GUIDE NO. AERB/NF/SG/S-1

GUIDE NO. AERB/NF/SG/S-1

GOVERNMENT OF INDIA

AERB SAFETY GUIDE

ATMOSPHERIC DISPERSION AND MODELLING

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY GUIDE NO. AERB/NF/SG/S-1

ATMOSPHERIC DISPERSION AND MODELLING

Atomic Energy Regulatory Board
Mumbai-400 094
India

February 2008

Price

Orders for this Guide should be addressed to:

The Administrative Officer
Atomic Energy Regulatory Board
Niyamak Bhavan
Anushaktinagar
Mumbai-400 094
India

FOREWORD

Activities concerning establishment and utilisation of nuclear facilities and use of radioactive sources are to be carried out in India in accordance with the provisions of the Atomic Energy Act 1962. In pursuance of the objective of ensuring safety of members of the public and occupational workers, as well as protection of environment, the Atomic Energy Regulatory Board (AERB) has been entrusted with the responsibility of laying down safety standards and enforcing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, safety codes and related guides and manuals for the purpose. While some of these documents cover aspects such as siting, design, construction, operation, quality assurance and decommissioning of nuclear and radiation facilities, other documents cover regulatory aspects of these facilities.

Safety codes and safety standards are formulated on the basis of nationally and internationally accepted safety criteria for design, construction and operation of specific equipment, structures, systems and components of nuclear and radiation facilities. Safety codes establish the safety objectives and set requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised when necessary, in the light of experience and feedback from users as well as new developments in the field.

The code of practice on siting for safety in nuclear power plants (AERB/SC/S) states the requirements to be met during siting of nuclear power plants in India. This safety guide provides guidance for finding atmospheric dispersion modelling methodology and procedures for carrying out analysis as applicable for implementing the relevant parts of the code. In drafting this guide the relevant documents developed by the International Atomic Energy Agency (IAEA) under the nuclear safety standards (NUSS) programme, especially the Safety Guide on 'Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluation for Nuclear Power Plants' (NS-G-3.2) has been considered for implementing relevant sections.

Consistent with the accepted practice, 'shall' and, 'should' are used in the guide to distinguish between a firm requirement and a desirable option respectively. Appendices are integral part of the document, whereas annexures, footnotes and references are included to provide information that might be helpful to the user. Approaches for implementation different to those set out in the guide may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public, and protection of the environment.

This guide applies only for facilities built after the issue of the document. However during periodic safety review, applicability of current standards for existing facilities would be considered.

For aspects not covered in this safety guide, applicable national and international standards, codes and guides, acceptable to AERB should be followed. Non-radiological aspects of such as industrial safety and environmental protection are not explicitly considered in this guide. Industrial safety is to be ensured through compliance with the applicable provisions of the Factories Act, 1948 and the Atomic Energy (Factories) Rules, 1996.

This guide has been prepared by specialists in the field drawn from the Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Nuclear Power Corporation of India and other consultants. It has been reviewed by the relevant AERB Advisory Committee on Codes and Guides and the Advisory Committee on Nuclear Safety.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the draft and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.

(S.K. Sharma)
Chairman, AERB

CONTENTS

1. INTRODUCTION

1.1 General Considerations

Atmosphere is an important pathway to be considered in the assessment of the environmental impact of radioactivity releases from Nuclear Facilities (NFs). Estimation of concentration of released effluents in air and possible ground contamination needs an understanding of the relevant atmospheric dispersion and deposition processes. In the study of radiological impact on man and his environment, these estimates form an important input.

Atmospheric releases from NF can be either during normal operating conditions or during off-normal/accident conditions. The nature of the release (source height, source strength), the type of sources (specific nuclide released), duration of release (puff/continuous) and the relevant atmospheric parameters could widely differ in these cases. The domain of atmospheric flow to be considered (micro, meso or synoptic scale) would be governed by the range of distances over which the assessment is to be made.

This guide explains various atmospheric processes involved and methods to be used in evaluating the concentration in air/ground. This forms an essential input to environmental dose assessment [1].

1.2 Objectives

The estimation of ground level concentration of radioactivity due to effluent releases in air during normal operating/accident conditions from a nuclear facility is an important component of the regulatory safety assessment. The aim of this guide is to give various methodologies, which can be used to carry out such estimations. This document also provides the guidance on the nature of meteorological programme that is required to obtain the inputs appropriate for the chosen atmospheric models.

1.3 Scope

This guide covers the following aspects of atmospheric dispersion over a domain extending up to distance of 30 km radius around the NF:

- Eddy diffusion and advective transport of effluents
- Dry and wet deposition during their travel
- Source related effects like plume rise and wake effects
- Dispersion of instantaneous and continuous releases
- Methodologies to treat dispersion over complex non-homogeneous terrain

Mathematical models are good working approximations to reality. Hence, various mathematical models along with the assumptions are described in this guide, taking into consideration the different aspects listed above either individually or in combination as per requirement of different scenarios.

This guide also gives specific recommendations on:

- Characterisation of the site
- The selection of the appropriate mathematical model for predicting dispersion and deposition
- Relevant data to be collected during various stages of siting on parameters related to factors such as site, meteorology and releases as per measurement program
- The extent of validation required for the use of the model and the accuracy of model predictions
- Methodology of estimation of concentration distribution of effluents as a function of space and time

Dispersion models covered in this guide are valid for a range of a few tens of kilometers radius around the site. The methodology of dose estimates through different pathways from derived concentration values is covered in AERB guide 'Methodologies for Environmental Radiation Dose Assessment' [1].

2. DISPERSION OF EFFLUENTS IN THE ATMOSPHERE

2.1 General

Effluents released through the stack or at the ground level could be a continuous/instantaneous plume/puff. The effluents are transported by wind and diffused by turbulence present in the atmosphere. The combined transport and diffusion mechanism is termed as dispersion. In the case of nuclear facilities, the effluents can be noble gases or reactive vapours or particulates. If the effluents released are surface reactive vapours (such as free iodine) or particulates (aerosol), they are subjected to dry deposition at surface or washed out by precipitation. Radioactive decay is another mode of reduction of radioactive effluent concentration. The study of dispersion aims at understanding of these various processes acting individually and in combination.

2.2 Behaviour of Effluents in the Atmosphere

The behaviour of effluents (from NFs in gaseous or particulate form) released to the atmosphere is shown in Figure 2.1. Effluents, when released to the atmosphere from a stack of height 'h_s' and with a temperature higher than the ambient or with a finite exit velocity will undergo an upward rise defined as plume rise (Dh). The material is transported by wind in the direction of the mean wind flow and simultaneously diffuses in the crosswind and vertical directions. Diffusion is primarily caused by atmospheric eddies. The eddies range in different sizes consistent with the wide range of scale of flow of atmospheric motion. Eddies of size lesser than that of plume size, act as diffusing agents while those larger than that of plume bodily transport the plume. As the plume travels, effluents are subject to depletion by wet and dry deposition processes. Wet deposition by washout is defined to occur when the plume material below the precipitating cloud is scavenged by falling droplets, while rain-out occurs when the plume mixes with the cloud and scavenging occurs. Dry deposition over surface occurs when effluent material deposits on surface by adsorption of gases and by inertial impacting and gravitational settling of particulates (aerosols). Elemental and particulate forms of iodine (I_2) are typical examples for consideration of plume depletion processes. Noble gases (i.e. Xe, Kr, etc.) which are inert, undergo neither wet nor dry deposition. Some gases from certain NFs such as HWPs etc. chemically react with the surface material.

2.3 Factors Governing Atmospheric Dispersion

Dispersion is basically governed by two factors: (a) wind speed and (b) intensity of turbulence. Mean wind speed is distinguished from turbulent fluctuations superimposed on it by averaging the latter over sufficiently long interval (usually one hour in dispersion applications). Mean wind fields are dependent on the following (i) prevailing synoptic flow at the location (vector resultant of pressure gradient), (ii) Coriolis* and frictional forces, and (iii) local flows viz. terrain induced (valley winds etc.) or sea-land breeze circulation (at a coastal site). In tropical latitude, the synoptic flow is usually steady over the diurnal period and the diurnal pattern of the mean wind is mainly due to local circulation.

Turbulence intensity is due to two direct causes - mechanical turbulence caused by wind flow over irregular or rough surface and thermal turbulence due to differential density structure resulting from solar heating of the surface of the earth. Mechanical turbulence is significant when wind speed over the surface is high and when characteristic roughness of the surface is large and could on occasions overshadow the role of thermal turbulence. The latter is clearly diurnal with daytime heating causing increased turbulence while nighttime turbulence levels are very low due to strong cooling of earth's surface relative to air above.

2.4 Process Governing Depletion of Effluents

Either one or more of the following processes can deplete materials in the dispersing plume:

- Dry deposition
- Wet deposition
- Radioactive decay
- Chemical reactions

Dry deposition occurs when the dispersing effluent comes in contact with any surface. This process of dry deposition on the surface is governed by gravitational settling, impaction, adsorption and Brownian motion. For particulates of high density or large size (>15μm) deposition by gravitational settling is significant. For lighter and/or smaller particles, the other processes will be dominant. The exact incorporation of all these individual effects in a model is difficult and therefore only gross parameterisation in terms of depositional velocity is used to estimate dry deposition.

Wet deposition could be either due to washout when diffusing plume is below the precipitating cloud or due to rainout by in-cloud scavenging when the plume material mixes with the cloud. The latter process (rainout) though less common in occurrence is more efficient in removing the effluent material from

---

* Coriolis force is attributed to earth's rotation

the cloud. Wet deposition is significant for soluble vapors and particulates and could exceed in magnitude over dry deposition of effluents during precipitation. However over long periods of time, on the average, dry deposition will still dominate.

Apart from these common processes, in case of radioactive effluents, radioactive decay during the plume travel needs to be considered, if the radioactive half life is short enough compared to the plume travel time to the receptor to cause significant reduction in radioactivity levels. For example, ^{41}Ar with a half-life of 110 minutes would need to be corrected for decay over travel distances of a few kilometers while ^{133}Xe with a half-life of 5.3 days would undergo negligible decay.

2.5 Data Requirements

The basic parameters estimated in atmospheric dispersion models are air borne concentration of the effluent (g/m^3 or Bq/m^3) and the depositional flux (g/m^{2}s Bq/m^{2}s). The information needed to arrive at these estimates include the following:

- Source characteristics such as release rate, effluent composition, height of release, stack internal diameter and location of release
- Release characteristics such as effluent temperature, humidity, exit velocity and wind speed at release level
- Dispersion characteristics such as atmospheric stability, wind speed and direction, air temperature, humidity and mixing height
- Deposition characteristics such as deposition velocity, nature of aerosol and precipitation intensity
- Terrain characteristics such as topography, surface roughness, land use and soil texture
- Case specific information such as averaging time used for mean values of parameter, source release duration etc.

While some complex models may require more parameters as input, the above information adequately covers requirements of the simpler models in wider use. Specific additional data needed for complex models are indicated while describing such models [refer Section 3.3.2.5].

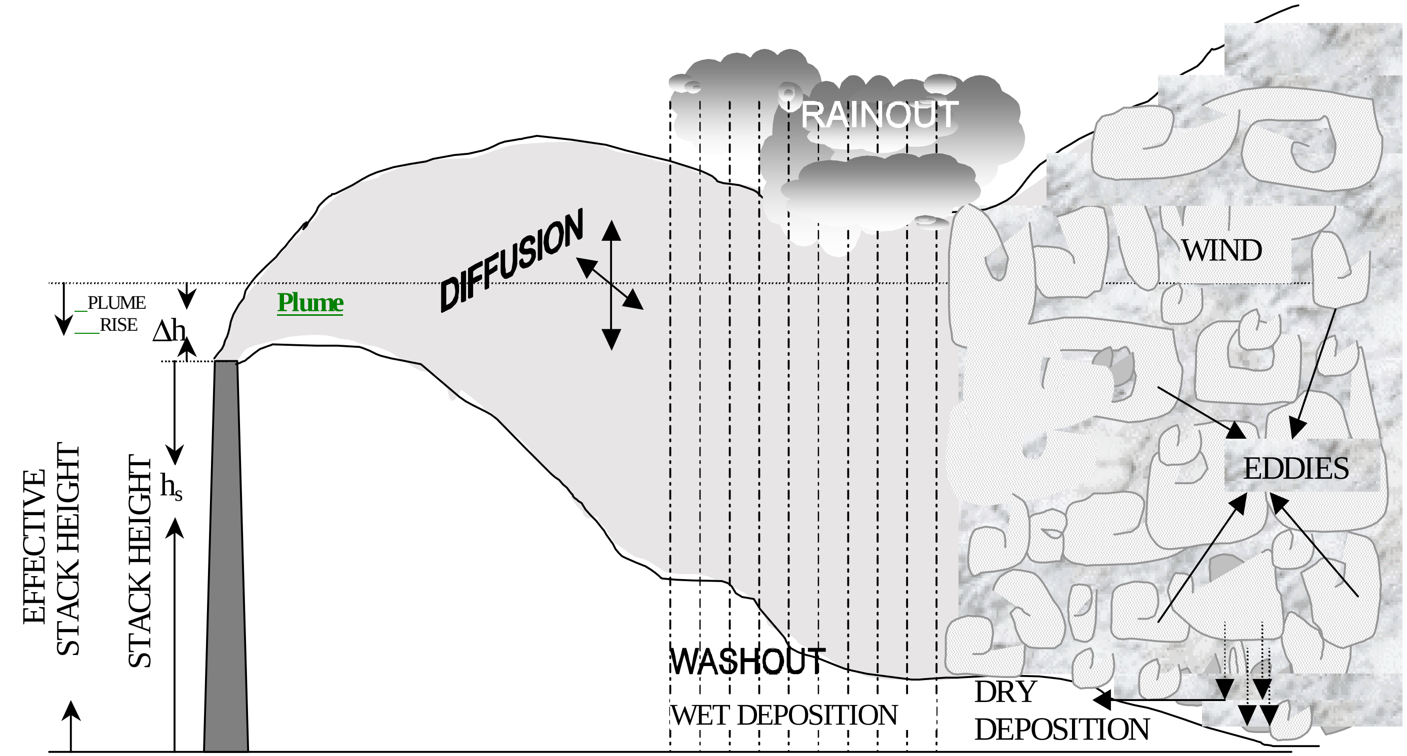


FIGURE 2.1 : BEHAVIOUR OF EFFLUENTS RELEASED TO THE ATMOSPHERE

3. ATMOSPHERIC DISPERSION MODELS

3.1 General

Atmospheric dispersion models deal with the evaluation of dispersion of effluents released to the atmosphere under a variety of flow conditions and terrain characteristics. Since the exact solution of the problem encompassing all varying features cannot be obtained in view of the complexity of turbulent flow in the atmosphere, the approach has to be necessarily through an appropriate model reasonably simulating the flow conditions. Many models have been developed in recent years [2,3] each of which is specific to a set of flow or terrain conditions. Models vary in complexity from simple box models to complex models involving numerical solutions of full set of flow equations. The selection of a model for particular situation is also guided by considerations of output requirements such as accuracy, computational capacity and time.

