included in this review of previous work. ADMLC has published seven annual reports, from the 1995/96 to 2002/03 financial years (at the moment two of these are not published) with annexes covering a variety of different topics. ADMLC and ADMWG have together published reports on a total of 30 topics. The list of reports is presented in Table 1. In the remainder of this report, it is necessary to refer to the reports on these 30 topics separately. For convenience each "topic report" was given a code-name, and this report refers to the code-names rather than the full report title. The list of code-names is also given in Table 1. So, for example, Annex A of NRPB-R292 "Atmospheric dispersion at low wind speed", is referred to as "R292a" in this report.

**TABLE 1 List of ADMWG and ADMLC reports, and the code-names used in this report**

Code-name	Full title
R91	The first report of a Working Group on Atmospheric Dispersion: a model for short and medium range dispersion of radionuclides released to the atmosphere. NRPB-R91 (1979)
R122	The second report of a Working Group on Atmospheric Dispersion: a procedure to include deposition in the model for short and medium range dispersion of radionuclides. NRPB-R122 (1981)
R123	The third report of a Working Group on Atmospheric Dispersion: the estimation of long range dispersion and deposition of continuous releases of radionuclides to atmosphere. NRPB-R123 (1981)
R124	The fourth report of a Working Group on Atmospheric Dispersion: a model for long range atmospheric dispersion of radionuclides released over a short period. NRPB-R124 (1981)

**TABLE 1 List of ADMWG and ADMLC reports, and the code-names used in this report**

Code-name	Full title
	The fifth report of a Working Group on Atmospheric Dispersion: models to allow for the effects of coastal sites, plume rise and buildings on dispersion of radionuclides and guidance on the value of deposition velocity and washout coefficients. NRPB-R157 (1983)
R157a	Effects of coastal sites
R157b	Models for plume rise
R157c	Effects of buildings
R157d	Guidance on the value of deposition velocity and washout coefficient
R198	The sixth report of a Working Group on Atmospheric Dispersion: modelling wet deposition from a short release. NRPB-R198 (1986)
R199	The seventh report of a Working Group on Atmospheric Dispersion: the uncertainty in dispersion estimates obtained from the Working Group models. NRPB-R199 (1986)
HB9	Preparatory studies for a complex dispersion model. CERC Report HB 9/88 (1988)
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 1995/96. NRPB-R292 (1997)
R292a	Atmospheric Dispersion at Low Wind Speed
R292b	Application of Computational Fluid Dynamics Codes to Near-field Atmospheric Dispersion
R292c	Rise of a Buoyant Plume from a Building Wake
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 1996/97. NRPB-R302 (1999)
R302a	Atmospheric Dispersion at Low Wind Speed
R302b	Review of Models for Calculating Air Concentrations when Plumes Impinge on Buildings or the Ground
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 1997/98. NRPB-R316 (1999)
R316a	Portability of Weather Data for Dispersion Calculations
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 1998/99. NRPB-R322 (2001)
R322a	Review of Deposition Velocity and Washout Coefficient
R322b	Review of Flow and Dispersion in the Vicinity of Groups of Buildings
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 1999/2000. NRPB-W2 (2002)
W2a	Review of dispersion over bodies of water
W2b	Best practice for binning meteorological data
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 2000/01. NRPB-W3 (2002)
W3a	Options for the most appropriate meteorological data for use in short range dispersion modelling
W3b	Methods for undertaking uncertainty analyses
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 2001/02. ADMLC-R1 (To be published in 2004)
R1a	Data assimilation following accidental releases in rain
R1b	Dispersion in complex terrain
R1c	Workshop on reliability of atmospheric dispersion models

**TABLE 1 List of ADMWG and ADMLC reports, and the code-names used in this report**

Code-name	Full title
	Atmospheric Dispersion Modelling Liaison Committee. Annual Report 2002/03. ADMLC-R2 (To be published in 2004)
R2a	Sources of meteorological data for use in dispersion modelling
R2b	Uncertainty in deriving dispersion parameters from meteorological data
R2c	Dispersion from accidental releases in urban areas
R2d	Effect on atmospheric dispersion of changing land use around Heathrow

The report R1b has been delayed, and was not available at the time of writing this report. It is not considered further in this review.

One of the aims of the work was to identify gaps or overlaps where different reports relate to similar topics. The reports were divided into a set of groups relating to similar topics. The groups and reports in each are listed in Table 2. One report (R302b) deals with concentrations when plumes impinge on buildings or on terrain features, and was included in both the buildings and the complex terrain group. One report (HB9) describes the prospects for updating the dispersion model; this report includes extensive sections for flat and for complex terrain, and is considered in both the "basic Gaussian model" and the "complex terrain" groups. One "report" (W3b) deals only with methods of undertaking uncertainty analyses, and is not considered further in this review. The remaining sections of this report discuss the different groups identified here, with a section describing each of the groups. The sections summarise the contents of the different reports and comment on the overlap and gaps between the coverage in the different reports in a section. The sections also include recommendations for future work; this is a summary of the recommendations given in the original reports rather than an outcome of this review.

A check was also made that there are no overlaps between reports in different groups. This was achieved by identifying any aspects of a report that might relate to a different group while undertaking the original review of the report.

**TABLE 2 Groups of topics**

Topic	Reports in group
Basic Gaussian model	R91, R122, R123, HB9
Plume rise	R157b, R292c
Values for deposition parameters	R157d, R322a
Dispersion at low wind speeds	R292a, R302a
Effects of buildings	R157c, R302b, R322b, R2c
Complex terrain	HB9, R302b
Coastal effects	R157a, W2a
Use of meteorological data	R316a, W2b, W3a, R2a, R2d
Rain and data assimilation	R198, R1a
Model uncertainty	R199, R1c, R2b
Capabilities of CFD modelling	R292b
Long range dispersion from a short release	R124

Some of the ADMLC reports which were published by NRPB appear on the NRPB web site. A further part of this work was to put copies of all other reports onto the ADMLC web site, and to include a set of keywords with each report that would enable them to be found by other people undertaking web searches. The reports held on the ADMLC website are in pdf format but the report text is also included in a hidden, searchable bitmap that accompanies each pdf. Some search engines on the Web are capable of searching these bit map files and will pick up the associated pdf if a match is found. In this case the user would access the pdf directly from the search engine which could present problems if the pdf is very large. It would be better if the search engine first picked up the HTML page that gives a summary of the report. This can be achieved using keywords and the hierarchical structure of the HTML Web page. The chosen keywords are entered into the title section of the HTML page which is the first part of the page to be searched by the search engine. This increases the likelihood that the HTML page is picked up first and the user can then access the pdf through the link provided.

Inevitably some keywords could be used for more than one of the ADMLC documents, and so a consistent set of keywords was devised and keywords for each of the reports were then chosen from that list. The complete list of keywords used is presented in Table 3, which also shows which report each keyword is used in. The information on keywords is also summarised in Table 4, which shows the complete set of keywords for each of the reports. This table gives keywords for parts of reports, such as R157a. However, the web site will not be able to distinguish the different parts of a report in this way, and the keywords will apply to the report as a whole.

**TABLE 3 Keywords used for the reports, and included in the web site**

Keyword	Used for
Accidental release	R1a
Atmospheric dispersion	All reports
Atmospheric stability category	R91, R123, HB9

**TABLE 3 Keywords used for the reports, and included in the web site**

Keyword	Used for
ADMS	HB9, R1c, R2b, R157b, R292c, R322b, W2a
AERMOD	R1c, R2b
Binning	W3a
Boundary layer	R91, HB9
Boundary layer parameters	R1c, R2b, HB9
Buildings	R157b, R199, R292c, R302b, R322c, R1c, R2c
Calm conditions	R292a, R302a, R2b
CFD	R292b, R292c, R302b
Coastal effects	R157a, R199, W2a
Complex terrain	R302b, HB9
Continuous release	R123, W2b
Data assimilation	R1a
Deposition	R122, R123, R124, R157d, R199, R322a, R1a
Deposition velocity	R122, R123, R157d, R322a
Evaluation	R1c, R2b
Friction velocity	R322a
Fumigation	R157a
Gaussian plume model	R91, R122, R123, R157a, R157b, R157d, R198, R199, HB9, R292a, R292c, R302a, R302b, W2a, R1a, R1c, R2b
Groups of buildings	R322c, R2c
Impinging plumes	HB9, R302b
Interception	R157d
Internal boundary layer	R157a, R199
Interpolation	R1a
Kriging	R1a
Long range dispersion	R123, R124, R199
Low wind speed	R199, R292a, R302a, R2b
Met data	R199, R292a, R302a, R316a, W2b, W3a, R1c, R2b, R2d
Meteorological data	R199, R292a, R302a, R316a, W2b, W3a, R1c, R2b, R2d
Met pre-processor	R1c, R2b
Mixing layer	R91, R123, HB9
Monitoring	R1a
NWP data	W3a, R2a, R2d
Occult wet deposition	R322a
Plume rise	R157b, R199, R292c
Puff model	R198
Rain	R122, R322a, R1a
Rainfall rate	R157d, R198
Rainout	R122, R157d, R198
Roughness length	R91, R322a
R91	R91, R122, R123, R157(all parts), R198, R199, HB9, R322c

**TABLE 3 Keywords used for the reports, and included in the web site**

Keyword	Used for
Scavenging coefficient	R322a
Sea-breeze	R157a, R199, W2a
Short release	R124, R198, R199
Single building	R157c, R322c
Uncertainty	R199, HB9, R292b, W3b, R1c, R2b
Urban dispersion	R322c, R2c
Validation	R199, R1c
Washout	R122, R157d
Washout coefficient	R122, R123, R157d, R198, R322a, R1a
Wet deposition	R198
Wet removal coefficient	R157d
Wind-tunnel	R292c, R302b, R3232c, R2c

**TABLE 4 Keywords used for each of the reports**

Report code-name	Keywords
R91	Atmospheric dispersion, atmospheric stability category, boundary layer, Gaussian plume model, mixing layer, roughness length, R91
R122	Atmospheric dispersion, deposition, deposition velocity, Gaussian plume model, rain, rainout, R91, washout, washout coefficient
R123	Atmospheric dispersion, atmospheric stability category, continuous release, deposition, deposition velocity, Gaussian plume model, long range dispersion, mixing layer, R91, washout coefficient
R124	Atmospheric dispersion, deposition, long range dispersion, short release
R157a	Atmospheric dispersion, coastal effects, fumigation, Gaussian plume model, internal boundary layer, R91, sea-breeze
R157b	Atmospheric dispersion, ADMS, Briggs, buildings, CFD, Gaussian plume model, plume rise, R91
R157c	Atmospheric dispersion, buildings, R91, single buildings, wind tunnels
R157d	Atmospheric dispersion, deposition, deposition velocity, Gaussian plume model, interception, rainfall rate, rainout, R91, washout, washout coefficient, wet removal coefficient
R198	Atmospheric dispersion, Gaussian plume model, puff model, rainfall rate, rainout, R91, short release, wet deposition, washout coefficient
R199	Atmospheric dispersion, buildings, coastal effects, deposition, Gaussian plume model, internal boundary layer, long range dispersion, low wind speed, met data, meteorological data, plume rise, R91, sea-breeze, short release, uncertainty, validation
HB9	Atmospheric dispersion, atmospheric stability category, boundary layer, boundary layer parameters, complex terrain, Gaussian plume model, impinging plumes, mixing layer, R91, uncertainty
R292a	Atmospheric dispersion, calm conditions, Gaussian plume model, low wind speed, met data, meteorological data
R292b	Atmospheric dispersion, CFD, uncertainty
R292c	Atmospheric dispersion, ADMS, Briggs, buildings, CFD, Gaussian plume model, plume rise, wind-tunnel
R302a	Atmospheric dispersion, calm conditions, Gaussian plume model, low wind speed, met data, meteorological data