In the following sections, generic models in use will be described followed by a discussion of the various considerations in the selection of a model for a specific application. The status of the validation of the model along with uncertainty in the respective model predictions is given in the subsequent sections.

Dispersion studies at a site involves (i) selection of a basic model appropriate for the particular dispersion application and (ii) selection of a method for evaluating required input parameters for the selected model (refer subsection 3.3).

Illustrative table giving typical general model inputs is given in Annexure I and typical output is given in Annexure II.

3.2 Types of Models

3.2.1 General

Models in use for atmospheric dispersion studies can be broadly grouped into the following:

- Gaussian plume model (GPM) [2]
- Eddy diffusivity models
- Complex terrain models

Of these, Gaussian plume model is widely used. This guide lays more emphasis on application of this model, which covers the dispersion aspects of atmospheric release. This model is simple in formulation and use: it provides reasonable accuracy in practical dispersion estimates. The theory and application of complex terrain models are also described in detail as it would be sometimes more appropriate to use them in dispersion estimation for sites with a complex terrain or in coastal regions. The salient aspects of other models, their applicability and limitations are also covered in this section.

3.2.2 Gaussian Plume Model

Gaussian plume model assumes distribution of material to be Gaussian or normal in the co-ordinate directions. The details of the model formulation are given in Appendix-I (continuous plume and puff models) and only the method of its application to dispersion estimates is outlined in this section.

Since the basic parameters used in Gaussian distribution (say for a continuous plume) are s_y and s_z (the crosswind and vertical standard deviation values of the distribution of concentration), their specification as a function of downwind distance forms the important input in the model.

In general this is done as follows:

- Using measurements of appropriate parameters, the atmospheric stability classes are determined.
- s_y and s_z at any distance are determined from the appropriate formulae Table 3.1 and 3.2 selected for the site, which give the values of these parameters as a function of downwind distance from the source.
- Use other input parameters like extrapolated wind speed at the height of release, plume rise and averaging time as required for the evaluation.

The various methods of determining stability classes and determination of s_y and s_z are outlined in Appendix-II. The models pertaining to plume rise and deposition of effluent material on the ground are described in detail in Appendices-III and IV respectively. An illustrative example of estimation of concentration using GPM is given in Annexure-III.

3.2.3 Eddy Diffusivity Models

This model is based on concepts of molecular diffusivity in kinetic theory of gases with turbulent eddies acting as diffusing agents. However, unlike Fickian diffusion models of kinetic theory, the treatment herein is more complex due to the large variation of eddy diffusivity with space and time scales of the dispersing plume or cloud.

The general treatment in eddy diffusivity model is to solve the equation of conservation of material which is similar in form to that of Fickian diffusion equation. Usually numerical methods are employed to solve the equation for arbitrary specification of space and time variation of eddy diffusivity and wind field, with appropriate boundary conditions.

Though eddy diffusivity models have been extensively studied in atmospheric dispersion, proper specification of eddy diffusivity generally involves parameters not easily available on a routine basis. For this reason, it has not found as wide an application as GPM.

3.2.4 Complex Ierrain Models (flow equation models)

These models are more basic and could be expected to yield more realistic estimation of dispersion than models referred earlier as they include the generalised picture of the flow field causing the material dispersion. However, their solution involves complex numerical methods and is also computationally time consuming and intensive. While these models are not routinely applied, they will be useful for situations of complex topography or coastal regions.

3.3 Selection of a Dispersion Model and Input Parameters

3.3.1 Procedure for Model Selection

One of the three models listed in Section 3.2 can be selected for use. As discussed earlier, based on consideration of simplicity in use, accuracy in estimates and extent of its validation, GPM is suitable for use in many practical situations. However for use at a site of complex terrain either GPM model can be modified to account for the site-specific factors or where appropriate, complex terrain models can be considered. Complex terrain modeling such as those given in Section 3.3.2.4 would yield improved accuracy only if the more extensive input parameters required for the model are available. Table 3.3 gives characteristic features of these models and a comparison of their applicability for different terrain and flow conditions.

3.3.2 Input Parameters

3.3.2.1 General

The input parameters needed for the models have to be actually measured or evaluated indirectly from related parameters for which data are available. These are briefly outlined in the following:

3.3.2.2 Gaussian Plume Model

GPM needs specifying s_y and s_z as a function of distance and stability. Stability classification is an important input if Pasquill-Gifford (PG) nomograms are used for s_y and s_z estimation. Appendix-II gives details of various methods of stability classification. The following guidelines are given in selecting one of the methods for stability classification for use.

(a) If data on vertical and horizontal turbulence indices are available (viz.: s_q,s_f or DT/DZ where s_q and s_f are the horizontal and the vertical wind fluctuations and DT/DZ is the vertical temperature gradient), 'Split Sigma method' (Appendix-II) can be employed for stability classification. This can be used for reading σ_y, σ_z from PG nomograms curves. Data on σ_θ, σ_ϕ can also be used directly to evaluate σ_y and σ_z respectively using empirical relationship discussed in Appendix-II. This avoids discrete stability typing schemes. Since σ_θ values may characterise dispersion only locally under non-homogeneous terrain conditions, and in such cases, the empirical formulae cannot be applied to entire dispersion domain.

(b) If only σ_θ data are available, a site-specific stability classification scheme can be evolved based either on dispersion data or through comparison with classification made for sites with similar terrain characteristics, then it can be used to specify particular atmospheric stability for the site. It is desirable to avoid the use of σ_θ for stability classification under low wind speed conditions (especially in stable atmosphere) and in a complex terrain where σ_θ values will be representative of the nature of the terrain only close to the measurement location. Further, it is implicit in this method that σ_θ values also characterise vertical turbulence. In some cases σ_θ values may not show significant variation with stability, which might make it difficult to evolve a stability classification scheme.

If parameters mentioned above are neither continuously available nor appropriate for the site stability classification, insolation (qualitative specification) and/or cloud cover and surface wind speed can be used as parameters for stability typing. This is the original parameterisation scheme developed by Pasquill. If measured data on insolation are continuously available from a solarimeter, it should be used along with ranges specified in Table II.2A of Appendix-II. In the absence of measurements, insolation can be inferred from solar elevation and cloud cover and stability class determined through use of Table-II.1 of Appendix II. It should be noted that the ranges in solar elevation given in the Table are based on conditions for temperate latitudes and could be different for tropics. Night time stability classes are based on cloud cover observations (if net radiation data are not available) and wind speed. It is natural that insolation at any location can vary significantly due to higher average turbidity levels or frequent haze conditions and hence the measured values should preferably be used.

3.3.2.3 Eddy Diffusivity Models

The basic input data required in eddy diffusivity models is governed by the specific formulation used to obtain eddy diffusivity as a function of space (especially in the vertical direction) and time. Generally used models require (i) surface turbulence parameters that can be estimated from wind speed and surface heat and evaporation fluxes. (ii) mixing height (obtained from radiosonde data) (iii) nature of topography (to estimate surface roughness length).

While surface wind speed data are generally available, surface energy fluxes (thermal and evaporation) are obtained from specialised turbulence instruments or indirectly obtained with lesser accuracy from tower based temperature and water vapour profile measurements. Variation of topographical characteristics over the domain considered may have to be quantified in each of the grids of the domain.

3.3.2.4 Complex Terrain Models

These models can be broadly classified into (i) models that develop wind field in a gridded domain from interpolation of measured data at specific locations (ii) models that obtain the wind fields from solution of basic flow equations using appropriate initial and boundary conditions.

Complex terrain dispersion modeling require the following input data :

- Surface wind speed and direction at different locations covering the domain. The minimum number of locations where measurements are needed depend on the degree of complexity of topography but generally data at more than six appropriate locations have been found to be necessary
- Upper wind data (Rawin and radiosonde data)
- Topographical characteristics (surface roughness etc.) over each of the grid in the domain
- Atmospheric stability category
- Vertical eddy diffusivity profile (optional).

Flow equation models/computational fluid dynamics models do not require the elaborate network of surface wind measurements as required in the interpolation method. However they are computationally intensive. The input data requirements of these models are:

- Topographical characteristics of the site (roughness length, elevation etc.)
- Soil and vegetation characteristics in each grid.
- Rawin and radiosonde data from weather station at the site or at the nearest location
- Surface pressure chart data from weather station to obtain geostrophic (synoptic) wind characteristics (optional)
- Sodar or radio acoustic sound system (RASS) data in the domain (optional).

In the case of these models, temporal and spatial discretisation should be given due consideration.

3.4 Validation and Uncertainty Analysis of Models

3.4.1 General

In the application of the models described earlier, an assessment of uncertainty in model estimates and the extent of their validation through field data are important. In this section these aspects are briefly discussed with respect to each of the models. More details are given in Appendix-V.

3.4.2 Gaussian Plume Model

Uncertainty in Gaussian plume model prediction occurs due to one or more of the following causes.

- Random nature of atmospheric turbulence (Stochastic uncertainty)
- Idealisation inherent in the model (e.g. temporal and spatial variation of mean wind speed not considered)
- Extent of appropriateness of the model for chosen application
- Imprecision in the measurement or estimate of the input parameters

Many validation studies have been made on application of Gaussian plume model both for smooth and complex terrain conditions. Uncertainty in the values of input data (e.g. stability class) has been examined in detail and the possible error in predictions has been analysed (Appendix-V).

3.4.3 Eddy Diffusivity Model

Uncertainties in eddy diffusivity models essentially stem from the incorrect specification of spatial and temporal variation of diffusivity by the empirical formulation used in the model. Thus under strongly convective conditions, eddy transfer hypothesis is violated (flux may not be proportional to concentration gradient) and use of model in such areas should be avoided.

Section 3.3.2.4 gives details of input parameter data needed for application of the model. The general principles of parametric analysis in terms of sensitivity and robustness can be applied to study the effects of imprecision in measurement/estimation of different parameters in model prediction.

Since the basic principles on which eddy diffusivity model rests are satisfied when the dimension of the diffusing plume/cloud is much larger than the scale of turbulence in the atmosphere, these models are often employed in dispersion computations over long ranges (distances from source greater than tens of km).

Validation exercises for eddy diffusion models have been sparse since concentration measurements need to be made at large downwind distances for model comparison. Recent field studies with SF_6 as tracer extend concentration measurements to tens of km in the downwind and crosswind directions of the plume transport and are being used for validation of long-range dispersion models.

3.4.4 Complex Terrain Models

Among the four models listed, complex terrain models are the most recently studied. In view of the elaborate infrastructure requirements, field trials towards their validation have been very sparse. In recent years, tracer studies using SF_6 were aimed at validation of such models and some of the results of these studies indicate that they perform better than GPM for predicting dispersion over complex terrain. However, the improvements over simple models are seen only when the input data fed to the complex terrain models were realistic and reasonably accurate. The major advantage of complex terrain models over GPM and other simpler models is the realistic prediction of space-time evolution of plume trajectory over the terrain. As uncertainty in plume trajectory is the source of significant errors in concentration estimation, importance of complex terrain models is indicated when plume dispersion is studied over such terrain. Use of GPM under these conditions could result in uncertainties of the order of magnitude or more, in concentration estimates. Studies using long range models have been used in validation exercise conducted for releases occurred during Chernobyl accident [4].

TABLE 3.1 : FORMULAS RECCOMENDED BY BRIGGS FOR $s_Y(x)$ AND $s_Z(x)$ ($10^2 < x < 10^4$m)* [3]

Pasquill type	s_y, m	s_z, m
Open country conditions		
A	$0.22\,x\,(1+0.0001x)^{-1/2}$	$0.20x$
B	$0.16\,x\,(1+0.0001x)^{-1/2}$	$0.12x$
C	$0.11\,x\,(1+0.0001x)^{-1/2}$	$0.08\,x\,(1+0.0002x)^{-1/2}$
D	$0.08\,x\,(1+0.0001x)^{-1/2}$	$0.06\,x\,(1+0.0015x)^{-1/2}$
E	$0.06\,x\,(1+0.0001x)^{-1/2}$	$0.03\,x\,(1+0.0003x)^{-1}$
F	$0.04\,x\,(1+0.0001x)^{-1/2}$	$0.016\,x\,(1+0.0003x)^{-1}$
Urban Conditions		
A-B	$0.32\,x\,(1+0.0004x)^{-1/2}$	$0.24\,x\,(1+0.001x)^{-1/2}$
C	$0.22\,x\,(1+0.0004x)^{-1/2}$	$0.20\,x$
D	$0.16\,x\,(1+0.0004x)^{-1/2}$	$0.14\,x\,(1+0.0003x)^{-1/2}$
E-F	$0.11x(1+0.0004x)^{-1/2}$	$0.08\,x\,(1+0.00015x)^{-1/2}$

* downwind distance

TABLE 3.2 : PARAMETERS TO OBTAIN $\sigma_Y(x)$ AND $\sigma_Z(x)$ (P-G MODEL) [5]

$\sigma_y = A_y\, x(m)^{0.9031}$ and $\sigma_y = A_z\, x(m)^q + R$

Stability		*x* < 0.1 Km			0.1 Km ≤ *x* ≤ 1.0 Km			x > 1.0 Km		
	A_y	A_z	q	R	A_z	q	R	A_z	q	R
A	0.3658	0.192	0.936	0	0.00066	1.941	9.27	0.00024	2.094	-9.6
B	0.2751	0.156	0.922	0	0.038	1.149	3.3	0.055	1.098	2.0
C	0.2089	0.116	0.905	0	0.113	0.911	0	0.113	0.911	0
D	0.1471	0.079	0.881	0	0.222	0.725	-1.7	1.26	0.516	-13.0
E	0.1046	0.063	0.871	0	0.211	0.678	-1.3	6.73	0.305	-34.0
F	0.0722	0.053	0.814	0	0.086	0.74	-0.35	18.05	0.18	-48.6

Where x (m) is the distance from the source in m.

TABLE 3.3 : COMPARATIVE EVALUATION OF DISPERSION MODELS AND THEIR APPLICATION

Model	Type	Input data needed	Application	Accuracy	Computational Requirements	Remarks
Box model	Meteorological model	Vertical average wind speed, volume of model domain, Mixing height	Area sources, distributed sources, long range plume trajectory modeling	Gives uniform concentration in domain, hence poor for point source near field application	Minimal, easily operated on PC	Generally used as screening model
Gaussian plume model (GPM)	Combined meteorology and diffusion model	Surface wind speed, direction, insolation, cloud cover	Point, area, volume source	Gives concentration estimates within an order of magnitude for continuous releases over homogeneous terrain	Minimal, easily operated on PC	Widely used
Interpolation/ mass consistency model	Meteorological model	Wind speed and direction at many locations in the domain, upper air data at least at one location	For wind field over complex terrain with ridges and valleys	Improves with increasing number of observation locations, Poor representation under strong local circulating flows	Needs large memory capacity & computational time.	Used in emergency response planning for instantaneous releases
Gaussian puff model	Dispersion model	Surface wind speed, direction, insolation, cloud cover	Dispersion under time varying meteorological conditions, continuous short term releases under emergency situations.	Better than Gaussian plume model for time varying meteorology. Not satisfactory under strong wind shear	Moderate	Used also in mesoscale models

TABLE 3.3 : COMPARATIVE EVALUATION OF DISPERSION MODELS AND THEIR APPLICATION (CONTD.)