**TABLE 4 Keywords used for each of the reports**

Report code-name	Keywords
R302b	Atmospheric dispersion, buildings, CFD, complex terrain, Gaussian plume model, impinging plumes, wind tunnels
R316a	Atmospheric dispersion, met data, meteorological data
R322a	Atmospheric dispersion, deposition, deposition velocity, friction velocity, occult wet deposition, rain, roughness length, scavenging coefficient, washout coefficient
R322b	ADMS, atmospheric dispersion, buildings, groups of buildings, R91, single buildings, urban dispersion, wind tunnels
W2a	ADMS, atmospheric dispersion, coastal effects, Gaussian plume model, sea-breeze
W2b	Atmospheric dispersion, met data, meteorological data, NWP
W3a	Atmospheric dispersion, met data, meteorological data, NWP
W3b	Atmospheric dispersion, uncertainty
R1a	Accidental release, atmospheric dispersion, deposition, data assimilation, Gaussian plume model, interpolation, kriging, monitoring, rain, washout coefficient
R1c	Atmospheric dispersion, ADMS, AERMOD, boundary layer parameters, buildings, evaluation, Gaussian plume model, met data, meteorological data, met pre-processor, uncertainty, validation
R2a	Atmospheric dispersion, met data, meteorological data, NWP
R2b	Atmospheric dispersion, ADMS, AERMOD, boundary layer parameters, calm conditions, evaluation, Gaussian plume model, low wind speed, met data, meteorological data, met pre-processor, uncertainty
R2c	Atmospheric dispersion, buildings, groups of buildings, urban dispersion, wind tunnels
R2d	Atmospheric dispersion, met data, meteorological data, NWP

## 2 REVIEW OF REPORTS RELATING TO THE BASIC GAUSSIAN MODEL

The basic model is considered in three reports, all from ADMWG (R91, R122 and R123). Options for updating this model are considered in HB9.

### 2.1 Scope of R91

R91 describes the basic formulation of the Gaussian plume dispersion model. This model enables calculations to be performed for a range of atmospheric stability, with allowance for the influence of duration of release. The original model was developed for application to the dispersion of radioactive material, but it found equal relevance to the dispersion of chemical species.

The report notes that the Gaussian plume model was chosen ahead of other models, considered to represent better the physical processes of turbulent diffusion in the atmosphere, for example closure models of which eddy-diffusivity models are the simplest. However these intricate models, according to

results obtained in previous studies, did not warrant the additional complexity and cost to users. In selecting the Gaussian plume model consideration was given not only to the developments in calculations of atmospheric dispersion, but also to the availability of a scheme to classify any given set of meteorological conditions into parameters for use in the various models available. On the basis of these considerations a Gaussian plume model was used.

The models included in the report apply to the atmospheric diffusion of a neutrally buoyant plume over land from an isolated stack for short and medium range dispersion i.e. less than a few tens of kilometres from the source, while the meteorological and topographical conditions remain steady. It is assumed that the released material undergoes no chemical or radioactive transformations. The procedure proposed in the report for estimating dispersion is only applicable when the release point is sufficiently distant from surrounding buildings for the air flow at the release height to be relatively undisturbed.

The report suggests that when modelling continuous releases the horizontal dispersion of the plume is no longer satisfactorily described by the Gaussian plume model. Instead the horizontal dispersion of activity is assumed to be constant over each individual sector.

R91 advises typical values of wind speed, boundary layer depth and stability category distribution. Furthermore, methods for calculating the vertical and horizontal plume standard deviations and the sector angle for meteorological data in continuous releases are provided.

The report considers atmospheric stability categories and recommends Smith's diffusion typing scheme. The scheme proposed is quantitative and attempts to account for sensible heat flux in the lower layers of the atmosphere, wind speed, the effect of ground roughness and also clearly distinguishes night-time conditions.

The models were chosen so that they could be extended to deal with dry and wet deposition, plume rise and entrainment of the effluents into the wake behind buildings.

## **2.2 Scope of R122**

R122 describes methods for extending the original Gaussian dispersion model to include dry and wet deposition. This report contains a brief outline of the dispersion model followed by sections describing methods for the inclusion of dry and wet deposition.

The report highlights that the models for wet and dry deposition can be applied for any release duration although there are limitations on the use of the wet deposition model for short releases.

The report recommends that the dry deposition rate should be calculated using the concept of a deposition velocity. The report suggests the use of the source

depletion model for including dry deposition (as opposed to the alternative approach, surface depletion models). The source depletion model does not necessarily represent the physical distribution of activity in the atmosphere but it is simple to use and gives results which are considered sufficiently reliable for use in assessing the dosimetric consequences of radioactive discharges. The principal area in which the model breaks down is for dispersion from a low stack in stable conditions (especially categories F and G). A further restriction is that the model makes no allowance for gravitational settling and should not be applied to particles with a settling velocity greater than a few centimetres per second, corresponding to particles of diameter greater than around 10  $\mu\text{m}$ .

The report suggests that the wet deposition rate during rainfall be calculated using a washout coefficient. This approach includes both of the main removal processes, washout and rainout.

The report considered three models which describe the intermittent nature of rainfall and lead to the calculation of the fraction of the time that a dispersing plume from a continuous release is subject to rainfall. The model describing the explicit passage of activity between periods of wet and dry conditions was selected, as it is physically more realistic and not much more complicated to apply.

The model was selected primarily for application to a continuous release and is only appropriate for application to short releases when a large number of short releases in category D are considered or when averages are being calculated. It predicts the amount of material left in the plume using a statistical treatment of the sequence of wet and dry conditions affecting a dispersing plume. For wet deposition the report recommends values of  $P_D$  and  $P_W$  (the probability of dry weather stopping in unit time and the probability of wet weather stopping in unit time respectively).

The report assumes that rainfall only occurs in category D conditions.

The report does not include consideration of values of washout coefficient for use in the model. Furthermore, the report suggests that when using the recommended model, the solution given will over estimate wet deposition due to rainout at short distances, where the plume has not spread fully through the mixing layer.

### **2.3 Scope of R123**

R123 describes a method for extending atmospheric dispersion calculations to long ranges for continuous releases. In reaching its conclusions on a model for long-range dispersion from a continuous release, the report considered the results of two studies comparing concentrations and deposition rates predicted by a range of models. The model chosen represents a compromise between those giving a good description of the physical processes involved and those which are simple to use.

The report recommends that long-range dispersion should be evaluated assuming that all releases occur in neutral stability but allowing for a range of wind speeds, and using a mixing layer depth of 800m for all conditions. This was considered to reflect the average effect of changing conditions during plume travel.

The report suggests that, when calculating concentrations, the original model (R91) should be used at distances less than 50km and the model described in this report at greater distances.

Further recommendations are made for the values of numerous dispersion parameters including wind speed and frequency distribution in different directions and vertical standard deviation of the plume.

## **2.4 Scope of HB9**

This report was written in response to concerns that the model in R91 was becoming dated, and that research since it was written might enable a relatively simple, but improved, model to be developed. It is restricted to considering dispersion within about 30 km of the source, and does not consider deposition. The report proposes the use of indicators of the stability of the atmosphere (and the corresponding turbulence and dispersion coefficients) which vary continuously in place of the discrete stability categories of earlier Gaussian models.

The report describes stable, neutral and convective boundary layers. It includes sections relating to the structure of the boundary layer and dispersion within the boundary layer. Much of the report relates to situations where the boundary layer is in equilibrium but there is a short discussion of problems when the boundary layer structure is changing with time, and does not fit into any of the idealised categories. There is also a discussion of the effects of spatial changes in the boundary layer structure, though this concludes that the boundary layer is likely to be able to accommodate such changes, retaining one of the idealised structures.

Other work (not through ADMLC) has shown that different methods of estimating atmospheric stability may give very different results. The report HB9 suggests that this reflects the general weakness of schemes (such as that in R91) which derive the boundary layer structure using only information on conditions at the ground, and that an improved model could remove much of this variation.

The report describes the motion of discharged particles and gases, leading to descriptions of the concentration distribution at different distances and for the different boundary layer structures considered. It identifies a number of aspects of dispersion which are not well described by Gaussian models generally. This leads to a more general description of where relatively simple changes could be made to improve simple Gaussian models, proposing formulae for an improved

model. Some predictions of the suggested model are compared to results from R91, and areas where the models might give different predictions are identified. The report notes that a limitation of the Gaussian plume model is that atmospheric conditions must remain constant over the period of interest, and discusses puff models as a means of avoiding some of the limitations. The report also gives a brief review of some research grade models, considering whether they might be useful in specific situations. It also comments on validation of models by comparing their predictions with those of numerical simulation techniques.

## **2.5 Areas of overlap between the reports**

R91 describes a simple model which does not allow for deposition and is only appropriate within a few tens of kilometres of the release point. R122 extends this model to include dry deposition for both short and continuous releases. It also extends the model to include wet deposition primarily for continuous releases. R123 extends R91 by giving a method of applying the model at larger distances. There are no contradictions between these reports.

HB9 overlaps considerably with R91. It proposes ways of improving the original model and therefore is an update to the earlier report. It identifies a number of weaknesses in simple Gaussian plume models.

## **2.6 Gaps in the areas covered by the models**

HB9 and R91 cover the same general areas, and therefore references in the following to R91 should be interpreted as meaning the scope of both R91 and HB9.

The reports only consider the dispersion of neutrally buoyant material. ADMLC and ADMWG have extended the models to consider plume rise from buoyant material (see Section 3) but have not considered dispersion of dense gases.

The reports neglect the consideration of large particles and the impact they have on atmospheric dispersion, notably in R122.

The models in the reports are incapable of dealing with variable atmospheric conditions. For example a condition of the model in R123 is neutral stability (representing changes of stability during travel) and the model in R91 is only applicable while the initial stability conditions persist.

R91 assumes no chemical and radioactive transformations occur, therefore the model does not account for radioactive decay.

R122 does not give any guidance on the values of the parameters for use in the models suggested. This is given in other reports, as discussed in Section 4 of this report.

The reports do not recommend models suitable for use when calculating wet deposition from a specific short release. ADMWG considered this in R198, as discussed in Section 10 of this report.

Finally the model from these reports does not consider plume rise or wake effects, however the model can be extended to account for these effects, which were considered in subsequent reports (See Sections 3 and 7 of this report).