Model	Type	Input data needed	Application	Accuracy	Computational Requirements	Remarks
Particle in cell model	-do-	Surface wind speed, direction, insolation, cloud cover	Dispersion over complex terrain	Better than GPM for complex terrain applications	Large memory capacity.	-do-
Particle trajectory model	-do-	Atmospheric stability, wind and turbulence data from prognostic model	-do-	Good for complex terrain	Computational time large, can be reduced by parellelisation	-do
Prognostic model	-do-	Wind data are needed for only initialisation, upper wind data and soil characteristics are used as input	For wind and turbulence over complex terrain, coastal sites	Improves with data assimilation of boundary values and observations and also with increasing grid resolution.	Needs large memory capacity & computational time.	Used in emergency response planning for instantaneous releases

4. METEOROLOGICAL PROGRAMME AT VARIOUS STAGES OF SITING

4.1 General

The usual practice in NF Siting involves *inter alia*, investigation of atmospheric dispersion aspects with different degrees of emphasis and accuracy requirements relating to the estimates of dispersion during different stages of siting viz. (a) site selection (b) site evaluation and (c) pre-operational and operational stages. Since data available could vary during each of these phases, the information needed and meteorological programme would differ significantly. The results of meteorological investigation should be used to confirm the suitability of the site;

- To check whether the local meteorological characteristics have changed between the site evaluation stage and the plant commissioning stage;
- To facilitate the choice of appropriate dispersion models;
- To establish limits for atmospheric discharges;
- To establish limits for design performance like containment leak rates and for evolving emergency preparedness plans.

This section deals with the nature of data to be collected, their analysis and application to dispersion estimation during the different stages.

4.2 Site Evaluation Stage

4.2.1 General

Data during this stage would be more extensive than at site selection stage. Meteorological data collected at the site at least for a year should be available for the dispersion evaluation. During site evaluation stage meteorological data collected at the site should be used for the statistical analysis and estimation of input parameters needed in dispersion models. Data needed at this stage are wind speed, direction, surface temperature and humidity, rainfall, type of terrain and topographic features and turbulence parameter (Appendix II). These meteorological parameters can also be used in estimating various design parameters like stack height, release rate limits, exit velocity etc.

Hourly values of Pasquill stability classes should be evaluated using the adopted procedure and used in dispersion estimates. Estimation of dispersion parameters for the corresponding stability classes should be made using standard Pasquill-Gifford (PG) nomograms. These should be corrected for the necessary averaging time used, terrain roughness length etc. Power law empirical fits for PG nomograms are available [5,6] and these can be used to facilitate computation.

4.2.2 Source Characteristics

Dispersion estimation at site evaluation stage needs specification of source characteristics such as magnitude of release, type of release and height of release.

4.2.3 Meteorological Data Collection

4.2.3.1 General

Data collection at the site of NF during site evaluation has to be planned based on the nature of the site. For homogenous level terrain, data from a single location measurement can be unambiguously used. However for complex terrain (e.g. valleys and ridges) and coastal sites where significant terrain induced flow modifications are observed, interpretation of data collected at a single station should be carefully made and often may not be representative over the entire region. Measurement of meteorological parameters at more than one location should be made in such a case and the locations of these stations can be carefully chosen to identify significant flow pattern differences due to terrain.

The basic meteorological variables to be measured at the site are given in Table 4.1. The required measurement accuracy and threshold are also indicated. Some brief details of the data collection are discussed below.

4.2.3.2 Positioning of Instruments

The positioning of meteorological instruments, especially wind instrument needs careful consideration. The wind sensors should give the wind speed and direction of the ambient atmosphere and not affected by the flow modifications due to the structure over which it is mounted or vortices created by nearby buildings or topographic features like trees. The sensors should be mounted at a suitable location at an appropriate height from the ground to give an unaffected exposure to ambient wind. Some guidelines in this regard are available in the literature [6,7]. Locating the instruments directly downwind of obstructions under predominant wind direction should be avoided. Where practicable, levels of natural or manmade obstructions to the air movement should be less than the wind measuring level and with a horizontal separation of ten times the obstruction height.

Solar radiation instrument (Pyroheliometer) should be mounted horizontally with no obstruction for the full solar movement in the horizon. This should ensure full collection of direct and diffuse component of insolation*. Rain

---

* Insolation : Incoming solar radiation

gauges should be installed in an open area sufficiently away from nearby structures to ensure unobstructed collection of precipitation even during high wind speed conditions.

4.2.3.3 Wind Measurements

Wind speed and direction should be measured continuously at an appropriate height using a rugged instrument with low measurement threshold and with accuracy described in Table 4.1. Wind direction measurements should be made by usual potentiometric wind vanes, which gives continuous 360^o or 540^o (to avoid gap smearing) direction. Wind speed measurement should preferably be made by anemometers of analog type to enable estimate of magnitude of short period (3 minutes or less wind gusts*). Such short period wind data would be needed in the context of extreme value analysis and design of civil structures [8,9]. Averaged hourly data (or for shorter periods if required) should be obtained through a suitable data logging system.

4.2.3.4 Turbulence Measurement

Wind direction fluctuation is one of the indices used in the atmospheric turbulence measurements and in stability classification (Appendix-II). A data logging system should be interfaced with the wind direction sensor, with suitable software to record directly standard deviation of wind direction fluctuation for averaging over any required period (usually one hour).

4.2.3.5 Precipitation

Hourly precipitation measurements should be made using a recording rain gauge (siphon or bucket type) for documenting rainfall intensity. In addition, total rainfall over a period of 24 hours is needed in conformity with standard weather station measurements.

4.2.3.6 Surface Measurements (air temperature, humidity)

Air temperature and humidity are standard measurements collected at any weather station of India Meteorological Department (IMD) and should be collected at the site also. The instruments (Thermograph and Hygrograph) are mounted inside a Stevenson screen at 1.2 m height. Daily data can be used to obtain surface values of dry bulb temperature and humidity.

4.2.3.7 Solar Radiation (insolation)

Total solar radiation (diffused and direct component) should be continuously measured using solarimeter with recording or digitisation of the output. Hourly

---

* Gusts : Wind gust is the maximum 3 second wind speed forecast to occur within a 2 minute interval at a height of 10 meters.

values of insolation are obtained for use essentially in stability classification schemes. The solarimeter at site should be calibrated periodically with standard solarimeter available with IMD.

4.2.3.8 Meteorological Towers and Sound Detection and Ranging (SODAR)

In addition to the above measurements, in complex topography characteristics of site meteorology have to be studied using more sophisticated measuring systems like meteorological towers, SODAR etc. Tower installation would facilitate vertical profile measurements of wind speed, direction and temperature. Heights of meteorological towers are typically between 50 to 100 m. Towers of more than a few tens of meters are costly and difficult to maintain. Hence remote sensing measurement by SODAR, is widely employed. Doppler SODAR can give on-line data on three components of mean wind speed, turbulence intensity, and mixing heights. It can also give stability characteristics with the help of suitable software interface.

It may be noted that in addition to installation of SODAR, a measurement system should still be maintained to record the conditions at 10m elevation.

4.2.3.9 Analysis of Meteorological Data

The hourly meteorological data collected at the site should be statistically analysed before input to dispersion models. Wind data are usually classified into joint frequency distribution (JFD) of wind speed and direction. Wind direction is usually classified into sixteen compass directions, and wind speed in four or five categories. This can also be represented in a graphical polar plot known as wind rose (Figure 4.1). Wind direction (in wind rose) represent the direction from which wind is blowing. For atmospheric dispersion calculation diffusion climatology data is generated as shown in Table 4.2. The method of estimating long term averaged concentration is outlined in Appendix- VI. Table 4.3 gives a sample of the long-term dilution factors (c/Q) for different wind direction sectors using such a computation for a particular site.

4.2.4 Methodology for Dispersion Estimation

4.2.4.1 General

Dispersion estimation in site evaluation stage is based on meteorological data collected at the site at least for a period of one year. The nature of terrain is taken into consideration in the computation.

4.2.4.2 Site Characteristics

Site characteristics need to be considered in arriving at realistic atmospheric dispersion computations. Three types of terrain are usually considered.

Plain terrain*:* Local terrain with uniformly distributed roughness elements like vegetation over a domain of 30 km radius around the NF. The site should be well inland, at least 10 km or more from the nearest coast (shoreline).

Uneven terrain (Ridges and Valleys): These sites include terrain with medium or large ridges or hills or valleys formed by ridges with significant slopes greater than 1/50.

Coastal areas or areas near a large water body*:* These include sites situated near coast, (less than 10 km from shoreline) or near large lakes say with width greater than 5 km where significant land and sea/lake breeze can be seen to occur even from sparse qualitative observations.

4.2.4.3 Data Requirements for Each Terrain

Following are guidelines for meteorological measurement program for different terrains:

In case of plain terrain, meteorological parameters like mean wind speed, direction and turbulence can be expected to be horizontally homogenous and hence measurements at a single location at the concerned site will be representative of the entire domain. The meteorological measurement program discussed in Section 4.3.3 is adequate.

In case of uneven (complex) terrain, significant spatial variation in the values of the meteorological parameters exists and the measurement program and dispersion model to be used should take this into consideration. For this purpose meteorological measurements are made at more than one location and the measurement network should be planned as per site requirements and no general guidelines can be given. This will need site visit and expert judgment to fix the locations for site measurements. Representative measurements at valleys and top of the ridges should be suitably interpreted to examine presence of up slope and down slope (valley) winds. Vertical wind profile measurements by SODAR, synoptic data from IMD stations and numerical modeling would help delineate characteristic flow features at the site (e.g. bowl effect, valley channeling etc.) and can support the surface meteorological network.

In case of coastal terrain, the main feature to be considered is the predominance of land and sea breeze systems in the local climatology. From site dispersion consideration, sea breeze is important and should be properly interpreted. For local dispersion estimates (less than a few kilometers from coast) data from a meteorological station at the site near the coast is often representative to give plume transport. Dispersion models with GPM modified to account for sea breeze fumigation effects [10, 11] should be used in coastal sites [see Appendix-VII]. Internal boundary layer and coastal circulation (sea breeze cell) often govern plume transports over larger distances and turbulence dispersion at a coastal site. This could be studied by data collected from SODAR at the site and/or coupled with flow dynamic model. Additionally, a meteorological station at an inland location (10 km or more from the coast) should also give useful data for studying the diffusion climatology of a coastal site.

4.2.4.4 Atmospheric Stability Classification

Table 4.4 gives the list of various stability classification schemes in use and their corresponding governing parameters. The details of the Pasquill stability classification scheme and that based on horizontal wind direction fluctuations are given in Appendix-II. In the GPM, s_y and s_z (root mean square deviation of the distribution of concentration) specify dispersion parameters. In Pasquill-Gifford dispersion model (PG), these parameters are specified as a function of downwind distance for six Pasquill stability categories. The formulas given in Table 3.2 showing the variation of s_y and s_z are based on data for plain terrain and sampling time of 3 minute and 10 minute for s_y and s_z respectively. There has been modification from these basic curves taking into account different terrain conditions [Appendix-I]. The various methods of obtaining s_y and s_z values have been discussed in Appendix-II and suitable model should be selected.

4.2.4.5 Model Applications

The steps involved in the application of dispersion model are as follows:

Selection of model : An appropriate model for the given site and situation should be employed taking into account terrain roughness and height of release. This can be carried out based on the discussions made earlier (refer Section 3.3).

Determination of stability class: Scheme for stability classification should be identified and appropriate parameters should be measured. (refer Appendix II).

Wind speed at the release height: If SODAR data is available, it can be used directly to obtain hourly wind speed at any desired release height. If wind speed is available only at a height lower than release height, the speed for release height can be calculated using a logarithmic or power function relationship [2,3].

Release height: Effective stack height is determined using internal and external diameter of the stack, ambient wind speed, effluent exit velocity, temperature of effluent and ambient air temperature [Appendix-III].

Parameter s_y and s_z: These are obtained from PG nomograms or formulae appropriate to the model used [Appendix-II].

Ground level concentration (GLC) and depositional flux: These are determined from appropriate formula [Appendices-I and IV].

Time Integrated Concentration (TIC): This is of importance for routine release from NFs for evaluating long term integrated concentration (e.g. annual integrated concentration). For this purpose, data on joint frequency distribution of wind speed direction and atmospheric stability are required over the annual period. The detailed procedure for such computation is presented in Appendix VI.

Additional data : Some of the additional data that may be relevant for a particular computation are:

- Averaging time used for concentration estimation [Appendix-II]
- Radioactive decay of the nuclides in the effluent [Appendix-IV]
- Dry deposition : This would require specification of deposition velocity [Appendix-IV]
- Wet deposition : This would require washout coefficient, which can be obtained for specific rainfall intensity [Appendix-IV]

One can use the necessary algorithm for dispersion estimates involving the above procedure using the details in various appendices indicated. Estimates of GLC and depositional flux can be expected to be relatively more realistic than at the site selection stage since site specific input data are used.

4.3 Pre-operational and Operational Stages

4.3.1 General

Extensive site specific database, both on source and site meteorological characteristics, can be expected to be available during these stages of NF. Final safety analysis report (FSAR) prepared for the site can be used for obtaining source data while meteorological data will be available from data acquisition systems including sophisticated instruments which will be fully operational at the site.

4.3.2 Source Characteristics

Estimates for source term should be made for a variety of postulated accident scenarios as per FSAR analysis, which take into account design features of NF related to safety provisions to prevent and/or mitigate magnitude of release.

4.3.3 Meteorological Data Collection

During the pre-operational and operational stage of NF, meteorological data collection program should fully take into account the site characteristics such that the data collected should be representative of the site and its surroundings over which dispersion estimates are to be made.

Brief guidelines are given below for the approach to be taken in the meteorological measurements program taking into account nature of the terrain on which NF is located and its surroundings.

In case of plain terrain, meteorological parameters like mean wind speed, direction and turbulence can be expected to be horizontally homogeneous and hence measurements at a single location at the concerned site will be representative of the entire domain. The meteorological measurement program discussed for the site evaluation stage is adequate and can be continued during the pre-operational and operational stages.

For complex terrain, the meteorological measurement program discussed for the site evaluation stage during pre-operational and operational stages should be continued. Improvement in the numerical model used and its validation can be attempted using the data obtained during the pre-operational phase. The examination of the data would also enable any relocation of the measurement network if found necessary based on the nature of flow features observed at the site. Detailed study of characteristic features in a complex terrain like bowl effect, valley winds, re-circulating flows etc. should be made using the data and theoretical approach. Optimisation of measurement program as a permanent feature during the operation of NF should be undertaken based on the results of such detailed studies.

Over coastal areas, the characteristics flow features relevant to dispersion estimation are the development of internal boundary layer (IBL) during onshore flow and typical land and sea breeze circulation with a diurnal cycle. The use of SODAR and the surface meteorological station at a location (10 km or more from the coast) is suggested to meet the requirements of coastal dispersion modeling. Guidelines for planning the instrumentation for a coastal terrain can be obtained from the preliminary results of a numerical dispersion model applied for the site.

4.3.4 Methodology for Dispersion Estimation

When the site and surrounding areas are located on a level homogeneous terrain, GPM can be used for dispersion estimation during this stage also. However, when dealing with complex and/or coastal terrain sophisticated dispersion models that fully take into account site topography are employed in place of GPM. A combined meteorological and dispersion model is employed for this purpose. Two types of models can be considered for complex topography. When a network of meteorological stations distributed at the site and surrounding domain (say six stations or more) are operational, interpolation models such as MATHEW-ADPIC [12] can be employed for dispersion estimates. In the absence of such detailed data collection network, flow equations model (dynamic model) should be applied for the terrain. Synoptic data from the nearest weather station of IMD should be used as input and these should be made available in as much detail as practicable.

TABLE 4.1 : BASIC METEOROLOGICAL VARIABLES TO BE MEASURED AT A SITE

Variable measured	**Characteristics of Instrumentation System**		
	Sensor type	**Required measurement threshold**	**Accuracy**
Wind direction (hourly value)	Potentio metric	0.5 m/s with 10^o deflection	$\pm 5^o$
Wind speed (hourly value)	Cup Anemometer	0.5 m/s	0.1 m/s
	Sensitive (e.g. Propeller type)	0.2 m/s	0.05 m/s
Temperature (hourly value)	Resistance temperature detectors (RTDs)	-	± 0.5 K
Temperature difference (hourly) between two elevations	Matched RTD pair	-	± 0.1 K
Humidity (hourly value)	Hygrograph	-	± 5% relative humidity
Precipitation (hourly value)	Recording tipping bucket or rapid response type rain gauge	Rate 0.25 mm/hr total 0.1 mm	± 10% (resolution of gauge)
Solar radiation (insolation) (hourly value)	Solari meter	-	0.1 langley /min
Net radiation (hourly value)	Net radio meter	-	± 0.01 langley /min
Time		-	± 5 min

TABLE 4.2: TYPICAL DIFFUSION CLIMATOLOGY AT A PARTICULAR SITE

STATION XXX PERIOD: JAN-DEC

WIND DIR	STABILITY CLASS											
	A		B		C		D		E		F	
	(i)	(ii)	(i)	(ii)	(i)	(ii)	(i)	(ii)	(i)	(ii)	(i)	(ii)
N	0	0.00	69	9.81	91	11.68	98	16.33	84	9.17	381	36.31
NNE	4	1.15	45	9.31	34	4.49	90	16.59	87	11.47	139	18.75
NE	3	0.77	33	5.87	60	6.72	166	24.49	72	7.66	113	15.66
ENE	7	1.92	33	5.03	134	17.93	131	18.73	57	5.66	195	24.88
E	3	0.77	40	6.05	97	11.93	63	9.82	15	1.91	66	9.26
ESE	1	0.38	100	12.89	106	14.51	58	7.07	9	1.22	67	8.29
SE	1	0.38	49	7.89	87	10.90	113	8.37	13	1.29	22	2.51
SSE	0	0.00	55	8.14	98	14.26	40	4.73	19	1.22	16	2.00
S	0	0.00	36	5.63	58	8.24	31	3.90	25	1.73	19	2.21
SSW	3	0.58	22	3.00	39	5.57	40	4.38	70	5.51	28	3.73
SW	1	0.38	39	5.38	67	6.34	173	14.31	69	7.61	24	3.11
WSW	0	0.00	36	5.35	107	7.68	412	25.59	118	8.14	54	5.14
W	0	0.00	28	3.77	58	4.60	140	11.85	61	5.21	54	6.64
WNW	0	0.00	67	5.99	357	25.56	424	30.16	169	12.40	216	18.82
NW	1	0.38	16	2.76	49	3.70	289	17.53	239	12.11	218	19.07
NNW	1	0.38	7	1.19	0	0.00	51	8.29	66	5.19	275	29.99

Notes: (1) Column (i) indicates the number of hourly observation for the given wind direction under that particular stability class, N.

(2) Column (ii) is the value of $\sum_{i=1}^{N} Ni/Ui$ where Ni is the number of hours in that particular wind direction and stability class and Ui is the corresponding wind speed in km/h.

TABLE 4.3 : VALUES OF DILUTION FACTOR C /Q (sm^{-3}), [SITE SPECIFIC]

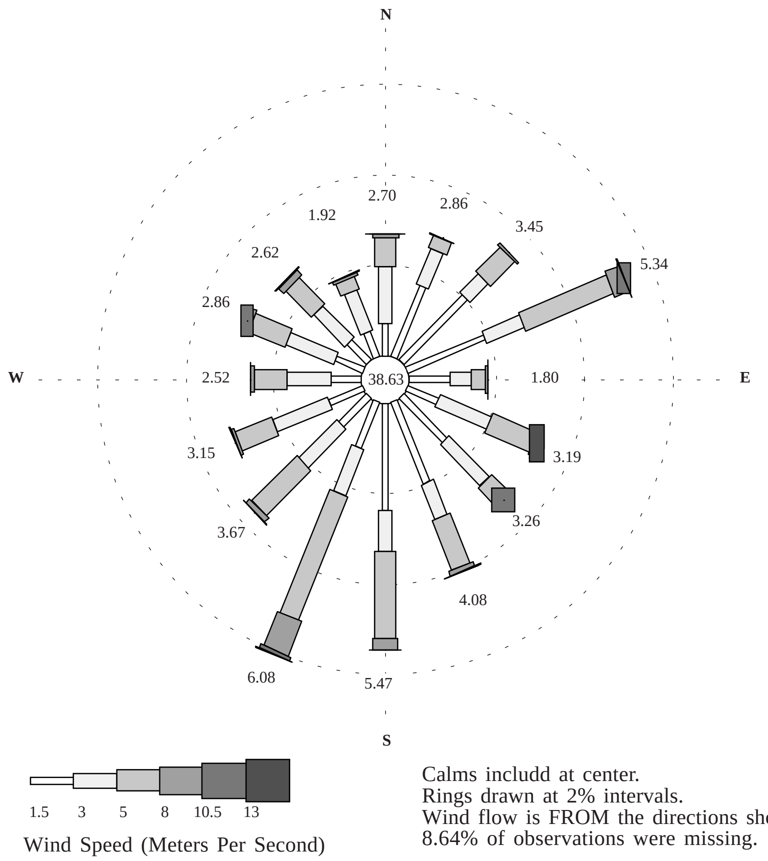
RELEASE HEIGHT: 100.0 m PERIOD: JAN-DEC DISTANCE: 1.6 km

DIRECTION	(C/Q) s/m^3
N	1.202E-07
NNE	8.372E-08
NE	9.313E-08
ENE	1.372E-07
E	9.764E-08
ESE	1.331E-07
SE	9.734E-08
SSE	1.098E-07
S	6.880E-08
SSW	4.660E-07
SW	7.355E-08
WSW	9.560E-08
W	5.467E-08
WNW	1.944E-07
NW	5.504E-08
NNW	1.689E-08

TABLE 4.4 : LIST OF STABILITY CLASSIFICATION SCHEMES AND RELATED PARAMETERS

Scheme	Relevant Parameters	Instrumentation	Remarks
Pasquill	Insolation (qualitative), wind speed, cloud cover	Anemometer	Widely used in view of easy availability of parameters
Turner	Insolation (quantitative), wind speed, cloud cover	Solarimeter, anemometer	Useful where solar radiation data are available
Turner improved version	Net radiation, wind speed	Net radiometer, anemometer	Better representation than Pasquill method during night
Temperature lapse rate	Vertical temperature gradient	Thermistors, RTDs	Useful in vertical stability index
Temperature lapse rate and wind speed	Vertical temperature gradient, wind speed	Matched thermistors, RTDs, anemometer	Better than lapse rate method
Slade	Standard deviation of wind direction fluctuation	Sensitive wind vane	Better index than Pasquill type method for horizontal turbulence
Split sigma method	Standard deviation of wind direction fluctuation and vertical gradient of temperature	Sensitive wind vane, thermistors, RTDs	Better indices than slade's method for both horizontal and vertical standard
Bulk Richardson method	Temperature lapse rate, wind speed	Thermistors, RTDs, anemometer	Formulation gives a better understanding of stability from energy consideration
Monin-obhukov scheme	Temperature lapse rate, wind speed, insolation	Thermistors, RTDs anemometer, solarimeter	Obtained from energy balance consideration and realistic indicator of stability

Joint Frequency Distribution
for Years 2000 - 2004



Calms includd at center.
Rings drawn at 2% intervals.
Wind flow is FROM the directions shown.
8.64% of observations were missing.

PERCENT OCCURRENCE: Wind Speed (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	1.5	3	5	8	10.5	13
N	0.70	1.28	0.64	0.07	0.01	0.00
NNE	1.69	0.85	0.30	0.02	0.00	0.00
NE	2.03	0.59	0.77	0.06	0.00	0.00
ENE	1.90	0.94	2.14	0.35	0.00	0.00
E	0.94	0.47	0.34	0.05	0.00	0.00
ESE	0.76	1.26	1.11	0.05	0.01	0.01
SE	1.38	1.28	0.58	0.01	0.01	0.00
SSE	1.95	0.82	1.20	0.11	0.00	0.00

TOTAL OBS = 43847 MISSING OBS = 3788

PERCENT OCCURRENCE: Wind Speed (Meters Per Second)
LOWER BOUND OF CATEGORY

DIR	1.5	3	5	8	10.5	13
S	2.37	0.92	1.92	0.25	0.01	0.00
SSW	1.10	1.10	2.96	0.81	0.09	0.01
SW	0.88	1.21	1.41	0.14	0.02	0.00
WSW	0.83	1.34	0.90	0.07	0.02	0.00
W	0.71	0.98	0.75	0.08	0.01	0.00
WNW	0.68	1.16	0.91	0.11	0.00	0.00
NW	0.63	1.00	0.82	0.16	0.01	0.00
NW	0.59	0.96	0.30	0.07	0.01	0.00

CALM OBS = 16940 PERCENT CALM = 38.63

FIGURE 4.1 : A TYPICAL WINDROSE DIAGRAM

APPENDIX-I

GAUSSIAN PLUME AND PUFF DISPERSION MODELS

I.1 Introduction

The fundamental premise of the Gaussian Plume Model (GPM) is that the concentration distribution in the spreading plume or puff is Gaussian (or Normal) in nature. This is conventionally represented by exp $(-(r-r_0)^2/2\sigma^2)$ where $(r-r_0)$ is the distance from the centre-line of the plume or puff, r_0 is the location parameter of the centre of the plume or puff and σ is the standard deviation of the distribution. Since the first and second moments fully describe the distribution statistics of a Gaussian distribution, r_0 and σ are the basic parameters that need to be specified in the model.

The assumption that the distribution is Gaussian is based on analogy with molecular diffusion process where turbulent eddies that spread materials in the plume are taken to play the role of molecules. The analogy is not strictly valid, as there is wide range of scales in the turbulent diffusion process. However experimental evidence indicates that Gaussian distribution is satisfied in many practical situations except for ground level releases under strong convective conditions.

The theoretical formulation of Gaussian plume from a continuous source of release can be considered to embody three processes:

(a) Transport by wind, assumed homogeneous in space and time

(b) Diffusion by turbulent eddies

(c) Diffusion in downwind direction is neglected

Since diffusion in the crosswind and vertical directions can be taken to be independent of each other, the concentration distribution of the pollutant in space for a continuous point source can be represented as

$$\chi(x,y,z) = \underbrace{(Q/\{2\pi u\,\sigma_y\sigma_z\})}_{(A)}\ \exp[-(\underbrace{\{y^2/2\sigma_y^2\}}_{(B)} + \underbrace{\{z^2/2\sigma_z^2\}}_{(C)})] \qquad \text{(I-1)}$$

where

χ : is the steady state concentration of the effluent at (x, y, z) (Bq/m^3)

Q : the source strength (the rate at which the effluents are released) (Bq/s)

u : the mean wind speed (m/s)

σ_y : cross wind dispersion parameter (m)

σ_z : vertical dispersion parameter (m)

Here the origin of the Cartesian coordinate system is at the source. X-axis is along the mean downwind direction, Y-axis is the horizontal crosswind direction and Z-axis is the vertical direction. The inverse relationship with mean wind (Term A) is due to plume transport while terms B and C represent the double Gaussian distribution in the Y and Z directions respectively. It is apparent that the concentration distribution is specified if σ_y and σ_z are given as function of downwind distance. In dispersion formulation of a continuous plume, these parameters are assumed to be functions of downwind distance and atmospheric stability.

I.2 Basic Working Formulae of Dispersion

In this section, working relationships to evaluate concentration for different source and receptor configuration (elevated release, cross-wind position etc.) often used in practical computations using the basic equation I-1 are discussed. They refer to the coordinate system given in Figure I-1. (Origin of coordinate system is on the ground just below the source).

A general formula for evaluation of concentration distribution in space (considering reflection at the ground) is given as

$$\chi(x,y,z) = (Q/\{2\pi u\,\sigma_y\sigma_z\})\ \exp(-y^2/2\sigma_y^2)\ \{\exp(-(z-H)^2/2\sigma_z^2) + \exp(-(z+H)^2/2\sigma_z^2)\} \qquad \text{(I-2)}$$

Here H is the effective stack height (stack height + plume rise). The receptor is located at (x, y, z) from the origin.

I.2.1 Ground Level Release (GLR)

For a ground level source H = 0. Then the equation I-2 modifies to

$$\chi(x,y,z) = (Q/\{\pi u\,\sigma_y\sigma_z\})\ \exp[-\frac{1}{2}(y^2/\sigma_y^2) + z^2/\sigma_z^2)] \qquad \text{(I-3)}$$

I.2.2 Ground Level Concentration and Elevated Release

This is obtained by making z = 0 in equation I-2

$$\chi(x,y,0) = (Q/\{\pi u\,\sigma_y\sigma_z\})\ \exp[-(y^2/2\sigma_y^2 + H^2/2\sigma_z^2)] \qquad \text{(I-4)}$$

I.2.3 Centre line Ground Level Concentration (GLC)

Very often computations are made of ground level centre line concentration from an elevated release. For this, y = 0. Then I-4 modifies to

$$\chi(x,0,0) = (Q/\{\pi\,\sigma_y\sigma_z u\})\ .\ \exp[-H^2/2\sigma_y^2] \qquad \text{(I-5)}$$

For an elevated release the concentration at small values of ‘x’ is near zero and goes through a maximum value to very small values at long distances.

For making conservative estimates, the maximum ground level concentration is given by

$$\chi_{max} = (2Q/\{\pi e u H^2\})\,(\sigma_z/\sigma_y) \qquad \text{(I-6)}$$

where 'e' is the base of natural logarithm. The distance at which χ_{max} occurs is where $\sigma_z = H/\sqrt{2}$.