## **2.7 Recommendations for future work**

R91, R122 and R123 do not give explicit recommendations for future work. HB9 notes that it is possible to develop a more advanced airflow and dispersion model than that of R91, capable of running on a PC, and that such a model should be developed. This recommendation has been implemented; the resulting model is the commercial software package known as ADMS.

# **3 REVIEW OF REPORTS RELATING TO PLUME RISE**

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Plume rise is considered in two reports, one from ADMWG (R157b) and one from ADMLC (R292c).

## **3.1 Scope of R157b**

R157b describes methods of modelling plume rise from isolated sources and discusses plume rise from sources discharging into a building wake.

For plume rise from an isolated source the report recommends two plume rise models, those suggested by Briggs or Moore. It suggests that the Moore model gives a marginally more accurate prediction of plume rise than the Briggs model. Termination of plume rise is discussed and the calculation of ground level concentrations under a rising plume is discussed. The problems associated with lift-off of buoyant plumes from sources at ground level are discussed.

For releases from a building wake, threshold values are defined for the source momentum and buoyancy fluxes such that if neither is exceeded then the emission can be assumed to be passive. The report does not give a model for plume rise from a building wake, for use if the threshold values are exceeded. However, a formula is given for the final height of a plume emitted with vertical momentum from a source on or above the building roof.

### **3.2 Scope of R292c**

R292c is a review of the (then) current practical modelling options for the rise of buoyant plumes from building wakes and a review of the likely future developments. Models to calculate the ground level concentration under a rising plume are recommended. The physical processes within a buoyant plume are discussed as well as the experimental and theoretical aspects which need to be considered. The report deals with source heights ranging from ground level to a little above roof level.

The report lists cases where it is reasonable (or at least conservative) to treat emissions as passive and other cases where this approach should not be adopted. The report then considers different modelling approaches and recommends situations where specific models may be appropriate.

The report suggests the ADMS model is potentially suitable for modelling plume rise as it contains a reasonably detailed representation of the modifications to flow and dispersion brought about by large buildings together with an integral model for plume rise. The report notes that small scale building or site details near to the source may introduce dispersion features at a scale well below that which the ADMS model can be expected to handle.

The use of computational fluid dynamics (CFD) calculations is discussed and results from a number of studies which use the  $k-\epsilon$  model are presented. The report notes that the accuracy of the calculations, where comparisons with data are possible, is best for passive emissions and tends to degrade with increasing plume buoyancy. The deficiencies in  $k-\epsilon$  modelling are also noted.

Wind-tunnel modelling is only mentioned briefly as it was outside the scope of the review. Situations where wind-tunnel modelling can be considered are listed and the report notes that results from wind-tunnel studies can be used in conjunction with computer modelling to complete an assessment procedure.

The report finishes by discussing areas where future development might proceed with reasonable expectation of success.

### **3.3 Areas of overlap between R157b and R292c**

The methods discussed in R157b should be considered as screening approaches and R292c notes that the threshold approach suggested in R157b is a very crude approximation. R292c considers more complex modelling techniques and uses experimental data to draw conclusions. There is little overlap but if there are any areas of disagreement, R292c should be considered as updating R157a.

### **3.4 Gaps in the areas covered by the models**

Plume rise from area and volume sources, directional releases, jets and heavier than air releases dominated by buoyancy have not been considered by ADMLC/ADWMG.

### **3.5 Recommendations for future work**

R157b does not give any specific recommendations for future work.

R292b notes possible extensions to simple Gaussian models, and suggests that these should be explored further. It also suggests that the capabilities of CFD modelling in this area should be assessed. It notes that a comprehensive set of test cases should be defined for which adequate data are available, so enabling future developments to be evaluated.

## **4 REVIEW OF REPORTS RELATING TO VALUES OF DEPOSITION PARAMETERS**

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Values for the deposition parameters are considered in two reports, one from ADMWG (R157d) and one from ADMLC (R322a).

### **4.1 Scope of R157d**

R157d includes guidance on the values of deposition velocity and washout coefficient for use in the models recommended in R122.

The report advises that deposition velocity, integral in determining dry deposition, be expressed in terms of the resistance to transfer through the turbulent boundary layer, the viscous boundary layer and the surface.

R157d considers the processes affecting dry deposition. The report summarises the impact of surface roughness and atmospheric stability, notably grass in neutral conditions, on the deposition velocity. The report also pays particular attention to the effect that material type (particles or gases) and the size of particular material have on deposition velocity. The report emphasises that the recommended values of deposition velocity are described by a range, as opposed to individual values.

R157d considers the processes affecting wet deposition. The report examines the variation of the washout coefficient with rainfall rate and particle size. Guidance is given on a range of values for the wet removal coefficient incorporating the effects of both rainout (removal within rain clouds by incorporation in rain drops as they form) and washout (removal by rain falling through the dispersing

plume) as it is very difficult to separate their individual contributions. The report suggests that use of the wet removal coefficient at short distances will tend to overestimate the deposition rate.

The report considers it adequate to ignore the variation of washout coefficient with rainfall rate, when calculating long-term average deposition rates, and to assume that rain falls at a rate of 1 mm per hour. The report considers type and intensity, and spatial and temporal extent of precipitation for a short release. This includes comparisons of frontal rainfall and showers. However the range of wet removal coefficient values given in the report does not consider these processes but assumes average conditions for a continuous release. The report also comments on the use of a washout coefficient when considering reactive gases.

Finally R157d considers the interception of deposits from the atmosphere by plants. The report considers an additional factor to determine the amount of material deposited on the edible parts of plants. The report recommends an approach using an interception factor and a retention half-life, and includes formulae for calculating the interception factor. Furthermore, the report recommends generic values for calculating the interception factor on pasture grass, however it notes that this recommendation does not extend to crops due to a lack of experimental data available.

## **4.2 Scope of R322a**

R322a seeks to expand upon and update the advice given in R157d, taking account of new information that has become available since its publication.

The report makes recommendations which are robust in terms of their dependence on meteorological conditions, on physico-chemical form of the pollutant, and in representing the trends in variation amongst a number of key surface types, whilst at the same time reflecting current uncertainties. Where recommendations are made, two types of value are given in the report, a "best judgement" value and a "conservative" value.

A review of values of deposition velocity for particulate material and for those gases of interest to the nuclear industry was undertaken. The report considers particles in the (aerodynamic) diameter range 0.1 micron to 10 microns, paying particular attention to those particles in the range 0.1 micron to 1 micron since many of the pollutant particles surviving well beyond the immediate vicinity of primary sources lie in this size range. The report also considers iodine in elemental and organic forms.

For dry deposition, the dependence on surface type and weather conditions is considered. The primary surface type of interest is taken to be grass and crop canopies, but separate consideration is given to forest canopies and water bodies. In addition, the particular features of the urban environment are discussed and recommendations of deposition velocity for all mentioned surface

types are made. The dependence on weather conditions is discussed in terms of windspeed and atmospheric stability.

For wet deposition, both washout and rainout are discussed. Separate consideration is also given to deposition in fog or in hill cloud.

A review of values of washout coefficient for particulate material (as for deposition velocity) concentrates on particles in the size range from about 0.1 to a few microns AMAD and iodine in elemental and organic forms. The report gives little guidance on the variation of washout coefficient with rainfall rate and with the type of rain (e.g. rain from frontal systems or thunder storms) but does consider the enhancement of deposition under conditions of orographic rainfall, described by the seeder-feeder mechanism.

Furthermore the report compares its own approach to modelling wet and more notably dry deposition with other approaches. The comparison of deposition velocities comprises of data compilations, empirical relationships, semi-empirical approaches and theoretical models.

### **4.3 Areas of overlap between R157d and R322a**

R157d and R322a both review deposition velocity and washout coefficient and therefore there exists a significant amount of overlap. Both reports consider values for reactive gases intended primarily for elemental iodine. Particle sizes of 0.1 to 10 microns are considered in both reports, as is a generic rainfall rate of 1 mm per hour.

R322a describes the deposition velocity in an analogous manner to R157d. That is in terms of a transfer resistance, which can be broken down into the components: aerodynamic resistance, sub-layer resistance and surface resistance.

R322a expands and updates the recommendations in R157d. Therefore, if there exist any areas of disagreement, R322a should be considered as updating R157d.

### **4.4 Gaps in the areas covered by the models**

The reports give little guidance on the variation of washout coefficient with rainfall rate and with the type of rain. It is out of the scope of R322a (and R157d) to consider the impact of the large-scale motions associated with thunderstorms, which can lead to pollutants being deposited at locations far removed from those implied by the boundary-layer wind field.

There exists relatively little guidance regarding the deposition of methyl iodide (organic iodine), particularly for its deposition velocity in urban areas and its washout coefficient.

#### **4.5 Recommendations for future work**

Neither of these reports makes explicit recommendations for future work.

## **5 REVIEW OF REPORTS RELATING TO DISPERSION AT LOW WIND SPEEDS**

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Atmospheric dispersion in conditions with low wind speeds is considered in two reports, R292a and R302a.

### **5.1 Scope of R292a**

This report reviewed dispersion models for two sets of situations (i) where there is very small wind speed over the period of interest and (ii) where the vector average of the wind velocity over the period of interest is zero. It also looked at the frequency of calm conditions and anemometer response at low wind speeds.

The report reviews several models for conditions with a very low wind speed, including ways of adapting the simple Gaussian plume model, approaches based on modelling puffs and solutions of the diffusion equation. While there is no clear recommendation on choice of model, the emphasis is on simple modifications to the R91 model.

The report also describes a model for concentration in unstable conditions in periods when the vector average of wind velocity is zero, but where there are shorter periods with non-zero wind speed. This model leads to predictions for the probability distribution of concentration for different averaging times and distances from the release; some results of the model are presented graphically.

The report also briefly considers plume rise, the effects of buildings and terrain on dispersion, and the calculation of annual average concentration including that during "calm" conditions. The review for plume rise notes that Briggs discussed how elevated inversions would terminate rise. The report points out that modern integral plume rise models automatically include rise at low wind speed if the atmospheric conditions are adequately described.

### **5.2 Scope of R302a**

This report was written by W S Atkins. At the time of this report, they were working for HSE on the importance of modelling dispersion at low wind speed when undertaking quantified risk analyses; this work was extended for ADMLC to include methods for allowing for low wind speed conditions when calculating annual average concentrations. This report therefore concentrates on the cross-wind integrated air concentration, rather than the centre-line concentration.

The report reviews appropriate models, referencing R292a. It points out that the travel distance is limited by the wind speed and the typical duration of low wind speed conditions, and therefore that the models should only be used close to the site. It suggests that the simple Gaussian plume model, as in R91, with a minimum wind speed and an allowance for the possible travel distance in low wind speeds is a reasonable approach. The report advises that the best approach is to consider the application and to use an appropriate methodology with suitable assumptions.

The report discusses the availability of data on the frequency distribution of wind speed, and suggests that using a single representative wind speed for each stability category is not adequate, but that the frequency of different wind speeds should be considered.

This report presents a number of comparisons of the variation of concentration with distance predicted using different dispersion models or different amounts of detail on the distribution of wind speed, for annual average concentrations and for concentrations in specific conditions.