I.2.4 Centre Line GLC for GLR

The centre line ground level concentration for a ground level release is given by, (along plume centre line)

$$\chi(x,0,0) = Q/(\pi\,\sigma_y\,\sigma_z\,u) \qquad \text{(I-7)}$$

As can be seen from the above formulations for a ground level release, the centre line ground level concentration decreases monotonically with distance unlike for elevated release, where the concentration initially increases with distance, reaches a maximum and thereafter decreases.

I-2.5 Dilution factor (χ/Q)

The concentration normalised by source strength (χ/Q (sec/m^3)) is often used to obtain estimates of dilution. Since it is not a dimensionless quantity, it should be noted that it is not a real dilution factor. However the term is in wide use.

I-3 Puff Dispersion Models (PDM)

I-3.1 General

The Gaussian plume model discussed earlier essentially applies to a continuous plume release (period of release extending an hour or more) and short-term releases are more effectively treated by Puff Dispersion Model. In general, if the travel time from the source to receptor is large compared to period of release, then PDM may be used.

The basic assumptions in a puff model are:

- At any time, the distribution of material within the puff is Gaussian in all the directions with maximum concentration at the centre of the puff.
- Puff centre moves with the mean wind vector.
- After a large time of travel (several times the timescale of largest atmospheric eddies), succession of puffs released becomes equivalent to a continuous plume.

I-3.2 Features of PDM

I-3.2.1 Steady Mean Wind Vector

Under steady mean vector, it is assumed that the puffs move in a sequence along the straight line given by the mean wind direction. The concentration at any point x, y, z and time t for a single puff since its release is given by

$$\chi(x,y,z,t) = (Q/\{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z\}) \ \exp[-\frac{1}{2}\{(x-ut)^2/\sigma_x^2 + y^2/\sigma_y^2 + z^2/\sigma_z^2\}] \quad \text{(I-8)}$$

where symbols retain the same meaning as in I-1, except Q (Bq) is the quantity of material released in the puff and σ_x is the value of along wind dispersion parameter (in metres). The origin of the co-ordinates for x, y, z lies at the release point. For elevated releases, with coordinates referred in Figure I.1, the above equations is modified into

$$\chi(x,y,z,t) = (Q/\{(2\pi)^{3/2}\ \sigma_x\ \sigma_y\ \sigma_z\}) \exp[-\frac{1}{2}(x-ut)^2\ /\sigma_x^2] \ \exp[-y^2\ /2\sigma_y^2] \exp[-1/2\ \{(z+H)^2\ /\sigma_z^2\ +(z-H)^2\ /\sigma_z^2\}] \quad \text{(I-9)}$$

At any receptor location x, the concentration from puff attains its maximum value at a time t from release given by t = x/u (centre of the puff above the receptor). It should be noted that σ_x appears in the PDM unlike in the GPM where it is neglected compared to plume transport by wind. The basis of obtaining σ values in PDM as a function of time usually follows the theoretical treatment of turbulent diffusion of puffs. Eddies of sizes less than the dimension of puffs cause mixing while those of larger sizes cause bodily movement of puffs. Since the dimension of puff increase with time, the eddy size ranges causing dispersion and movement also continuously changes.

The variation of dispersion parameters with distance (or time) in the three-component direction could be different from those used for GPM though many practical puff models disregard the difference. In any case, by considering a continuous plume to be equivalent to a succession of puffs released, the results of GPM can be approximated by integration of individual puff contribution from PDM.

I.3.2.2 Variable Wind Vector

The puff models are more useful where mean wind vector transporting the puff is variable in space and time. This is because these variations can be directly incorporated in a numerical scheme whereby they are used to transport the centre of the puff during each time step. Dispersion of the puff (Gaussian distribution) is evaluated using the concept of virtual source at each time step. The trajectories and dispersion of each puff can be continuously tracked and concentration at any receptor location can be described as a function of time.

This model can be used for instantaneous or planned or off-normal releases using real time meteorological parameters. Non-stationary stability regimes can be directly taken into account in the model and the application of the model is particularly useful in near calm (low wind speed) conditions.

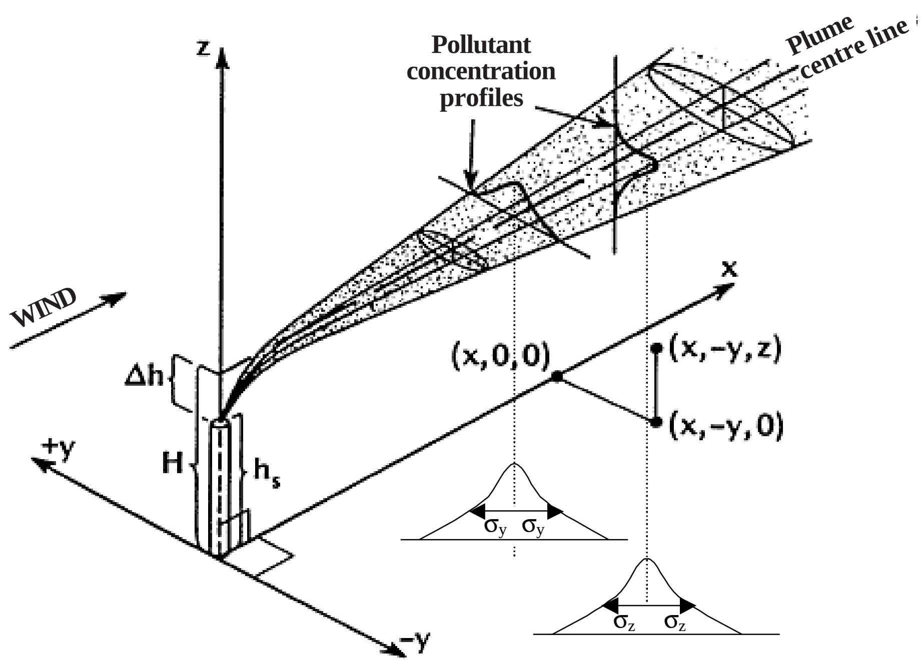


FIGURE I.1 : SCHEMATIC REPRESENTATION OF A PLUME DISPERSING IN A NORMAL (GAUSSIAN) DISTRIBUTION ALONG TWO AXES-DISTANCE CROSSWIND (Y) AND DISTANCE VERTICAL (Z), THE GAUSSIAN DISTRIBUTION OF CONCENTRATION IN Y AND Z DIRECTION ARE SHOWN AT THE BOTTOM WITH STANDARD DEVIATION σ_Y AND σ_Z RESPECTIVELY.

APPENDIX-II

ATMOSPHERIC STABILITY CLASSIFICATION AND ESTIMATION OF DISPERSION PARAMETERS

II.1 Introduction

The estimation of plume or puff dispersion parameters used in GPM can be considered in two steps:

- Arrive at the prevalent atmospheric stability class using measured and/or observed meteorological parameters.
- Use empirical formulations or nomograms, which give s_y and s_z as a function of downwind distance for the stability class determined.

The basic idea of classifying atmospheric stability condition into discrete classes was originally proposed by Pasquil[13] while introducing a practical scheme for estimating atmospheric dispersion from continuous point source releases over a smooth terrain. Six classes were defined (viz.: A, B, C, D, E and F). The stability class-A denotes a state of highly unstable atmosphere (typified by strong convective conditions). The stability classes B, C, … etc. are indicative of progressively increasing stability with category F denoting maximum stability that exists during cloud-free nocturnal inversion conditions.

Various approaches have been proposed for identifying stability classes. The approaches differ in the use of meteorological parameters as stability indices and the method used for estimating dispersion parameters. A few of them, which have been in practical use, are discussed below.

II.2 Pasquill-Gifford Scheme (PG)

This is a classical method, which is still in wide use because it is based on easily measured parameters. For stability classification the parameters employed in this method are:

- Wind speed at 10 m level
- Qualitative estimation of insolation during day and cloud cover during night.

The reasoning behind the selection of the above two parameters is that while wind speed is an index of mechanical turbulence level in the atmosphere, insolation and cloud cover indicates measure of thermal turbulence. Table II-1 gives the PG scheme of stability classification.

Insolation can also be estimated quantitatively from solar angle (using site latitude, longitude, time and day of the year) or more accurately from continuous measurement using Solarimeter during daytime. Measurements made by net-radiometer which gives net radiation (sum of short wave (solar) and long wave (terrestrial)) can be used for both day and night time stability classification. Stability classification tables based on measured values of solar and net radiation is available in literature. Wherever net-radiation measurements are available, it is recommended that they should be used instead of the qualitative PG scheme (Table II-2B).

For σ_y and σ_z estimation at various downwind distances for each of the Pasquill stability classes (A to F), PG nomograms are used. The values correspond to data obtained from field experimentation over a smooth terrain and for a sampling time of 3 minutes and 10 minutes for σ_y and σ_z respectively.

The concentrations based on the nomograms mentioned above should be corrected upto a few hours to allow for difference in sampling time. The corrected concentration may be obtained by multiplying the uncorrected concentrations by the following factors:.

$(T_a/T_s)^{0.5}$ for $15\ \text{min.} < T_s \leq 60\ \text{min.}$

$(T_a/T_s)^{0.4}$ for $60\ \text{min.} < T_s \leq 240\ \text{min.}$

where T_s is the averaging time used for concentration (in minutes) and T_a is time average appropriate for PG nomogram curve used.

II.2.1 Advantages/Limitation

The main advantage of PG scheme is the easy availability of input parameters for stability classification. These can be obtained from routine weather data collected by nearby IMD stations where continuous data on wind speed, direction and cloud cover are available. It is particularly suitable for application at site evaluation stage. Another useful feature of the scheme is that it gives a stability class representative of a large area around the site of measurement. At the site evaluation stage this obviates the need of collecting site specific solar radiation data.

PG scheme suffers from the following limitations:

- Discreteness of stability classification resulting in concentration estimates to vary discontinuously when crossing over stability class.
- Does not consider site terrain features.
- Classification is essentially based on data applicable to temperate mid-latitudes. At tropics, insolation ranges suggested in PG schemes may not be directly applicable.
- Effect of cloud cover and turbidity is built-in.
- Qualitative judgment of insolation.

The quantitative method of assessing insolation will require use of actual solar insolation in day time and cloud cover or net-radiation in night time (Table II 2.A and Table II 2.B).

II.3 Temperature Lapse Rate Method

The method uses bulk vertical potential temperature gradient between two levels as an indicator of atmospheric stability and hence turbulence. Potential temperature at any level is defined as the temperature an air parcel would attain when it is brought adiabatically from that level to a level corresponding to a pressure of 1000 mb. This has been used to classify atmospheric stability classes (A-F) (See Table II-3).

Plume dispersion parameters are determined using PG nomograms as discussed in previous section (II-2).

II.3.1 Advantages/Limitations

An advantage with this method is that vertical stability is well-characterised even under low wind speed conditions where other stability schemes often fail. In general, temperature information at different height levels will help to identify any stability transition (inversion) in the vertical direction.

The disadvantage with the above method is that horizontal turbulence and dispersion is not properly accounted.

II.4 Wind Fluctuation Method

Fluctuations in wind components (both vertical and horizontal) are direct indicators of the degree of turbulence and hence dispersion in the respective directions. The parameters used are s_q and s_f which are *rms* values of horizontal and vertical wind directional fluctuations. They are obtained through processing of the instantaneous output of a sensitive bi-directional vane or in an approximate way from observed direction range values from chart records.

There are two approaches which use s_q and s_f to deduce dispersion. The first evolved by Slade maintains the discrete stability classes of PG method and gives ranges of s_q values corresponding to each of the stability classes. These are given in Table II.4. Subsequent studies have revealed that s_q range values corresponding to stability class are site specific . Once these discrete stability classes are established using s_q values, PG nomograms are used to obtain dispersion parameters. In the second method empirical forms relating s_y and s_z to s_q and s_f are used. These are

Stable	*Unstable*	
$\sigma_y = 0.15\sigma_\theta x^{0.71}$	$\sigma_y = 0.045\sigma_\theta x^{0.86}$	(II-1)
$\sigma_z = 0.15\sigma_\phi x^{0.71}$	$\sigma_z = 0.045\sigma_\phi x^{0.86}$	(II-2)

where s_q and s_f are expressed in degrees and *x* in meters.

II-4.1 Advantages/Limitations

The method being a direct measure of turbulence more accurately represents dispersion levels than the earlier methods discussed. Values of s_q are routinely available at NF sites where continuous wind direction measurements are made using potentiometric type wind vane. Further, s_q values implicitly includes the effect of terrain roughness which are not incorporated in PG and lapse rate methods.

It must be noted that sq values actually represent the immediate history of the wind flow over the terrain. Thus dispersion parameters derived from them can be highly local and may not be applicable to distances where terrain conditions are vastly different from that of the location of measurement. This aspect has to be evaluated before the unrestricted use of the method at a site. Further s_q values under low wind speed conditions are influenced by variable and meandering winds and its interpretation should be made with care. Another aspect to be studied is the site-specific nature of s_q ranges as mentioned earlier. Thus field dispersion studies to derive appropriate ranges of s_q for various stability class applicable to a site are recommended when using the method.

Use of empirical formulation (equations II-1, II-2) avoids the need to use discrete stability classes and this is an important advantage. But continuous data on s_f are generally not available since bi-directional vanes are not suitable for extended field installation. However, this method can still be used for s_y determination and preferred over discrete classification when reliable s_f values are available.

II-5 Split Sigma Method

This method is a hybrid of methods using temperature lapse rate and wind fluctuations.

Vertical temperature gradient (Dq/DZ) is used to characterise vertical turbulence while values of s_q are used to characterise for lateral turbulence (Table II-5).

The use of Dq/DZ for vertical stability in place of s_f in wind fluctuation method makes the above method more appropriate mainly for field applications. The limitations discussed earlier in the use of s_f and Dq/DZ are applicable for this method also. Discrete classification scheme can be avoided at least for determination of s_y for which empirical equation II-1 may be used as discussed in section II.4.

TABLE II.1 : ASSIGNMENT OF PASQUILL STABILITY CLASSES [MODIFIED FROM [13]

A	Extreme unstable	D	Neutral
B	Moderately unstable	E	Slightly stable
C	Slightly unstable	F	Moderately stable

Wind Speed *u* (m/s) at 10 m	**Stability class**				
	Day			**Night**	
	Degree of insolation			**Sky conditions**	
	Strong	**Moderate**	**Slight**	**Thinly over cast or $\geq$ 4/8 cloud cover**	**$\leq$ 3/8 cloud cover**
$u < 2$	A	A - B	B	F	F
$2 \leq u < 3$	A - B	B	C	E	F
$3 \leq u < 5$	B	B - C	C	D	E
$5 \leq u < 6$	C	C - D	D	D	D
$6 \leq u$	C	D	D	D	D

In case actual solar insolation measurement data is not available then

(1) 'Moderate' insolation implies the amount of incoming solar radiation when the sky is clear and the solar elevation is between 35^o to 60^o. The terms 'strong' and 'slight' insolation refer to solar elevation of more than 60^o and less than 35^o respectively.