### **5.3 Areas of overlap**

During the period when these reports were being prepared, W S Atkins were undertaking work on low wind speed dispersion for HSE, with a report on the first part of their study published in 1996, and referenced in R292a. The work for ADMLC was added on to the second part of the study by slightly extending its objectives. Although R302a references R292a there is some overlap between the two reports.

Both reports review dispersion models for low wind speeds, and make comments on the assumptions involved in such models. However, neither report comes to clear conclusions on the most appropriate model for particular applications and so the reports do not contradict each other.

### **5.4 Gaps in the areas covered by the models**

The two reports provide a reasonable review of models for dispersion of non-buoyant material from point sources. There are probably no gaps here. The reports make some comments on the effects of buildings, complex terrain and plume rise on dispersion, and the variation of deposition velocity with wind speed or stability. Some of this seems to be little more than speculation, and there may be some benefit in a more detailed examination of these topics.

R302a includes numerical comparisons of different models or assumptions. Many of these are limited to annual average concentrations or the cross-wind integrated concentration in specific conditions. The report says that specific modelling is less important in the nuclear industry than in the chemical industry, because of the linear dose response relationship used in studies for releases of

radioactive material. There may be benefit in doing similar calculations for peak concentration for short releases.

## **5.5 Recommendations for future work**

R292a notes that there are no simple models for calculating concentration in stable conditions at very low wind speeds, and suggests that the likely importance of such conditions should be assessed. R302a does not make any specific recommendations for further work.

# **6 REVIEW OF REPORTS RELATED TO DISPERSION FROM SOURCES CLOSE TO BUILDINGS**

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Dispersion from sources close to buildings is considered in 4 reports; R157c mainly relates to sources near single buildings, R302b relates to concentrations when plumes impinge on buildings, R322b relates to dispersion from sites with several buildings while R2c relates to dispersion from short duration releases within urban areas.

## **6.1 Scope of R157c**

R157c gives advice on dispersion for five positions of the source relative to the building.

It gives a detailed description of models for concentration in the near and main wake for use when all emitted material is entrained (i.e. for a source on or just above the roof, or within the re-circulating wake region). The model for the near wake is appropriate for an averaging time of a few tens of minutes and the report gives a method of extending this to longer duration releases, including continuous releases. For sources well above the roof, R157c recommends the use of a model by Hunt and Robins, which is said to be too complex for the equations to be included in the report. Concentrations at distances beyond the wake for a source well above the building roof should be calculated using an effective stack height.

For a source upwind of the building where the plume can impinge on the building face, the report suggests that the concentration on the building face should be taken as the maximum concentration at that distance from the source in the absence of the building. The report also suggests when plumes should be considered as impinging on the building face. The report notes that material may travel upwind for some source positions, but gives no information on the concentration or extent of upwind travel; it also gives no recommendations for calculating the concentration downwind of the building for sources upwind.

The report discusses the problems of modelling sources within the main wake, on the upwind face of the building or on or near a side face of the building, but does not recommend a model for these cases. It identifies a method giving a conservative prediction of the concentration at locations on a building surface from a source at another point on the surface of the building.

The report suggests that physical modelling (i.e. the use of wind or water tunnels) could be appropriate for many situations for which there is no suitable analytical model.

R157c relates only to the dispersion of neutrally buoyant material released without vertical momentum. The plume rise section, R157b, gives criteria for which it is reasonable to ignore plume rise for releases near a building. It suggests that wind tunnel studies should be considered if the conditions are such that the criteria are not met.

## **6.2 Scope of R302b**

The main aim of this project was to review concentrations on building surfaces when plumes impinge on the building. However, it addressed a number of other aspects of modelling dispersion near buildings.

The report sets out the interactions between plumes and buildings for different sizes of the plume compared to the building, and concentrates on the situations where the plume width is less than or comparable to the building size. This implies that the source is relatively close to the building, and so the report considers dispersion from sources which are close to buildings. The report describes the airflow around a single building, and briefly considers the influence of nearby buildings. The report considers methods for calculating the concentration on a building face for sources which are upwind of the building, on the building, above the building roof or within the re-circulating wake. The discussion for the re-circulating wake covers the concentration close to the source before it diffuses through the wake as well as the average concentration in the wake. The report also examines the amount of material that becomes entrained into the wake for sources in various locations near the building. The report states that it is nearly impossible to formulate an accurate empirical model for complex sites, but gives some pointers to work on this topic.

The report includes a simple model for calculating the concentration indoors from plumes outdoors, in terms of air exchange rates. It also considers the applicability of CFD modelling to dispersion around buildings.

## **6.3 Scope of R322b**

R322b is entitled "review of flow and dispersion in the vicinity of groups of buildings". It primarily encompasses modelling for nuclear/industrial sites and

urban areas but also covers some aspects of dispersion from a single building as this is required in understanding the effects of groups of buildings.

The report gives a description of the physical processes involved in flow and dispersion, including single buildings, groups of buildings, porous obstacles and the development of plumes over arrays of obstacles. The discussion on dispersion over arrays of obstacles is divided into three regimes - close to the discharge, the intermediate region and the region far from the source. The discussion on dispersion close to the source relates mainly to dispersion from a single building, but extends the discussion of R157c by giving more information for source positions other than in the main wake. The report states that "the precise prediction of concentrations resulting from specific arrangements of source and obstacles generally requires wind tunnel or field experiments, as observed distributions of concentration are usually quite different from those found for obstacles in isolation".

The report then describes current practical approaches to dispersion modelling for single buildings, groups of buildings and urban areas. The review for single buildings covers R157c, ISC and PRIME but concentrates on the ADMS model which covers all aspects of dispersion near a single building. The discussion for groups of buildings is short, covering effective building sizes as used in ISC and ADMS. The discussion for urban areas covers the role of Gaussian models, street canyon models and methods linking detailed numerical modelling close to the source with Gaussian modelling at longer distances.

The report covers the role of what it terms "more complex approaches", namely physical modelling and computational modelling. The section on physical modelling includes wind tunnels, scale models in the field and full scale urban dispersion experiments. The section on computational modelling covers solutions of the diffusion equation and flow field modelling such as  $k-\epsilon$  or CFD modelling.

The report includes a review of recent experimental work on dispersion following emissions above building arrays, through porous obstacles and within groups of buildings. It then discusses the implications of recent work for modelling, with the emphasis on plumes where  $\sigma_z$  is greater than the general building height. This identifies problems with enhanced spread along the wind direction as a result of material "held up" in the wakes of buildings.

Finally the report reviews the limitations of current understanding and the prospects and limitations of future modelling work.

#### **6.4 Scope of R2c**

The report distinguishes three aspects of the problem, namely dispersion at the building/street scale, the neighbourhood scale and the meso-scale; these regions correspond to the three regimes considered in R322b. It discusses models for the airflow and dispersion for each of these scales. There is also a

brief section on dispersion in enclosed spaces, such as a courtyard surrounded by tall buildings.

The report distinguishes between fully computational models (FCM) and fast approximate models (FAM) for both the air flow and the dispersion. FCM require substantial amounts of computer time, and are essentially research models. FAM are based on simplifications of the appropriate equations or other parameterisations of the dispersion process.

The section on airflow at the building/street scale distinguishes several regions depending on the typical sizes and spacings of the buildings, and gives criteria for identifying the different regions.

The section on dispersion concentrates on FAMs. It gives detailed equations for dispersion very near the source and for the building/street scale. Dispersion on the larger scales is described mainly by references to appropriate published papers and a small number of equations. The emphasis, particularly for the shorter scales, is on releases from sources below the height of the buildings, though models for the dispersion of material which has spread above the height of the buildings are described.

The report gives a review of field experiments on dispersion in real cities and artificial structures and on laboratory experiments in modelled realistic cities or artificial structures.

The report notes that the meteorological data currently available are not sufficient to support the use of urban models for assessments of dispersion from an actual release. It suggests that information on wind direction could perhaps be obtained by examining CCTV pictures.

## **6.5 Areas of overlap**

R157c, R302b and R322b all review aspects of dispersion near a single building. R302b and R322b both reference R157c, but R322b does not reference R302b.

R157c considers five positions of the source relative to the building, but does not recommend models for all situations. There are no recommended models for sources in the main wake, or for most aspects of sources upwind or to the side of the building. R322b reviews dispersion modelling for a single building, giving models for more situations than R157c. In this respect R322b should be regarded as updating R157c, rather than contradicting it. R302b gives further information, particularly for the concentration close to a source in the re-circulating wake. R322b concentrates on when plumes impinge on buildings, rather than the concentrations further downwind.

R322c and R2c both cover dispersion in urban areas, though the emphasis is rather different. R322c tends towards dispersion from sources above the building height while R2c concentrates on sources below roof level. Both include discussions and descriptions of air flow and dispersion in urban areas; these can

be considered as complementing each other. R322c gives more detailed equations than R2c for dispersion from a single building, while R2c gives a more detailed treatment of dispersion from a point source for different building sizes and spaces.

The reports complement, rather than contradict, each other.

## **6.6 Gaps in the areas covered by the models**

None of the reports include detailed guidance on dispersion from explosions. R2c presents information on the initial plume size but does not relate this to the force of the explosion. The section in R2c on dispersion in courtyards mentions partially covered areas such as railway stations, but does not give much information on this; it could not be considered as a report on dispersion within buildings.

## **6.7 Recommendations for future work**

The recommendations given in the reports can be summarised as follows.

R157c did not give recommendations for further work.

R302b points out that there is a large amount of published information on wind tunnel studies, but that they tend to concentrate on simple rectangular objects. It suggests that further studies for buildings which are wide and squat or tall and slender, or for groups of buildings, walls, lattice structures would be useful. It also points out that the simple extensions to the Gaussian plume model identified in the report could be incorporated into computer programs for modelling dispersion.

R322b concludes with an extensive discussion of the limitations of current understanding and the prospects and limitations of modelling. This lists research topics for 12 general modelling areas. Unfortunately, this section is too long to be easily summarised here.

There are a number of statements throughout R2c pointing to areas where models might be improved, including extending current street canyon or traffic models to consider the effects of short releases, or where comparisons would be beneficial. The conclusions and recommendations section ends by suggesting that more data on wind direction in urban locations are needed, methods for using measured concentrations in urban areas to locate a source should be developed and that further work is needed to validate FAMs against predictions of FCMs.

## **7 REVIEW OF REPORTS RELATING TO EFFECTS OF COMPLEX TERRAIN**

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Aspects of dispersion in complex terrain are considered in three reports. HB9 discusses ways of updating the simple Gaussian dispersion model, with extensive discussions on dispersion in complex terrain. R302b discusses models for calculating concentration when plumes impinge on the ground. Complex terrain will also be considered in R1b, which is not included here as it is not currently available.

### **7.1 Scope of HB9**

This report gives separate discussions on airflow and dispersion in complex terrain. It relates to changes in elevation and to changes in surface roughness.

The report gives a description of why terrain affects dispersion, concentrating on the effects on the maximum concentration at ground level and on the distance from the source to the maximum concentration at ground level. It identifies the features of air flow which can affect dispersion, namely the change in the height of the streamlines, streamline convergence and divergence, changes in wind speed and changes in the turbulence levels along the streamlines. It describes a range of models for calculating the wind field in complex terrain, including deflection/impingement models, interpolation models and predictive models (i.e. ones based on differential equations including perturbation methods for their solution) and discusses the strengths and weaknesses of the various models.

The report describes a range of possible dispersion models for complex terrain, covering simple Gaussian plume models which allow only for the deflection and/or impingement of the plume, Gaussian plume models which include specific consideration of the effects of complex terrain, and research grade models. The report comments on the validity of the different types of models in terms of the assumptions that they make.

### **7.2 Scope of R302b**

The aim of this study was to examine models for the concentration when plumes impinge on higher ground in complex terrain. In order to do this, it examined a number of features of flow and dispersion in complex terrain. The report describes flow around hills, discussing the deflection of streamlines and the concept of a dividing streamline height, and identifies mechanisms that can bring plumes to ground level. It considers the conditions for hills to behave like two or three dimensional obstacles.

The report describes the derivation of the diffusion equation, and how its assumptions relate to flow over hills. It considers several corrections, of different

degrees of complexity, to extend simple models for application to flow over hills and discusses where the extensions are applicable. It then describes models specifically designed for dispersion over hills. The report includes comments on the likely accuracy of some models for calculating dispersion over hills, and restrictions on their applicability. The report indicates situations where model predictions might be particularly sensitive to atmospheric conditions.

There are several areas where the report considers the use of CFD models, identifying some problems in the models and possible pitfalls in their use.

### **7.3 Areas of overlap**

There is considerable overlap between HB9 and R302b, as both discuss modelling of airflow and dispersion in complex terrain. Both describe models for particular applications with equations for some idealised situations, and make comments on the applicability of different techniques. The description in HB9 gives more detail than that in R302a. The reports complement, rather than contradict, each other. There are differences in emphasis, with HB9 giving more attention to analytical methods while R302b tends towards the benefits of CFD methods, although it points out that there are problems with them. This could reflect the change in computer power over the period between the reports.

### **7.4 Gaps in the areas covered by the models**

The reports HB9 and R302b provide an extensive discussion of the general features of airflow and dispersion in complex terrain, and the strengths and weaknesses of various modelling approaches or specific models. There are no obvious gaps in such a general discussion. However, they do not give guidance on how to apply models in a specific situation (e.g. the choice of model for a specific situation, the balance between grid size and the area around the site which can be considered, the need to consider upwind flow in a particular calculation).

### **7.5 Recommendations for future work**

The main recommendation of HB9 is that models based on the improvements to the simple assumptions used in R91 could be developed, suggesting that simple Gaussian modelling for dispersion would be improved by using better models for the airflow and turbulence levels in the boundary layer. It specifically recommends the perturbation approach (adopted in FLOWSTAR) for modelling airflow and dispersion on modest computer systems, but points out that there will need to be further testing and developments of existing codes before they can be relied on to cover most situations of importance.

R302b suggests that further experiments for idealised symmetrical hills are of limited value because of the problems in applying the results to more general situations. It suggests that studies in specific sites for which releases might occur would be valuable, particularly as the number of nuclear sites is limited. The report suggests that a scientific assessment of the assumptions made in a model is vital. It notes that the EPA model CTDMPLUS is a modified Gaussian model for application when plumes impinge on elevated terrain, and suggests that the assumptions behind this model should be examined carefully before it is used in the UK, pointing out that there are some situations, for example in reverse flows downwind of a hill, where this model would be completely invalid.

## **8 REVIEW OF REPORTS RELATING TO COASTAL EFFECTS**

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Coastal effects are considered in two reports, one from ADMWG (R157a) and one from ADMLC (W2a).

### **8.1 Scope of R157a**

R157a describes models for dispersion during a sea-breeze, conditions when a sea-breeze is likely to occur and the effects of the changes in roughness length and stability at the coast.

The report gives little guidance on dispersion when the wind is towards the water. It recommends using the normal Gaussian model for dispersion between the source and the coast, but gives no information on the calculation of concentration while the plume is flowing over water.

The report concentrates on conditions where the wind is blowing towards the land. If the water is warmer than the land, the report suggests that coastal effects will be very small and that the normal model should be used. If the land is warmer than the water, then coastal effects are important. The report recommends a model for use close to the coast, whether or not a sea-breeze is blowing. This is essentially the normal Gaussian model but uses the depth of the thermal internal boundary layer (TIBL) in place of the depth of the mixing layer. The report gives three alternative formulae for the depth of the TIBL. It also gives methods of calculating the values of  $\sigma_y$  and  $\sigma_z$  for sources in either the stable air originating over the water, or the more unstable air over the land.

The report suggests that, for a site with large buildings near the coast, it would be better to ignore the coastal effects and simply use the buildings model.

The report also considers the calculation of long term average concentrations.

The report also gives a model for concentration when a sea-breeze is blowing; this covers the velocity of the sea-breeze front, the depth of the sea-breeze and the concentration in the region affected by the sea-breeze.

## **8.2 Scope of W2a**

W2a concentrates on sea-breeze models. It includes a literature review covering the structure and general effects of a sea-breeze, fumigation effects and circulation/recycling, and recent advances in understanding sea-breezes. It describes dispersion in a sea-breeze, when sea-breezes might occur and their general prevalence, and their penetration inland. It includes sample calculations using different models and an assessment of the strengths of current modelling approaches, concentrating on simple models and CFD techniques. It includes a review of previous work on sea breezes, noting that a large number of studies have used CFD models. It points out that CFD is able to model all of the effects of sea breezes identified in the report, and suggests that results from simple models developed in this area should be compared with either field studies or results of CFD calculations. R157a is considered throughout the review. The ADMS model is also considered.

## **8.3 Areas of overlap between R157a and W2a**

W2a extensively references R157a. Therefore, if there are any areas of disagreement, W2a should be considered as updating R157a.

## **8.4 Gaps in the areas covered by the models**

W2a relates only to sea-breezes and so dispersion when the wind is blowing towards the land; R157a gives only limited information on dispersion when the wind is blowing towards the coast. Neither report considers plume growth over water, or concentrations over land after a plume has passed over water. The reports therefore do not consider dispersion over small bodies of water such as lakes or estuaries.

## **8.5 Recommendations for future work**

R157a does not make any specific recommendations for future work.

W2a notes that, because of the complexity of the situations being modelled, it is unlikely that simple Gaussian models could be modified to take account of all relevant effects. It notes that CFD is much more suited to the problem, but suggests that its applications are likely to be site specific. It identifies a number of possible improvements to simple modelling as having potential for investigation.

## **9 REVIEW OF REPORTS RELATING TO THE USE OF METEOROLOGICAL DATA**

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Items relating to the use of meteorological data are covered in five reports from ADMLC. R316a considered the extent to which data from one site could be used for other sites. W2b considered the calculation of long term averages and whether this is best done using hourly sequential data or statistical data. Three reports (W3a, R2a and R2d) looked at the most appropriate source of data and some aspects of the use of data from numerical weather prediction (NWP) models.

### **9.1 Scope of R316a**

This report describes two studies to compare concentrations calculated using meteorological data from different sites, for two releases (a buoyant release from a tall stack, representing a power station plume, and a weakly buoyant release from a short stack, representing a factory release).

The first study compared predicted concentrations using meteorological data for 17 sites in southern England; the sites were between 40 and 310 km apart. It compared the mean and the 99<sup>th</sup> percentile of the hourly concentration distribution for five cases (all conditions over a five year period together with day and night in both summer and winter). The concentrations were calculated on a grid around the site; the maximum values for each site were then compared.

Results are presented relative to the predicted concentration at one of the sites. The annual average concentrations range from 0.82 to 1.27 for the tall stack and 0.94 to 1.13 for the short stack. The ranges for the 99<sup>th</sup> percentile are smaller than this. There is no indication of a trend in concentration ratios with distance between the sites; however there are correlations between the mean concentration and the mean wind speed for the sites. The report suggests that meteorological data from other sites can be used for dispersion studies, and that the main requirement is that the annual mean wind speeds at the two sites should be similar. The report notes that other studies do not support this view, in particular a Met Office study by Davies and Thomson suggested that weather data should be taken from within 70 km for a typical factory source and within 20 km for a typical power station source.

The second study considered whether information on wind speed and direction from one site could be combined with other data from a neighbouring site. It calculated concentrations for a three month period in summer for three sets of meteorological data:

- a all data taken from Heathrow,
- b wind data from Gatwick with other data from Heathrow

c wind data from Stansted with other data from Heathrow. This showed that the combined data sets gave concentration predictions that did not compare well with those obtained using only the Heathrow data – the average concentrations predicted using combined data were between 0.76 and 0.95 of those predicted using data from only one site.

## **9.2 Scope of W2b**

This report considers the differences between using statistical or sequential meteorological data when calculating long term average concentrations, or percentiles of the hourly concentration distribution. The calculations were undertaken using ADMS version 3, and some of the conclusions may reflect specific features of ADMS. Concentrations were calculated using data for three separate years.

The first part of the study considered concentrations from three sources, namely those used in R316a and a buoyant source from a short stack. This showed good agreement between the values calculated using statistical or sequential data; the results mostly differed by less than 20% with the worst discrepancy being almost 50% for one percentile and one year. Some of the comparisons were repeated using ADMS version 2.2; this showed larger differences, in one case with almost a factor of 2 between the predicted concentrations.

The study was extended to consider a range of release heights from 10 to 100 m for two release temperatures, 15° C and 40° C. The concentrations predicted using sequential or statistical data for the 40° C release differed by less than about 20%. The two predictions for the 15° C release however differed by up to about 70%.

Further studies were undertaken to identify the cause of this difference. These showed that changes to the binning scheme used in preparing the statistical data set had little effect on the results of the comparison. The differences are caused by a specific feature of ADMS version 3. If using sequential data, the code considers both the effluent and the ambient temperature for each hour – the effluent temperature of 15° C means that in some cases the plume is slightly buoyant and in others it is below ambient temperature. If using statistical data, the code assumes that the ambient temperature is 15° C, and therefore that the released plume is always at ambient temperature.

This study concluded that the use of statistical data is adequate, and that there is no evidence that the current binning scheme is inadequate, other than for one situation. The comments about modelling the release at 15° C may be specific to ADMS rather than to other dispersion programs.

### 9.3 Scope of W3a

W3a presents three studies, aimed to investigate whether meteorological data sets have a "shelf life", whether NWP data can be used in place of observational data and the capabilities of the Site Specific Model (a version of the NWP model used for detailed predictions at a specific location) in providing data in particular regions of the UK.

In the first part of the study, the "shelf life" of data sets was investigated by calculating maximum values of long term averages and 99.9<sup>th</sup> percentiles of the hourly concentration distribution for a buoyant release from a short stack for 12 years between 1950 and 1999, using meteorological data for Heathrow and for Waddington in Lincolnshire. The Heathrow results showed that the predicted peak annual average concentration generally decreased over time, with concentrations in the 1990's being around half the values from the 1950's. There is little variation in the predicted 99.9<sup>th</sup> percentile over the same period. However, for Waddington, the predicted annual average concentration increased slightly over time, again with little variation in the 99.9<sup>th</sup> percentile. The change in concentration predicted using the Heathrow data was considered to be an effect of the change in urbanisation around Heathrow over the period considered. The study concluded that some data sets do have a "shelf life", which may reflect changes in urbanisation rather than other changes in climatology.