(2) Solar elevation may be obtained for a given date, time and latitude from astronomical tables. Since cloudiness reduces insolation, it should be considered along with solar elevation in determining the Pasquill stability class. Insolation that would be 'strong' may be expected to be reduced to 'moderate' with broken middle clouds (cloud cover 5/8 to 7/8) and to 'slight' with broken low cloud cover.

(3) Where data from solar radiation measuring instruments are available, the values of insolation corresponding to 35^o to 60^o on clear days may be obtained and used as a limit in classification irrespective of cloudiness data.

(4) Overcast conditions during day or night refer to Neutral class 'D'. Night refers to a period from 1 hour before sunset to 1 hour after sunrise.

(5) To obtain σ_y and σ_z for (A - B), etc. use is made of the average of those for A and B, etc.

TABLE II.2 A : SCHEME BASED ON INSOLATION/CLOUD COVER AND WIND SPEED*

Wind Speed *u* (m/s) at 10 m	Stability class					
	Solar Insolation (S*), (langley/h)				Cloud Cover	
	Strong	Moderate	Slight	Weak		
	> 75.5	45.5< S< 75.5	15.5< S< 45.5	0< S< 15.5	< 0.5	>0.5
< 2	A	A	B	D	F	E
2 < *u* < 3	B	B	C	D	F	E
3 < *u* < 4	B	C	C	D	E	D
4 < *u* < 6	C	D	D	D	D	D
u > 6	C	D	D	D	D	D

* The numerical values of insolation fluxes are used as a typical example. Site specific values have to be evaluated when applied to a site.

TABLE II.2 B : MODIFIED STABILITY CLASSIFICATION TABLE, USING SOLAR RADIATION AND NIGHT NET-RADIATION, WITH WIND SPEED

A	Extremely unstable	D	Neutral
B	Moderately unstable	E	Slightly stable
C	Slightly unstable	F	Moderately stable

Wind Speed *u* (m/s) at 10 m	**Stability Class**						
	Solar Insolation R_D (Iangley/h) during day				**Net-radiation R_N(langley/h) during night**		
	$R_D \geq 50$	$50 > R_D \geq 25$	$25 > R_D \geq 12.5$	$12.5 > R_D$	$R_N > -1.8$	$-1.8 \geq R_N > -3.6$	$-3.6 \geq R_N$
$u < 2$	A	A - B	B	D	D	-	-
$2 \leq u < 3$	A - B	B	C	D	D	E	F
$3 \leq u < 4$	B	B - C	C	D	D	D	E
$4 \leq u < 6$	C	C - D	D	D	D	D	D
$6 \leq u$	C	D	D	D	D	D	D

Note: 1 langley = 1 $cal.cm^{-2}$ = 4.187 $J.m^{-2}$

TABLE II.3 : RELATIONSHIP BETWEEN PASQUILL STABILITY CLASS AND TEMPERATURE LAPSE RATE

A Extremely unstable
B Moderately unstable
C Slightly unstable
D Neutral
E Slightly stable
F Moderately stable

Dq/ DZ (ºK/100m)	**< -1.9**	**- 1.9 to -1.7**	**- 1.7 to -1.5**	**- 1.5 to - 0.5**	**- 0.5 to 1.5**	**>1.5**
Stability Class	A	B	C	D	E	F

Dq/ DZ represents potential temperature lapse rate.

TABLE II.4 : TYPICAL RELATIONSHIP BETWEEN STABILITY CLASS AND s_q

A Extremely unstable
B Moderately unstable
C Slightly unstable
D Neutral
E Slightly stable
F Moderately stable

s_q	**25^O**	**20^O**	**15^O**	**10^O**	**5^O**	**2.5^O**
Stability Class	A	B	C	D	E	F

TABLE II-5 : HORIZONTAL WIND DIRECTION FLUCTUATIONS AND LAPSE RATES

STABILITY	**PASQUILL CLASS**	**s_q SLADE**	**DT/DZ (°C / 100 m)**
Extremely unstable	A	25°	< -1.9
Moderately unstable	B	20°	-1.9 to -1.7
Slightly unstable	C	15°	-1.7 to -1.5
Neutral	D	10°	-1.5 to -0.5
Slightly stable	E	5°	-0.5 to 1.5
Moderately stable	F	2.5°	1.5 to 4.0

APPENDIX-III

MODELS FOR PLUME RISE

III.1 General

Plume rise (Dh) occurs due to two effects.

- Rise due to momentum (exit velocity) of plume released from the stack.
- Rise due to buoyancy of the plume when the effluent temperature is higher than the ambient temperature.

III.2 Model Description

Except for release under accident conditions, plume rise due to buoyancy effects is not significant for NF's and only momentum rise is generally considered. The following formulations are applicable for stacks with height at least 2.5 times the height of adjacent solid structure (within a radial distance of about 10 times the stack height):

Under neutral or unstable conditions two formulations are suggested:

$$Dh = 1.44\, D_i\, (W_0/U)^{2/3} (x/D_i)^{1/3} - C \qquad \text{(III-1)}$$

$$Dh = 3\, D_i\, (W_0/U) \qquad \text{(III-2)}$$

where

C = $3(1.5 - W_0/U)\, D_e$ [= Down wash correction factor for $W_0 < 1.5$ U]

W_0 = Exit velocity (m/sec)

x = Downwind distance (m)

U = Wind speed (m/sec) at stack height

D_i = Internal stack diameter (m)

D_e = External stack diameter (m)

Dh = Plume rise

For the sake of conservatism, the lower of the two values obtained from III-1 and III-2 are suggested to be used. Again for stable conditions, two equations are recommended.

For stable condition

$$Dh = 4(F_m/S)^{1/4}$$

$$Dh = 1.5\, S^{-1/6} (F_m/U)^{1/3} \qquad \text{(III-3)}$$

In the equations, F_m is the momentum flux parameter, and S is the stability parameter, defined as

$$F_m = W_0^2 \left(\frac{D}{2}\right)^2 \qquad \text{(III-4)}$$

$$S \approx \frac{g}{T}\left(-\frac{\partial \theta}{\partial z}\right)$$

For E stability class, $S = 8.7 \times 10^{-4}$

For F stability class, $S = 1.75 \times 10^{-3}$

g	=	acceleration due to gravity (ms^{-2})
T	=	ambient temperature in °K
$-\partial\theta/\partial Z$	=	potential temperature lapse rate ($K\ m^{-1}$)

The smaller of the two values of Δh (III-1, III-2, III-3 and III-4) are to be used.

For short stacks (stack height less than 2.5 times building height) the detailed method can be used [2,3]. To avoid effluent down wash from nearby building structures (bluff bodies) stack height H should be 2.5 times that of the tallest structure except when the releases are so low that even down washed plume does not result in significant concentration.

III. 3 Plume Down Wash Due to Building Wake effect*

III 3.1 Effects due to building wake

Effluents released from a building get rapidly mixed close to the building due to fluid vortices generated by airflow passing the structure. Here the source can hardly be considered as a point source under such conditions and a realistic assumption would be to consider it as a well-mixed volume source released at ground level. Usually the computation of effluent concentration is carried out in the following manner:

III 3.1.1 Gifford method:

Here the normal short-term centre line dispersion equation I-5 in Appendix-I is modified in the following manner.

$$(\chi/Q)_A = 1/\left[\,u\,(\pi\sigma_y\sigma_z + C_w\, A)\right] \qquad \text{(III-5)}$$

---

* Building wake effect: Air flows around buildings on a site have the potential to influence the local air concentrations and resulting deposition (building wake effects).

where $(\chi/Q)_A$ is corrected for wake effect. 'A' is the cross-sectional area of the building normal to the wind. C_w is the fraction of A over which plume is dispersed by the wake (building shape factor) taken to be 0.5.

It is assumed that the effective release height is at ground level. In using equation, one can not decrease the value of $(\chi/Q)_A$ to less than one-third of the uncorrected value at the same distance. The effect of wake becomes insignificant when $A \ll \pi \sigma_y \sigma_z$.

III 3.1.2 Correction for building wake effects

The wake effects with the actual topography of buildings can be easily simulated with a number of codes. The site specific correction factors should be estimated for a set of typically prevailing wind conditions.

III.4 Virtual Point Source Method

This can be used for any volume source plume. In this, one defines a virtual source at distance X meters, which corresponds to the distance from the point source where plume dimensions would be equal to the vertical and crosswind section of the volume source. The virtual distance for crosswind dispersion is taken by equating horizontal dimension of volume source to $\sqrt{2\pi}\,\sigma_y$. Also, that for vertical dispersion is taken by equating vertical dimension to $\sqrt{2\pi}\,\sigma_z$. Knowing the dimension of volume source σ_y and σ_z obtained are corresponding to the virtual source distances and these corresponding virtual distances can be added to the actual distance of receptor location from source to compute the concentration based on GPM equations given in Appendix-I. For travel distances larger than a few kilometers, the volume source effect would be insignificant.

APPENDIX-IV

DEPLETION MODELS-DEPOSITION AND WASHOUT

IV.1 General

Two important processes of depletion of effluents dispersing in the atmosphere are:

- Dry deposition
- Wet deposition

IV.2 Dry Deposition

Effluent plume gets progressively deposited during its travel from the source as a result of deposition of particles by impaction on earth's surface. Heavy particles settle down significantly by gravitational settling while gases and vapour may also be adsorbed on the surface.

The widely used parameterisation procedure for deposition is to define the quantity deposition velocity 'V_g' as

$$V_g = \frac{\text{Rate of deposition or deposition flux}}{\text{Concentration near the surface}} \qquad \text{(IV-1)}$$

The deposition flux taking into account plume deposition is given by source depletion model for an elevated source.

$$W_d(x, y) = \frac{V_g . Q_x}{p s_y s_z u} \exp\{-1/2\,(y^2/s_y^2 + H^2/s_z^2)\} \qquad \text{(IV-2)}$$

W_d is the deposition rate at a down and cross wind distances of x and y. Depleted source strength at distance x, Q_x is given by

$$Q_x = Q\left[\exp \int_{x_0}^{x} \exp(-H^2/2\sigma_z^2)\frac{dx}{\sigma_z}\right]^{-\left(\frac{2}{\pi}\right)^{1/2}\left(\frac{V_g}{u}\right)} \qquad \text{(IV-3)}$$

x_0 is a suitable distance near the source point of release specified to avoid the singularity $s_z = 0$ at the release point. The depletion factor f_g is defined as Q_x/Q.

It must be noted that values of V_g varies widely with atmospheric stability, wind speed and surface conditions for any effluent as also on its physical and chemical properties. In general, since adequate database is not available to quantify these dependencies, an appropriate value of V_g is used for an effluent based on available data and with reference to the relevant parameters specific to the situation treated. Typical values of V_g used for particulate and vapour of importance for NFs dispersion study are given in Table IV.1.

IV.3 Wet Deposition or Depletion by Precipitation

There are two processes of wet deposition of effluents:

(i) ***In-cloud scavenging***, when the plume material is mixed by convection process with cloud droplets and (ii) ***subsequent precipitation scavenging*** of particulate and soluble vapours by precipitating droplets falling through the plume interacting with the plume. In general both the aspects are treated in terms of a correction factor 'f_1' to account for such effects as

$$f_1 = \exp\left(\frac{-Wx}{u}\right) \qquad \text{(IV-4)}$$

where

W (sec^{-1}) is the rain washout coefficient. It is a function of rainfall intensity and physio-chemical characteristics of the pollutant.

This parameter is a function of precipitation rate, precipitation drop or particle size spectrum, solubility of the effluents in water etc. These coefficients have been given in nomograms based on studies by Chamberlain and others [7, 14] and can be used to evaluate plume depletion.

For particulates of radius '*a*' cm and density 'r' (g/cm^3), Figure IV.1 may be used to obtain W for rainfall rates up to 5 mm/h. For higher rainfall rates, the curves may be extrapolated with caution. For soluble gases, the washout coefficient may be obtained using the following relation:

$$W = 5.9 \times 10^{-4}\, g.\, r^{0.59} \ (s^{-1}) \qquad \text{(IV-5)}$$

where

g = molecular diffusivity in cm^2/s of the gas in water, and

r = rainfall rate in mm/h

IV.4 Radioactive Transportation

Radioactive decay or build up of radioisotopes with time need to be considered if the half-life is significant compared to the plume travels time to receptor location. The concentration values should be corrected accordingly by the general expression 'f_2'

$$f_2 = \exp(-lt) = \exp\left(-l\frac{x}{u}\right) \qquad \text{(IV-6)}$$

The product of depletion factors f_g, f_1 and f_2 gives the overall depletion of a dispersing plume.

TABLE-IV.1 : TYPICAL VALUES OF V_g FOR SOME OF THE MATERIALS OF IMPORTANCE IN NFs

Material	V_g (m/s)
^{238}Pu, ^{239} Pu	0.001 - 0.01
^{131}I, SO_2, Ru	0.01 - 0.03
^{90}Sr, ^{137}Cs	0.001 - 0.01
Inert Particles	0.001 - 0.002

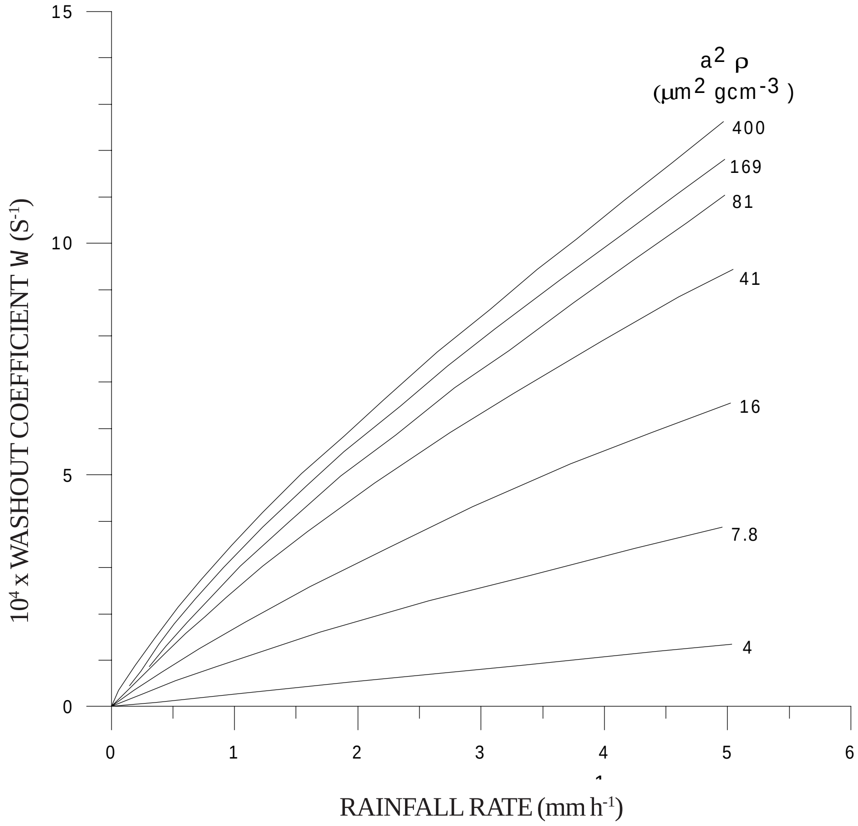


FIGURE IV.1 : WASHOUT COEFFICIENT OF RAINFALL RATE FOR PARTICULATES OF RADIUS ‘*a*’, (mm), AND DENSITY r (gcm^{-3})

APPENDIX-V

UNCERTAINTY ANALYSIS AND VALIDATION OF DISPERSION MODELS

V. 1 General

All the atmospheric dispersion models discussed in the guide have built in them some amount of idealisation regarding atmospheric and terrain conditions, nature of release and source and receptor configurations. Due to this, model predictions are beset with certain amount of inaccuracy, the magnitude of which should be ascertained. This is the purpose of model uncertainty analysis. The confidence in the use of a model in dispersion applications is considerably increased if it is validated by adequate field data. Both these aspects are briefly considered here.