The second part of the study considered the use of data from NWP output. This was used to calculate ADMS input data for one year, for two sites. Predicted concentrations (mean, 99<sup>th</sup> and 99.9<sup>th</sup> percentiles) were calculated for three sources at each site using the "NWP" data and observed data. This comparison used the minimum amount of data with which ADMS can be run. Mean values of various meteorological quantities (such as wind speed and cloud cover) were compared, showing reasonable agreement between values from the two types of data. The dispersion patterns predicted for the two types of data were found to be generally similar; the peak values for each of the quantities considered differed by between -28 and +31% for Ringway and between -31 and +6% for Waddington (a negative value means that the concentration predicted using NWP data is less than that predicted using observed data). On this basis, it was concluded that NWP data provide a reasonable alternative to observed data and would be appropriate for a site where there are no suitable observations. A further comparison was undertaken in which additional quantities, such as the depth of the mixing layer, were extracted from the NWP results, rather than allowing ADMS to calculate them. This data set gave a poorer representation of the results using observed data than was obtained from the comparison with the original ADMS data set using fewer input parameters. The report on this section ends with the somewhat ambiguous conclusion "... the results here show that while NWP data is a good viable alternative, including secondary variables should be seriously considered".

There is a section in R2b which discusses the use of NWP data to generate input data for dispersion models. This shows that data on the wind field derived from NWP compared well with measurements made at a site that was not used in the NWP process. Frequency distributions of heat flux, derived from NWP and the ADMS pre-processor, also showed good agreement.

The final part of the study considered the use of data from the Site Specific Model (SSM), for the Ringway site. Data were only available for a two month period. The average values of quantities such as wind speed, obtained from observations, the NWP and SSM models were compared. The SSM results were closer to the observed values than were those from the NWP model. However, both models "showed noticeable differences from the observations" for wind direction. Concentrations for the three sources predicted using observed, NWP or SSM data were compared. The differences between predictions using SSM and observed data were greater than those between predictions using NWP and observed data.

#### **9.4 Scope of R2a**

This report describes the ways in which observations of meteorological parameters are made and processed, and outlines the NWP and SSM process. It describes how data for dispersion models can be extracted from the results of the NWP or SSM, and the processing involved in deriving statistical data sets. It describes the data archives that are available, both for observed values and for values obtained from the various forecasting processes. It also describes the information that can be obtained for use in real time dispersion calculations.

The report also considers the representativity of meteorological data, discussing the spacing between observing stations that is required (mainly from the stand-point of weather forecasting). This discusses the conditions under which data from one site may be used at other sites, but does not compare concentrations calculated using data from different stations. It references R316a, W3a and R2d, together with other reports which have addressed similar questions.

#### **9.5 Scope of R2d**

This study was undertaken because of possible weaknesses in W3a, which used a grid spacing which may be too large to capture full details of the maximum concentrations.

W3a concluded that the change in urbanisation around Heathrow over the years may have explained some of the changes in predicted concentration. Changes in urbanisation are likely to affect mainly the roughness length, and so R2d includes a discussion on how roughness length changes might affect dispersion, and the most appropriate roughness length to adopt for calculations using Heathrow data.

Calculations of the annual average and high percentiles of the hourly concentration distribution were made for the same 12 years considered in W3a, for three releases (the buoyant release from a 10 m stack considered in W3a, a non-buoyant release from a 40 m stack and a buoyant release from a 150 m stack). These calculations assumed a roughness length for all years of 0.2 m. The predicted mean concentration for the buoyant releases decreases by about 50% over the period considered, with the changes showing a trend with time. The predicted mean concentration for the non-buoyant release tends to increase with time. The predicted percentiles of the distribution increase, but by different amounts for the three releases considered, with the values for the release from the 10 m stack changing by less than 10%. There is some evidence for a trend with time for the other releases.

Further calculations were carried out for the three releases, using the 1999 meteorological data but with a range of roughness lengths. The predicted percentiles for the buoyant releases increased with increasing roughness length; however, for the non-buoyant release the predicted percentiles decreased with increasing roughness length. The predicted annual average concentration also increased by factors of 1.9, 3.7 and 5.3 for the three releases as roughness length increased from 0.01 to 1 m. The earlier part of the study considered that the decrease in mean concentration with time might reflect the increase in roughness length over time, in disagreement with the finding here which shows that increasing roughness length increases the mean concentration. The study considered what the most appropriate roughness length might be for some years at Heathrow, and repeated some of the original calculations using the selected roughness length. This showed that the predicted mean concentrations decreased with time, but the decrease was smaller than that obtained in the first set of calculations. The report concludes that there is still evidence that the predicted concentrations vary systematically with time, and therefore supports the conclusion of W3a that meteorological data has a "shelf life".

Finally, the study compared predictions made using "spot data" (values measured over a period of a few minutes each hour) or hourly average data. This showed that the predicted higher percentiles of the distribution are generally greater for spot data than for average data, with the largest difference being an increase of 77%. The annual averages predicted using spot data are up to about 20% greater than those obtained using hourly average data.

## **9.6 Areas of overlap**

These reports are for closely related topics, with similar areas covered in two or more of the reports. However, the reports generally refer to each other, and there do not seem to be any instances where one report contradicts something said in a different report. The reports make comments on the adequacy of particular things, such as the use of old meteorological data or data from other sites. There are no "official" numerical criteria which can form the basis of judgements on the adequacy of data sets in these situations and therefore the

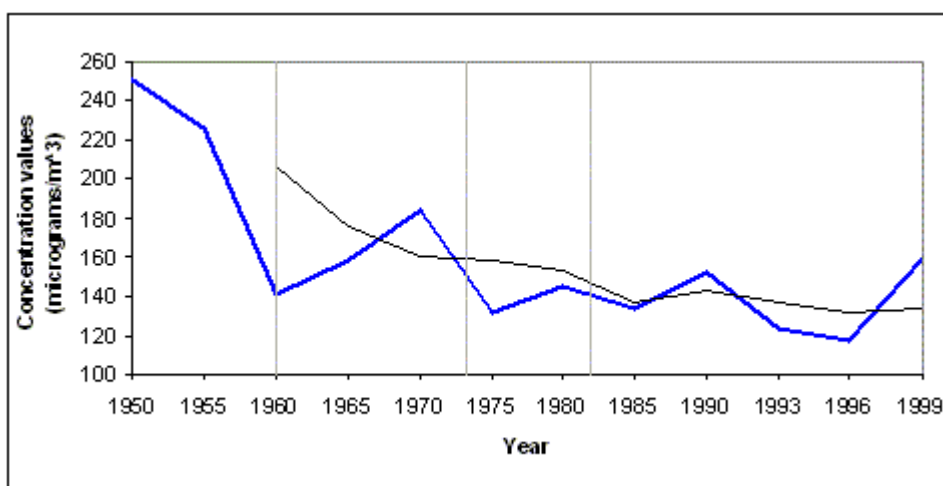
choice of criterion for adequacy must depend on the feelings of the particular author. There is some inconsistency in what is deemed adequate in the different reports.

## **9.7 Gaps in the areas covered by the studies**

There are no obvious gaps in the areas covered by the reports. However, they draw conclusions which are based on analyses of only a few, or even on only one, situation. There may be some benefit in repeating the studies for other situations to investigate whether the general conclusions drawn are robust. Some examples of this are given below.

R316a suggests that the most important point when using data from a “distant” met station is to find locations with similar mean wind speeds. This contradicts other Met Office work (Davies and Thomson (1996) not carried out for ADMLC) which suggests that data should be taken from a station within a few tens of kms of the point for which dispersion calculations are required. Reasons for this difference could be investigated further.

W3a concludes that met data has a “shelf life” as predicted concentrations differ over a period of years. This is supported by R2d. W3a shows that the predicted long term concentration decreases over time at Heathrow, but increases slightly at Waddington. W3a shows that the change in the predicted high percentiles of the hourly concentration distribution is much less than the change in the predicted long term average concentration. R2d supports these general findings for Heathrow. In all cases, there are large variations around the general increase. It is not clear if this represents an actual trend for concentrations to change systematically with time (with a large variation between years on top of this change) or to what extent the change is dominated by the effects of one or two particular years. For example, the following figure (taken from W3a) shows the predicted long term average concentration at Heathrow.



**Figure 1** Graph to show how the spatial maximum of the long term concentration value has changed from 1950 (blue line) to 1999, and the 10 year rolling average (black line). The grey lines indicate the years when the position of the anemometer was changed

Examination of this graph by eye suggests that the systematic variation with time would be much less convincing if the results for 1950 and 1955 were omitted. Both W3a and R2d show other graphs where similar comments could be made.

R2d and, to a lesser extent, W3a demonstrate that some quantities vary systematically with time, while others do not. Therefore, whether met data has a "shelf life" would seem to depend on the quantities to be calculated. It is also noted that the differences quoted are in general less than a factor of 2, and so are likely to be smaller than the general uncertainty in dispersion modelling.

R2d considers the effects on predicted concentrations of changes in roughness length; this can have a large impact on the predicted concentrations, with mean concentrations for some release conditions changing by a factor of 5 as the roughness length is altered from 0.01 to 1 m. W3a suggests that part of the difference between concentrations predicted using observed data or NWP data for Ringway may be an effect of roughness length changes within the area covered by a single grid square in the NWP process. These points suggest that there may be a need to look more carefully at the choice of roughness length, as this may differ between the release point and the met station.

## 9.8 Recommendations for further work

R316a suggests further work on possible ways of improving the estimates of wind speed at locations away from a measuring station, and that physical models might be used for this. It also recommends a comparison of dispersion estimates using met data from different periods, which was undertaken in W2b and R2d.

W2b notes the problems in using statistical and sequential data in modelling plume rise, particularly in ADMS. It suggests that this could be investigated further, noting that it might be a study of specific features of ADMS rather than of met data. It also notes that the highest concentrations are associated with wind speeds in the range from 1 to 2 m s<sup>-1</sup>, and suggests an investigation of how predictions could change for different methods of treating dispersion in calm conditions.

W3a includes a number of comments on things that should be considered in selecting the most appropriate data to use in a particular application; it identifies the use of SSM data as an area for further study.

R2a suggests that it would be useful to investigate whether alternative sources of met data are as good as, or better than, those currently available. It specifically suggests that it would be useful to investigate how sensitive dispersion calculations are to the use of cloud amounts from manual observations or derived from measurements using laser cloud base recorders (LCBR). Developing a better understanding of the NWP data products obtained from the model would also be very useful. A comparison of appropriate met parameters obtained from NWP model output with those recorded at a site (particularly if measurements from that site are not normally input to the model) could help understand how big the discrepancies are, and whether they are significant in dispersion modelling terms.