V. 2 Uncertainty in Model Predictions

Uncertainty in model predictions occurs due to one or more of the following causes.

- Due to the random nature of atmospheric turbulence (stochastic uncertainty)
- Idealisation inherent in any mathematical model
- Appropriateness of model for the chosen application
- Values ascribed to various model parameters

The complex nature of atmospheric turbulence defies an exact treatment of atmospheric dispersion. The dispersion model inevitably uses simplified assumptions of parameterisation in their description of various processes involved. Often, these are not explicitly stated and model uncertainty due to such idealisations may not be recognised.

When a model is applied in a situation where it is not meant to be applied uncertainties in its predictions could occur. For example Gaussian Plume Model assumes spatially invariant wind field and in an application where significant spatial variations in wind field are known to be present, the model would yield grossly inaccurate estimates of dispersion.

Even when a model is free from simplifications and properly applied, inaccuracies could result due to imprecise values of input parameters used in the model. There are always limitations to the accuracy with which input parameters can be measured or estimated. For example field measurements of wind speed with a standard cup anemometer can be made only to an accuracy of 0.1 m/s.

V.3 Uncertainty in Input Data

Since input parameters could be one or more, their effect individually or in combination must be analysed. The usual method is to examine the variation in model predicted values by changing the value of an input parameter by a specified amount based on its known range values *(sensitivity analysis).* The overall effect by changing all the input variables simultaneously gives an estimate of the robustness of the model *(robustness analysis).*

Quantitatively, various statistical techniques are available to study parameter error propagation analysis. The method in general involves choosing randomly each parameter value (random sampling) from a distribution corresponding to the known or assumed distribution of the possible parameter values. Proper representation of the parameter values can be achieved when using special techniques such as Latin Hypercube sampling*. The output gives the distribution of the dispersion model predictions and an estimate of the spread in predicted values.

V.4 Validation Results of GPM

Since GPM is widely used, most of the field experiments have been performed for its validation. Though GPM is applicable for level, smooth terrain under unchanging atmospheric conditions, the experimental data often represent situations not meeting these criteria. To simplify treatment of dispersion under complex flow conditions, GPM has been extended using some form of gross parameterisation (Appendix-I). These models also have been examined using data from field trials and in some case wind tunnel simulation experiments.

Many studies have reported results of GPM validations. The study gives the range of the ratio of predicted to observed concentration values for different releases, heights, averaging times, downwind distances and wind speeds. Plume concentration influenced by building wake effects has also been considered. Overall it is seen that prediction of concentration is within a factor of two for hourly values at highly instrumented sites or for long term averages within 10 km of the source. For specific hour comparisons with simplified parameterisation scheme, the predicted accuracy is found to be within an order of magnitude. Prediction under complex terrain or building down-wash conditions shows larger uncertainty.

Database for validating GPM models, especially its extension to non-ideal situations is still not adequate to obtain statistically firm estimates of model

---

* The statistical method of Latin hypercube sampling (LHS) was developed to generate a distribution of plausible collections of parameter values.

accuracy. It appears that the suggested estimates of GPM model accuracies given by Drake et. al. (Table V-1) can be used till more detailed validation data sets become available.

However, if conditions of thermal internal boundary layer (TIBL) exist like in coastal sites, the concentration estimates would vary. Under these conditions, the value must be arrived at using more appropriate models [11]. However, if conditions of thermal internal boundary layer (TIBL) exist like in coastal site, during an event of either planned or accidental release of higher order, then the presence of TIBL will modify the concentration pattern. Under such condition, the concentration estimates must be carried out using the SDM formulation to arrive at a realistic picture of the concentration distribution.

TABLE V-1 : ESTIMATES OF ACCURACY OF DISPERSION CALCULATIONS USING GPM MODEL

S. No.	Conditions	Accuracy
1.	**Ideal Conditions:** Near field (<1.0 km) short averaging times (min to hour), flat terrain, steady meteorology, surface source	10% to 20%
	Same as above for elevated source	20% to 40%
2.	**Real World Applications:** Meteorological parameters reasonably well known and steady with no exceptional circumstances	Factor of two
3.	**Exceptional Circumstances:** Building wakes, buoyant plumes, varied surfaces such as forests, cities, shorelines, rough terrain, extreme stable and unstable conditions, distances greater than 10-20 km.	Poorer than a factor of two; may be as poor as factor of ten.

APPENDIX-VI

TIME INTEGRATED CONCENTRATION

VI.1 General

The equations for air concentration discussed in Appendix-I for GPM are for continuous releases and steady meteorological conditions. The frequency of occurrence of specific wind speed, direction sector and stability condition would be relevant when considering annual averaged estimates. This Appendix discusses the approach recommended when dealing with temporally varying meteorological conditions. Methods are discussed for short term extending to a few hours and to long term (seasonal, annual etc.) averaged concentration.

VI.2 Short Term Averaged Concentration

When applying GPM for concentrations of any averaging time, the multiplying factor for the specific averaging time should be applied as discussed in the Appendix-II.2. The time integrated concentration (TIC) is obtained by replacing the source term (given as release rate) by the total amount of effluent released. The averaging time multiplying factor can be applied for time period (in TS minutes) extending upto 8 hours.

Another way in which plume averaging over period of one hour or more can be considered is to compute the sector-averaged plume. This considers plume meandering within a direction sector or specified angular width (say 22.5°) and estimates the concentration by integrating equation I.4 in the y-direction and distributing the total material uniformly within the sector. Thus sector-averaged concentration is given by (e.g. at ground level plume centre-line)

$$\chi(x, 0) = \left(2Q / \left(\sqrt{2\pi}\, x\, \theta\, \sigma_z\right)\right) \exp\left(-H^2 / 2\sigma^2\right) \qquad \text{(VI.1)}$$

where θ is the sector width in radians equal to $\pi/8$ for 22.5° sectors.

It should be noted that this equation gives sector averaged concentration assuming no change in direction sector while averaging time multiplying factor implicitly takes this into account.

VI.3 Long Term Averaged Concentration

A quantity of interest for fixing effluent discharge limits, stack design parameters etc. is the TIC over one year for a constant release rate. In evaluating this, the input needed is the joint frequency of occurrences of different wind speed classes, direction sectors and Pasquill stability classes. Usually direction sectors are divided into sixteen compass directions of 22.5° angular width. Typically wind speeds ranging from 3 km/h to 40 km/h or more are divided into

5 or 6 class intervals. One calendar year data (continuous hourly data) of wind speed, direction and stability class A to F are used in obtaining the joint frequency distribution.

The annual averaged concentration for steady continuous release is evaluated as follows:

For a given stability class i, direction sector j and wind speed class k, the concentration is given by the sector averaged plume formulation (Equation VI.2). The result is summed over wind speed class and stability for that direction sector. Thus TIC (y) ground level concentration for an elevated release (neglecting plume rise) is given by:

$$\psi_{i,j}(x,0)=\left[\sum_k \frac{N_{ijk}}{U_{ik}}\right]\left(\frac{2Q}{\sqrt{2\pi}\ x\theta\sigma_{zi}}\ \exp(-H^2/2\sigma_{zi}^2)\right) \qquad \text{(VI.2)}$$

Here Q is source term in Bq/s

U_{ik} is the wind speed in m/s for stability class 'i' and wind speed class 'k'

N_{ijk} is the number of hours in stability class 'i', direction sector 'j' and wind speed class 'k'.

The term N_{ijk}/U_{ik} is obtained from the triple joint frequency data for the site. When this is divided by total number of hours in a year one gets annual average concentration (i.e. (Bq/m^3).

In the statistical analysis of hourly data over a period of one year, two specific cases should be separately considered.

- Occurrence of calm (wind speed less than 3 km/h)
- Occurrence of variable winds (wind direction showing large transitory changes)

While the latter is generally not of much concern as their frequency of occurrence is low,. calm conditions need specific treatments. Dispersion under very low wind speeds (calm conditions) is not well understood and realistic modeling would involve treating the plume as puffs. However, in routine dispersion applications, the number of calm occurrence is distributed in different direction sectors in proportion to the frequency of the lowest measurable wind speed class.

A realistic approach is to consider calm as an extension of the wind speed class corresponding to instrument threshold. Based on this, the correction factor to concentration value is $\left[1+\frac{N_0}{N_j}\cdot\frac{N_{j1}}{N_1}\right]$ to obtain y adjusted for calms.

In the above expression

N_0 is the number of hours of calms

N_j is the number of hours with wind direction in the jth sector

N_{jl} is the number of hours with the lowest measurable wind speed class 1 in direction j

N_1 is the number of hours in the lowest wind speed class in all directions.

APPENDIX-VII

SEA BREEZE FUMIGATION

VII.1 General

Dispersion of any air borne effluent at a coastal site is influenced by local sea-land breeze circulation. When cold marine air advects over land during daytime, the lower layer of the air mass gets progressively heated up as it moves inland. The stable or neutrally stratified vertical potential temperature profile of the marine air mass gets eroded gradually as it enters the landmass by strong convection over warmer land surface. In consequence, a boundary layer develops over land region known as 'Thermal Internal Boundary Layer' (TIBL). For elevated release from stacks near coastline, the initial dispersion of the plume is governed by turbulence characteristics of stable marine airflow. However, when plume intersects the growing TIBL at any downwind distance, pollutants in the plume get fumigated to the ground by strong convective eddies in the layer. This is termed as sea breeze fumigation (SBF). This development near the coastline affects the concentration distribution.

VII.2 Description of the Models

Modeling of SBF process has been considered in recent studies. Model suggested in IAEA Safety Series 50-SG-S3 [13] guide is simple. It considers Gaussian distribution of the plume until it intersects the TIBL and later it considers instantaneous total fumigation (vertical mixing) in the TIBL. This results in discontinuity in the concentration at the intersection, which is not realistic. Shoreline dispersion model (SDM) proposed by Mishra, [11]], takes care of the discontinuity.

VII.2.1 Shoreline dispersion model (SDM)

The SDM considers that the release is in the stable layer above the TIBL. As it travels downwind, the part of the plume, which comes in contact with TIBL, gets fumigated within the layer. The part of the material, which has fumigated into TIBL, is assumed to be immediately uniformly mixed within the TIBL. Dispersion in the layers above and below the TIBL is according to the stability existing in the respective layers.

The centerline ground level concentration (CGLC) in the SDM is given by the expression

$$C(x,0) = \frac{1}{2\pi h_f(x)} \int_0^x \left(\frac{1}{U\sigma_y(x')}\right) \exp\left\{-\frac{1}{2}\left[\left(\frac{h_f(x')-H}{\sigma_{zs}(x')}\right) + \frac{y^2}{(\sigma_y(x'))^2}\right]\right\} \frac{d}{dx'}\left(\frac{h_f(x')-H}{\sigma_{zs}(x')}\right) dx' \qquad \text{(VII-1)}$$

$$\sigma'^2 = \sigma_{ys}^2(x') + \sigma_{yl}^2(x,x')$$

where

C(x,0)	=	Centre line ground level concentration (Bq/m^3)
U	=	Mean wind speed within the TIBL (m/s)
σ_{zs}, σ_{ys}	=	Vertical and horizontal standard deviations of the plume in stable layer (m) respectively.
σ_{yl}	=	Horizontal standard deviation of the plume in TIBL (m).
σ'	=	Combined horizontal standard deviation (m)
x'	=	X coordinate in the integration step (m)
h_f(x')	=	TIBL height at x' (m)
H	=	Plume height (m)
Y	=	Crosswind distance (m)
Q	=	Source strength Bq/s

The dispersion parameter σ_y and σ_z are evaluated by analytical expression given in Table 3.1 and 3.2.

VII.2.2 IAEA/SG-S3 Model

IAEA Safety Series 50-SG-S3 [13] has proposed following methodology to take into consideration the effect of TIBL at coastal sites. This formulation considers that dispersion of the pollutants in the layer above TIBL is governed by the dispersion parameters for the stability existing in that layer. At distance where σ_z, vertical distribution parameter above TIBL (m), satisfies $h_f \geq h + 2.\sigma_z$, total plume is considered to be fully in TIBL. The following expression gives CGLC assuming fumigated material to be uniformly vertically mixed within the layer and CGLC.

$$\chi / Q = \frac{1}{\sqrt{(2\pi)}\ \sigma_{yf}\ U\ h_f} \exp\left[-\frac{y^2}{2.\sigma_{yf}^2}\right] \qquad \text{(VII-2)}$$

where

χ/Q	=	CGLC within the TIBL (sec/m^3)
h_f	=	Height of the TIBL (m)
σ_{yf}	=	cross-wind dispersion parameter within TIBL (m)

VII.3 Determination of TIBL

Formation and development of TIBL in the sea-land interface depends on various parameters like temperature difference between sea and land, and the roughness parameters. The growth of TIBL as a function of coastal meteorological parameters has been studied [14,15] by various workers. The empirical method based on experimental data suggests the relationship [10,11]:

$$h_f(x) = Ax^{1/2} \tag{VII.3}$$

Where $h_f(x)$ is the height in metres of TIBL at the downwind distance x from the coastline. The coefficient 'A' is generally found to vary from 2 to 4 and square root dependence on downwind distance has theoretical support. The parameter 'A' is function of atmospheric stability, roughness length, sea-land surface temperature difference etc.