#### **9.8.1 Comment from the authors of this review**

Some of the discussion on the use of old met data is not convincing as the trend over time is not much larger than variations between concentrations calculated for different years or for different assumptions that might be made. This suggests that a more detailed review of this work, including investigations for other sites, would be justified.

## **10 REVIEW OF REPORTS RELATING TO RAIN AND DATA ASSIMILATION**

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Rain and assimilation are considered in two reports, one from ADMWG (R198) and one from ADMLC (R1a).

### **10.1 Scope of R198**

R198 extends the scope of the second ADMWG report, to consider the problems involved in calculating wet deposition from a short release. It defines the situations for which the Gaussian plume model (used in R122) is appropriate, and illustrates other simple models applicable to short releases in idealised or more realistic conditions.

R198 considers the deposition of material travelling entirely in rain and the deposition of material first encountering rain at some distance from the source, and gives guidance on suitable methods for modelling deposition under these conditions. The simple Gaussian model can be extended to calculate deposition when the dispersing material first encounters rain. The report considers the implications of two simple, and possibly extreme, descriptions of the effects of material encountering rain for the first time some distance from the source. The first uses a plume model and assumes that all material encounters a change in conditions at the same point. The second uses a puff model and assumes that all material encounters a change in conditions at the same time.

The report summarises the difficulties of modelling the variability of rainfall, and airflow within storms. Reversibility of the washout of gases is considered (i.e. rain becomes contaminated as it falls through the plume but the dissolved material desorbs as the rain falls through a region of low concentration below the plume).

R198 gives guidance on the variation of washout coefficient with rainfall rate. The report is unable to recommend a value for the washout coefficient for particulates, however, it does indicate a range of likely values.

The report considers values for washout coefficients of gases. It suggests that wet deposition be calculated using a washout coefficient derived from the small amount of experimental information available or from washout ratios. However, the report recommends that in view of the considerable uncertainty in the value of the washout coefficient for gases, a value suggested for particulate material should be used for inorganic iodine.

R198 highlights the lack of information concerning the washout of organic iodine. Indeed the data available on gases other than inorganic iodine discharged by the nuclear industry is very sparse. Therefore, the report suggests that the value of washout coefficient given for particulate material be used for other gases.

Much of the report assumes a washout coefficient appropriate to rain falling at a specified constant rate. However the report considers the variability of the rainfall rate within the UK. Furthermore the report considers modelling rainout separately to washout as a single step process.

Finally the report considers the accuracy of the wet deposition models and attempts to put the uncertainties highlighted within the report into context. The report suggests methods for defining when, where and how much it rains in the vicinity of the release (assuming that reliable and accurate information on the rainfall distribution during and after the release is unavailable).

## **10.2 Scope of R1a**

R1a considers the problems associated with assessing the consequences of an accidental release of radioactivity to the environment, concerning the interaction of the dispersing material with precipitation.

The report investigates the availability of rainfall data, and the likely spatial and temporal variation in rainfall in different conditions (frontal, showers, etc). The report considers ways of obtaining estimates of deposition in the period immediately after an accidental release, and in particular estimating deposition at places where it has not yet been measured. The report advocates supplementing the use of the measurements of radioactive contaminants in environmental samples with information on other quantities that are related to where the enhanced deposition is likely to occur and for which data are readily available (data assimilation). Procedures for interpreting monitoring data after an accidental release have been developed by considering the circumstances arising under wet conditions.

The effect of rain on dispersing plumes, considering the relative depositions in wet and dry conditions is discussed. The report considers the differences in interception, and in particular the short-term effects on plant surface contamination, in dry and wet conditions. The report also considers rainfall patterns typical of the UK and the way in which rainfall rates vary in time and space. The report identifies radar as a vital information source for determining rainfall rate at points away from meteorological measuring stations.

R1a considers the assimilation of rainfall information as an aid in making improved assessments of the amount of deposited radioactive material. The report considers both simple and advanced methods for estimating the rainfall rate at points where it cannot be measured directly. The simpler methods include Thiessen polygons and inverse distance weighted interpolation. The more complex methods generally use one of a number of geostatistical techniques, for example the Bayesian method. However other approaches such as basis function expansions and neural networks are also used. The report includes consideration of those processes deemed important in modifying a monitoring programme developed primarily for dry conditions, for use when rainfall has occurred after an accident. Within the comparison of methods for estimating rainfall, the procedure of weighting a model with the aid of linear estimation, known as kriging, is extensively used throughout the report. Subsequently a number of approaches are recommended for calculating the depletion of the plume due to rainfall. The report also considers the temporal effects of rainfall i.e. the importance of knowing when rain starts and ends in a particular area and when the dispersing plume passes over the area.

The report discusses the locations from which environmental samples are taken, and how these might be applied in an accident situation, notably preferential and optimal sampling. The report considers the modes of variation in monitoring programmes for accidents in wet and dry conditions, including the consideration of uniform and non-uniform rainfall. The method of obtaining suitable information for use in data assimilation procedures is also considered.

### **10.3 Areas of overlap between R198 and R1a**

Both R198 and R1a base their recommendations on the same simple model for calculating the fraction of material remaining in the plume as a function of time. Furthermore both reports relax the assumption that rain falls at a constant rate. Both reports consider the variability of the rainfall rate within the UK.

R1a extensively references R198. Therefore, if there are any areas of disagreement, R1a should be considered as updating R198.

### **10.4 Gaps in the areas covered by the models**

Neither report appears to consider the possibility of enhanced deposition during mist or fog, or in low-lying cloud on hills, frequently termed 'occult wet deposition'.

R1a recognises a number of areas where further investigations into the assimilation of rainfall data would be of use. Notably the suggested processes for assimilating the effect of enhanced radioactive deposition due to rainfall are not demonstrated due to a lack of data. There also exist some discontinuities between the boundary areas of rain and no rain.

### **10.5 Recommendations for future work**

R198 does not make specific recommendations for future work. R1a suggests that work to compare results of data assimilation techniques against deposition measurements following a short release in wet conditions would be useful. It suggests that the data obtained in the UK after the Chernobyl accident together with radar data for the appropriate period might be used for this.

## **11 REVIEW OF UNCERTAINTY IN DISPERSION MODEL ESTIMATES**

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The uncertainties in dispersion estimates obtained from models recommended by ADMWG are considered in R199. Some of the papers in R1c also consider the uncertainty of dispersion modelling. Report R302b considers the performance of models used to calculate air concentrations when plumes impinge on buildings or the ground. R322b includes a discussion of model evaluation and uncertainty in models that predict dispersion in the vicinity of buildings. The uncertainty arising from the measurements of meteorological data and the derivation of the value for parameters representing atmospheric stability is discussed in R2b.

### **11.1 Scope of R199**

The report identifies a number of sources of uncertainty, such as the random nature of atmospheric dispersion, the idealisations inherent in modelling and the choice of values for the many parameters involved. The report puts these uncertainties into context and comments on the reliability of models for use in practical situations in the UK.

To assess uncertainties associated with the idealisation inherent in modelling, the conditions where the Gaussian plume model (R91) and the deposition model (R122) can be applied are discussed. The uncertainty in parameter values depends on the type of application. The report concentrates on the range of values for parameters where realistic estimates of the mean concentration from a number of short releases or the average concentration from a continuous release are sought. The uncertainties associated with models for plume rise (R157b), building effects (R157c) and coastal effects (R157a) are also considered.

The report also summarises a number of experimental studies that have been carried out to validate dispersion models similar to those recommended by ADMWG. The level of agreement between predicted and observed values depends on the conditions and the type of application. For example, a ratio of between 0.5 and 2 is expected for long-term average concentrations at a specific point, over flat terrain and within 10 km of the release point. Experimental studies dealing with plume rise and the virtual source model for building effects are also included.

### **11.2 Scope of R302b**

This report reviews models suitable for predicting the dispersion of plumes that impinge on buildings or the ground. A range of models is considered which includes the Gaussian plume model and  $k$ - $\epsilon$  turbulence model. Model uncertainty is not discussed in detail but the performance of the models under various conditions is considered and in many cases the magnitude and sign of any inherent errors are identified.

### **11.3 Scope of R322b**

This report reviews flow and dispersion in the vicinity of groups of buildings with Section 4.4 addressing the issues of model evaluation and uncertainty. The requirements for successful model evaluation are identified and an example is given of typical uncertainties associated with computational modelling of a dense gas discharged from an L shaped building. Overall, solutions were found to be very sensitive to the modelling decisions employed by the modellers and consequently a need for 'codes of best practice' was identified. The report also includes tables that summarise the uncertainty, in qualitative terms, associated

with the application of various modelling techniques to different dispersion problems.

#### **11.4 Scope of R1c**

ADMLC held a workshop in 2000 to discuss the needs of atmospheric dispersion models used in a regulatory context and the reliability of existing models for those purposes. The presentations are published in R1c. Regulatory requirements include the need for input to nuclear site safety case assessments, estimates of the impact of radioactivity on food and COMAH safety reports. The reliability of dispersion models is addressed in several presentations that cover uncertainty, variability, validation and evaluation. In addition recent developments in research are discussed.

#### **11.5 Scope of R2b**

This report considers the uncertainty in deriving dispersion parameters from meteorological data. Measurement techniques and instrument accuracies associated with meteorological data are reviewed. The treatment of meteorological data in ADMS and AERMOD is considered and alternative meteorological data sources are discussed. A probabilistic assessment of uncertainty associated with meteorological inputs to ADMS is carried out. The conditions and parameters that contribute most to uncertainty in model predictions are identified.

#### **11.6 Areas of overlap**

The report R2b overlaps considerably with the issues discussed in the workshop presentation 'Uncertainties in meteorological pre-processing for dispersion models' published in R1c. However, in R2b these uncertainties are propagated through the 'new generation' atmospheric dispersion model ADMS to determine their impact on model predictions.

Two presentations given during the ADMLC workshop (R1c) expand on topics considered in R199. The performance of models for predicting dispersion affected by buildings and a study of concentration fluctuations arising from the inherent variability in the field of turbulence were discussed.

In general the different reports complement, rather than contradict, each other.

ADMLC has funded work in related areas. In 2000-2001 speakers were invited to give presentations on methods for undertaking uncertainty analyses. The overheads from these presentations are published in NRPB-W3. These relate to the techniques for undertaking uncertainty analyses, rather than the uncertainty on predictions of atmospheric dispersion models.

### **11.7 Gaps in the areas covered by uncertainty studies**

At the time of publication of R199 there was insufficient information available to quantify the uncertainty associated with plume rise. However, this subject is likely to be addressed by ADMLC in the near future. More generally, the data available for validating the overall performance of dispersion models are limited and those experiments that have been carried out have often been used in the model development.

### **11.8 Recommendations for future work**

R199, R302b and R3222b do not make specific recommendations for future work relating to uncertainty issues.

Two specific recommendations for future work are made in the presentations included in R1c. The first highlights the sensitivity of model predictions to the methods used to process meteorological data to provide estimates of boundary layer parameters and suggests that further development is required. The second suggests that it would be useful to establish a collection of data sets for dispersion in the vicinity of buildings that are judged to be of good quality and against which models such as ADMS-BUILD and AERMOD-PRIME could be assessed.