ANNEXURE-I

INFORMATION NEEDED IN COMPUTATION OF ATMOSPHERIC CONCENTRATION LEVELS AND DEPOSITIONAL FLUX OF RADIONUCLIDES FROM A NUCLEAR FACILITY

I	**SOURCE CHARACTERISTICS**:
I.1	Radionuclide
I.2	Half life
I.3	Release rate
I.4	Height of release
I.5	Location of release
II	**RELEASE CHARACTERISTICS**
II.1	Duration, Averaging time
II.2	Effluent temperature
II.3	Exit velocity
II.4	Stack diameter at top (internal, external)
II.5	Wind speed at release height
III	**DISPERSION CHARACTERISTICS**
III.1	Atmospheric stability
III.2	Wind speed
III.3	Wind direction
III.4	Air temperature
III.5	Mixing height
IV	**DEPOSITIONAL CHARACTERISTICS**
IV.1	Depositional velocity
IV.2	Nature of aerosol
IV.3	Precipitation intensity
V	**TERRAIN CHARACTERISTICS**
V.1	Height above MSL
V.2	Nature of terrain
V.3	Roughness length

ANNEXURE-II

TYPICAL MODEL OUTPUT GIVING ATMOSPHERIC CONCENTRATION AND DEPOSITIONAL FLUX OF RADIONUCLIDES RELEASED FROM A NUCLEAR FACILITY STACK

Isotope	I-131
Half life	8.05 days
Source strength	10^2 Bq/s (continuous, release)
Terrain	Flat
Stack height	100 m
Atmospheric stability category	D
Wind speed at stack level	3 m/s
Wind direction	NW
Deposition velocity	2 x 10^{-3} m/s

Downwind distance from stack (km)	Sector averaged ground level air concentration (Bq/m^3)	Ground level deposition rate (Bq/m^2s)
0.1	00.0E00	0.00(-00)
0.2	3.29E-31	6.58 (-34)
0.5	2.82E-09	5.64 (-12)
1.0	1.39E-05	2.78 (-08)
1.6	7.05E-05	1.41 (-07)
3.0	9.53E-05	1.91 (-07)
5.0	6.83E-05	1.37 (-07)
10.0	3.83E-05	7.66 (-08)

ANNEXURE-III

AN ILLUSTRATIVE EXAMPLE OF GPM COMPUTATION

A ground air sampling station is situated at 1600 meters towards east from a reactor stack of 100 m height. Release rate of the radio nuclide is 3.6×10^6 Bq./hr.,

(a) Find out concentration of fine particles released from the plant through the stack at the monitoring station under following meteorological conditions:

(1) Wind direction at stack level is SW,

(2) Wind speed is 3m/s,

(3) Weather category C.

(b) Find out annual average concentration likely to be at the sampling location assuming diffusion climatology table given as below. (For the wind direction sector in which the sampling location is located)

Diffusion Climatology Table (No of hours in each category and in each wind speed class in a year direction NNE)

Table AIII-1

Wind speed class (u) km/h	Stability category					
	A	B	C	D	E	F
3-5	3	1	11	5	2	0
6-11	4	11	61	41	25	0
12-19	6	12	40	81	79	8
20-29	3	4	18	27	47	0
30-38	0	0	1	6	11	2

(a) Concentration of fine particles released from the plant through the stack at a distance of 1600 meters towards east

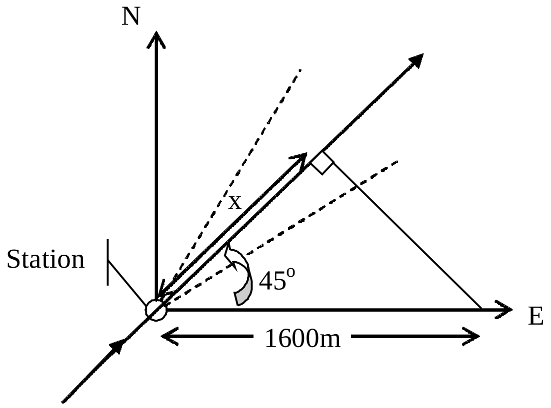
Equation for ground level concentration (GLC) is

$\chi(x,y,0) = (Q/\{\pi u \sigma_y \sigma_z\}) \ \exp[-(y^2/2\sigma_y^2 + H^2/2\sigma_z^2]$

Wind is SW i.e. coming from SW. Hence plume will be move towards NE. Co-ordinates of monitoring station will be

X axis = 1600 cos 45^0 = 1131m

Y axis = 1600 sin 45^0 = 1131m



Calculation of dispersion parameters at x = 1131 m.

For stability category C as per Table 3.1,

s_y = $0.11x\,(1+0.0001x)^{-0.5}$
= $124.4\,(1+0.1131)^{-0.5}$
= 117.9 m

s_z = $0.08x\,(1+0.0002x)^{-0.5}$
= $90.48\,(1+0.2262)^{-0.5}$
= 81.71 m

Q = 3.6×10^6 Bq/h i.e. 1×10^3 Bq/s

$\exp(-y^2 / 2s\,y^2)$ = 1×10^{-20}

$\exp[-H^2 / 2\sigma_z^2]$ = 0.47

$$\chi(x,y,0) = \frac{10^3}{3.1416 \times 117.9 \times 81.71 \times 3} \times 10^{-20} \times 0.47 = 5.18 \times 10^{-23} \ \text{Bq/m}^3$$

(b) Calculation of annual average concentration

The long term concentration is calculated using equation I.4 of section I.2.2 in Appendix-I.

Calculations are done in following steps-

(i) Assign mean u_k values to each wind speed class k given in the diffusion climatology table. For given classes these values work out to be as given below:

Table AIII-2

k =	1	2	3	4	5
u_k (km/h)	4	8.5	15.5	24.5	34
u_k (m/s)	1.1	2.4	4.3	6.8	9.4

Values are converted to m/s from km/h. Also, since given values are at 100 m height, i.e at release level, no extrapolation is needed.

(ii) Find out s_{zi} values at 1600 m for different categories (i.e. for different i). From the Table 3.2 or nomograms (Figure 3.2), these values are tabulated as below.

Table AIII-3

Stab.Cat(i)	A(1)	B(2)	C(3)	D(4)	E(5)	F(6)
s_{zi} (m)	1220	183	94	44	30	19.5

(iii) Calculation of

$$\sum_i \left[\sum_k \frac{N_{ijk}}{u_k \sigma_{zi}} \exp\left(-\frac{H_{ik}^2}{2\sigma_{zi}^2} \right) \right]$$

Calculate $\frac{N_{ijk}}{u_k \sigma_{zi}} \exp\left(-\frac{H_{ik}^2}{2\sigma_{zi}^2} \right)$ for each i and k, using u_k and s_{zi}.

N_{ijk} are given in the example. Put H_{ik} = 100 m (given). We do not consider plume rise. H_{ik} does not change with i as well as with k. Tabulate these values as listed below. U is measured in m/s, Q is in g/s and N_{yk} is in hours.

for i = 1, 2, 3, 4, 5 and 6 categories

Table AIII-4

Category, i	**1**	**2**	**3**	**4**	**5**	**6**
$\frac{1}{\sigma_{z_i}} \exp\left(\frac{-H^2}{2\sigma_{z_i}^2} \right)$	8.17E - 04	4.71E - 03	6.04 E - 03	1.72 E - 03	1.29 E - 04	9.98 E - 08

The calculated values of $\frac{N_{ijk}}{u_k \sigma_{zi}} \exp\left(-\frac{H_{ik}^2}{2\sigma_{zi}^2} \right)$ for x = 1600 m are given below.

The values of N_{ijk} are taken from Table AIII-1 and u_k from Table AIII-2. The values of 'i' varies from 1 to 6 and 'k' from 1 to 5.

Table AIII-5

k	i					
	1	2	3	4	5	6
1	2.228E-03	4.279E-03	6.041E-02	7.807E-03	2.343E-04	0.00E+00
2	1.362E-03	2.157E-02	1.535E-01	2.934E-02	1.342E-03	0.00E+00
3	1.140E-03	1.313E-02	5.620E-02	3.235E-02	2.368E-03	1.858E-07
4	3.604E-04	2.769E-03	1.599E-02	6.820E-03	8.907E-04	0.00E+00
5	0.00E+00	0.00E+00	6.427E-04	1.096E-03	1.508E-04	2.124E-08
Total sum over k for each i	5.090E-03	4.175E-02	2.868E-01	7.742E-02	4.986E-03	2.070E-07

Value of $\sum_k \frac{N_{ijk}}{u_k \sigma_{zi}} \exp\left(-\frac{H_{ik}^2}{2\sigma_{zi}^2}\right)$ is given in last row of Table AIII-5. by summing the entries in the last row of above table i.e. summing over i. This total works out to be 0.416

(iv) Putting this value in equation using q = p /8, x = 1600 m and Q = 1 x 10^3 Bq/s, total annual concentration works out to be

Y j (1600) = 0.662 Bq/m^3 over one year

(v) Average concentration is calculated by dividing above value by number of hours in a year i.e. 8760 h.

Y j (1600) = 7.55 x 10^{-5} Bq/m^3

Thus annual average concentration at the sampling location is 7.55 x 10^{-5} Bq/m^3/h.

REFERENCES

1. ATOMIC ENERGY REGULATORY BOARD, Methodologies for Environmental Radiation Dose Assessment AERB/SG/S-5, Mumbai, India, 2005.

2. Randerson(Ed), Atmospheric Science and Power Production, US DOE, 1984.

3. Hanna S.R., Briggs G.A and Hosker (Jr) R.P Handbook on Atmospheric Diffusion DOE/TIC 11223 ,Technical Information Centre, USDOE, 1982.

4. ATMES Report, Evaluation of Long range Atmospheric Transport Models using Environmental radioactivity data from Chernobyl Accident- W.King, G. Graziani, G. Grippa, D. Pierce C. Tassorie, Elsevier Applied Science - , Linton Road, Essex, England, 1992.

5. "Manual of Dose Estimation from Atmospheric Releases", R.K. Hukkoo, V.N. Bapat and V.V. Shirvaikar, Health Physics Division, BARC, 1988

6. Assessment of Impact to Air Environment Guidelines for Conducting Air Quality Modelling Programme Objective Series: PROBES/70/1997-99, Central Pollution Control Board, Ministry of Environment and Forest, Govt. of India, New Delhi

7. Indian Standards Guidelines for Micrometeorological Techniques in Air Pollution Studies, IS:8829, 1978

8. ATOMIC ENERGY REGULATORY BOARD, Extreme Values of Meteorological Parameters, AERB/NF/SG/S-3 (under publication)

9. Indian Standards Building Code IS-875 (Part III), 1987

10. Mesoney, R.N., Carnake, J.E and Yang B.T. 1975, 'Modelling of Atmospheric Transport and Fumigation at Shoreline Site', Boundary layer Met., 9, 69-90

11. Mishra P.K, 'Dispersion from Tall Stacks into a Shoreline Environment', Atmospheric Environment, Vol 14, p. 397-400, 1979

12. Rodrigues, D.J., Greenly, G.D., Gresho, P.M., Lange, R., Lawver, B.S., Lawson, L.A., and Walker, B., 1982**,** User's guide to the Mathew/ADPIC modes-Rodsignee D.J. LLNL California USA , UASG82-16, 1982.

13. INTERNATIONAL ATOMIC ENERGY AGENCY, Atmospheric Dispersion in Nuclear Power Plant Siting, No. 50-SG-S3, 1980.

14. Chamberlain, A.C., Aspects of Travel and Deposition of Aerosols and Vapour Clouds, UKAEA Report, AERE HP/R 1261, 1953.

LIST OF PARTICIPANTS

COMMITTEE TO PREPARE GUIDES AND MANUALS FOR SAFETY IN NUCLEAR POWER PLANT SITING (CPSGS)

Dates of meeting:	June, 26 1992	January, 27 1998
	May, 19 1995	February, 2 1999
	February, 13 1997	May, 2 2000
	February, 24, 1997	October 17, 2001

Members and Invitees of CPSGS:

Shri S. Krishnan (Chairman)	:	NPCIL (Former)
Dr. V.N. Bapat*	:	BARC (Former)
Dr. A.K. Ghosh	:	BARC
Shri R.P. Sudarshan	:	NPCIL (Former)
Shri G.K. De	:	AERB (Former)
Shri S.T. Swamy	:	AERB
Shri T.M. Krishnamoorthy	:	BARC (Former)
Shri K. Srivasista (Member-Secretary)	:	AERB
Shri V. Sitaraman*	:	BARC (Former)
Dr S. Panchal	:	BARC (Former)

*Authors of the draft of this guide

ADVISORY COMMITTEE FOR REGULATORY DOCUMENTS ON SAFETY IN NUCLEAR POWER PLANT SITING (ACRDS)

Dates of meeting:	March 2, 2005	May 31, 2005
	March 14, 2005	June 16, 2006
	March 15, 2005	August 14, 2006
	March 29, 2005	

Members and Invitees of ACRDS:

Shri G.K. De (Chairman)	:	AERB (Former)
Dr. A.K. Ghosh	:	BARC
Dr. Prabir C. Basu	:	AERB
Dr. V.N. Bapat	:	BARC (Former)
Shri A.R. Sundararajan	:	AERB (Former)
Shri R.P. Garg	:	NPCIL
Shri K. Srivasista	:	AERB
Shri Roshan A.D. (Member-Secretary)	:	AERB

ADVISORY COMMITTEE ON NUCLEAR SAFETY (ACNS)

Date of meeting	:	November 16, 2007

Members of ACNS:

Shri G.R. Srinivasan (Chairman)	:	AERB (Former)
Shri H.C. Hiremath	:	HWB (Former)
Shri R.K. Sinha	:	BARC
Shri H.S. Kushwaha	:	BARC
Dr. S.K. Gupta	:	AERB
Shri S.S. Bajaj	:	NPCIL (Former)
Prof. J.B. Doshi	:	IIT, Bombay
Shri D.S.C. Purushottam	:	BARC (Former)
Shri A.K. Anand	:	BARC (Former)
Shri S. Krishnamony	:	BARC (Former)
Shri K. Srivasista (Member-Secretary)	:	AERB

PROVISINAL LIST OF SAFETY GUIDES UNDER SITING CODE

Safety Series	Title
AERB/SC/S	Code of Practice for Safety in Nuclear Power Plant Siting
AERB/NF/SG/S-1	Atmospheric Dispersion and Modelling
AERB/SG/S-2	Hydrological Dispersion of Radioactive Materials in Relation to Nuclear Power Plant Siting
AERB/NF/SG/S-3	Extreme Values of Meteorological Parameters
AERB/SG/S-4	Hydrogeological Aspects of Siting of Nuclear Power Plants
AERB/NF/SG/S-5	Methodologies for Environmental Radiation Dose Assessment
AERB/SG/S-6A	Design Basis Flood for Nuclear Power Plants on Inland Sites
AERB/SG/S-6B	Design Basis Flood for Nuclear Power Plants at Coastal Sites
AERB/SG/S-7	Human-Induced Events and Establishment of Design Basis
AERB/NPP/SG/S-8	Influence of Site Parameters on Emergency Preparedness
AERB/SG/S-9	Population Distribution and Analysis in Relation to Siting of Nuclear Power Plants
AERB/NPP/SG/S-10	Quality Assurance in Siting
AERB/SG/S-11	Seismic Studies and Design Basis Ground Motion for Nuclear Power Plant Sites

AERB SAFETY GUIDE NO. AERB/NF/SG/S-1

Published by **:** Atomic Energy Regulatory Board
Niyamak Bhavan, Anushaktinagar
Mumbai - 400 094
INDIA.

BCS