R2b included an uncertainty analysis for a particular source type, and suggests that further studies for a range of source types would be useful. It also suggests a more detailed consideration of the uncertainty in roughness length, including an intercomparison of methods for allowing for spatial variation in that quantity. It also suggests that further investigations into the use of data from NWP models, particularly including other than the minimum quantities required by the dispersion model, would be useful. It suggests that a comparison of the output of meteorological pre-processors with measured vertical gradients of wind speed, wind direction and temperature, and with turbulence measurements, would help address the uncertainty found between modelling systems.

## **12 REVIEW OF REPORTS RELATING TO THE CAPABILITIES OF CFD MODELS**

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ADMLC funded one project, reported in R292b, to review the capabilities of computational fluid dynamics (CFD) modelling in general. However, other reports consider the use of CFD modelling in particular applications, and are also considered here.

## **12.1 Scope of R292b**

This report discusses the use of CFD for modelling dispersion in the near field. It discusses some problems with CFD, pointing out that, to obtain reliable results, users must be familiar with CFD (and the specific CFD program used) and with atmospheric dispersion modelling. The report identifies a number of studies where predictions of CFD models have been compared with results obtained in wind tunnel studies; it is not possible to draw general conclusions on the accuracy of CFD modelling from these studies.

The report describes a study where different organisations carried out calculations for the same situation, and points out that different users (or different CFD codes) generally produce different results for the same problem. Changes in the predicted values when users tried to improve their modelling tend to be smaller than the differences between predictions obtained by different users.

The report identifies a number of problems with the  $k - \epsilon$  turbulence model, suggesting that Large Eddy Simulation (LES) may be a better approach in some situations but that it requires considerably more computer time. The report also points out that there are no very good methods of including wet and dry deposition in CFD models.

The report identifies the design and resolution of the grid as an area leading to uncertainty in results or differences between modellers, pointing out that results generally depend on the grid resolution used. There are several comments referring to the number of grid points considered and the computing power required. Increases in computer power since the report was written in 1996 may mean that some of these comments are no longer appropriate.

The report includes a section discussing the situations for which analytical models, CFD applications or wind tunnel modelling are more appropriate. This considers the capability of the techniques to represent real cases (including representing realistic geometry for buildings and complex terrain, plume buoyancy and momentum effects and stable atmospheres), the effort involved in undertaking the work, the likely accuracy and uncertainty arising from the way in which the technique is used.

## **12.2 Comments on CFD in other reports**

R292c presents a review of models for the rise of a buoyant plume from a building wake, and considers the applicability of CFD for this application. It refers to a comparison of CFD and wind tunnel models, also considered in R292b, and notes that the accuracy of CFD calculations is best for passive emissions and tend to degrade with increasing plume buoyancy. This report also lists deficiencies in the  $k - \epsilon$  turbulence model. It suggests that CFD methods did not then provide practical models (the report was written in 1996), but that they will be increasingly used and that their capabilities should be assessed.

R302b considers the application of CFD models to dispersion in complex terrain, identifying some problems and possible pitfalls for their use.

R322b presents a review of modelling for sites with many buildings. It makes a number of comments on when CFD is appropriate, but does not include any discussion on the strengths and weaknesses of CFD modelling. This report includes a lengthy discussion of possible approaches to modelling different aspects of dispersion from groups of buildings, including CFD techniques.

W2a describes models for dispersion in a sea breeze. It points out that CFD models are an appropriate tool for this application, as they can describe all features of sea breezes. W2a states that studies using CFD models have led to a greater understanding of dispersion in sea breezes, and that CFD can represent all aspects of this topic. It does not otherwise consider the merits of the technique.

R2c points out that CFD techniques are appropriate for some studies of airflow in urban areas.

### **12.3 Areas of overlap**

R292b and R292c both make comments on the merits of CFD, giving the same general impressions of the capabilities of this technique.

### **12.4 Gaps in the areas covered by the reports**

The authors of this review have no expertise in CFD modelling. As far as we can tell, there are no gaps from the discussions in R292b, supported by comments in R292c, of the advantages and disadvantages of CFD modelling.

### **12.5 Recommendations for future work**

R292b points out the need to reduce the variability of results, and suggests that strict guidelines covering all aspects of applying CFD to a real site should be developed. It points out that good experimental data sets, which could be used as the basis of comparisons between results of CFD and other calculations, should be identified. It suggests that work is needed to improve the turbulence modelling for applications to atmospheric dispersion and to develop and validate appropriate techniques to enable CFD models to describe deposition.

R292c suggests that work should be done to assess the capabilities of CFD modelling.

## **13 MODEL FOR CONCENTRATION AT LONG RANGE FROM A SHORT RELEASE**

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The ADMWG only produced one report (R124) explicitly looking at the calculation of air concentration at long range from a short release. However, related problems are considered in other reports.

### **13.1 Scope of R124**

The model was intended primarily for use in submissions prepared under Article 37 of the Euratom Treaty. This requires operators to make calculations of the radiation doses that might be received by inhabitants of the nearest Member State of the European Union from an accidental release from the site of interest; for UK sites this means that the calculation must consider travel distances of a few hundred kilometres. The model is intended to provide a reasonably pessimistic estimate of the concentration that might occur for a release at some stage during the operation of the site, and therefore the atmospheric conditions at the time of the release cannot be known. The model includes the effects of the changes of atmospheric conditions along the trajectory of the plume in calculating the vertical spread. The report also considers the calculation of dry and wet deposition at the point of interest.

### **13.2 Areas of overlap with other reports**

R123 (see Section 2) and R124 model the likely concentration at a distance, allowing for the cumulative effects of changes of stability category during the travel time, but do not consider how to calculate concentration allowing for a known sequence of changes of atmospheric stability. R198 and, to a lesser extent, R1a (see Section 10) consider the problems caused by changes of rainfall rate.

The different reports relate to different applications, and there are no contradictions between the recommendations.

### **13.3 Gaps in the areas covered by the model**

ADMLC/ADMWG has not specifically considered a way of describing dispersion in changing atmospheric conditions.

### **13.4 Recommendations for future work**

Neither R123 nor R124 gave any specific recommendations for future work.

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## 14 SUMMARY AND CONCLUSIONS

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ADMLC and the Steering Committee which preceded it have produced a total of 30 reports. In some cases different reports relate to similar topics. ADMLC wanted a review of the work which has been carried out, intended to identify any contradictions between different reports and any gaps in the areas covered. The aim was not to summarise the work which has been carried out, nor to consider whether subsequent work elsewhere would support a possible review or revision of any of the earlier reports.

The 30 reports were divided into 12 groups where the reports referred to topics that were related; for example four reports related to aspects of dispersion from releases near buildings, and five reports related to aspects of the use of meteorological data. The main topics covered by each of the reports have been summarised, and the areas of overlap between reports or gaps in the areas covered have been identified. Many of the reports included recommendations for future work; these recommendations have also been summarised in this report.

There are several instances where different reports describe models for the same or very similar applications. In almost all such cases, the later report references the earlier one. In this case, the later report can be regarded as updating, rather than contradicting, the earlier report. In the few cases where the later report does not reference the earlier one, there are no instances of contradictions between the two reports. In all cases, the reports can be regarded as updating earlier documents or providing additional, complementary, information.

There are two instances where the authors of this report have reservations about the conclusions reached in ADMLC reports; these are identified below.

The first of reservation about the findings relates to the portability of met data, considered in R316a. R316a suggested that met data from a site at any distance from the source could be used provided that the mean wind speeds were similar in the two data sets. It also suggested that there is no correlation between predicted concentrations and the distance between sites from which met data are taken. This finding contradicts an earlier study by the Met Office (not undertaken for ADMLC) which suggested that met data should only be used for sites within a few tens of kilometres of the met station. Although R316a references the other Met Office study, it gives no discussion on the reason for the differences.

The second reservation relates to the "shelf life" of met data. Two reports considered the use of "old" met data and whether concentrations predicted using data from a site over a period of years show a trend with time. The reports identified a trend, which is not consistent between sites and differs depending on whether mean values or percentiles are being considered. There are large variations between years superimposed on a possible trend. The variation over time, particularly if using met data from Heathrow, may reflect changes in the urbanisation of the surrounding area, and so a change in the roughness length.

R2d compares the variation in predicted concentration over time with the variation in predicted concentration for different assumed roughness lengths; the variation with roughness length is greater than that with time. R2d also examines the difference between concentrations predicted using hourly average and "spot" winds, again identifying a difference comparable to that over time. The authors of this report feel that further work is justified to understand these topics. Commenting on the difference in the concentration predicted using different data sets is complicated by the lack of any general agreement on the accuracy required in regulatory applications.

This review also identified a number of gaps, either in the coverage of a single report or between the coverage of different reports on related topics. This will provide a useful input into discussions within ADMLC on future work programmes. The main gaps are summarised below.

There is no discussion in any of the reports of models for dispersion of dense gases. This may reflect a general assumption, particularly at the time that R91 was written, that there are no dense gases of importance in the nuclear industry.

There is no discussion of the modelling of chemical reactions in the atmosphere, either between different materials within a single plume or between material in a plume and the general background levels of other chemicals. Chemical reactions in the plume can affect both the predicted concentration and deposition rates of some materials. This omission reflects the restriction, until recently, of ADMLC interests to topics primarily of interest to the nuclear industry.

R122 described a model for calculating plume depletion due to dry deposition, and two subsequent reports recommended values for the deposition velocity. None of these reports have examined dispersion and deposition of particles which are large enough that their settling under gravity should be considered.

Two reports have looked at features of dispersion at coastal sites. Both concentrated on situations when the wind is blowing from the sea to the land, and did not consider dispersion over bodies of water. Although R124 considered the calculation of concentrations in other Member States of the European Union it did not explicitly examine dispersion over water. This means that ADMLC has not looked at situations where plumes travel over water bodies such as lakes or estuaries, or explicitly at the rate of plume growth over the sea.

There is only very limited coverage of the concentration indoors resulting from a plume outdoors. None of the reports have considered the question of concentration indoors from a release within the building.

Several reports relate to plume rise, from either a stack where airflow is not affected by buildings or a release into a building wake. These consider the contribution of plume vertical momentum and buoyancy to the rise; the models recommended are based on studies of typical plumes from power stations where the vertical velocity of the effluent is unlikely to be more than a few tens of metres per second. There may be accident situations, such as damage to a valve

on a container where a gas is under considerable pressure, in which material could be released at much higher speeds, or in directions other than vertically upwards. The authors of this report do not know whether the models given in ADMLC reports would be appropriate for such releases.

One report briefly mentions the size of an initial plume following an explosive release, although it does not relate this to the quantity of explosive (as in perhaps a terrorist act). A more detailed study of the likely size of a plume from an explosion, and its subsequent dispersion, would be of interest.

The authors note that these topics are identified as those needed to fill gaps in the general areas covered by previous ADMWG/ADMLC reports. Needs for future work outside these areas have not been considered.

## **15 REFERENCE**

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Davies B M and Thomson D J (1996) Investigating the importance of pre-processing in estimating dispersion climatology IN Proceedings of the Ostend Workshop on Harmonisation of Dispersion Models.