

**Description of the Atmospheric Dispersion Module RIMPUFF**  
RODOS(WG2)-TN(98)-02

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## Management Summary

This report contains the model description of RIMPUFF as integrated in RODOS PV 4.0 system within the METRODOS/LSMC (Local Scale Model Chain.)

RIMPUFF is written in HP- FORTRAN77 for a HP workstation with UNIX 10.20 operating system.

The model description document contains the following parts:

- physical characteristics of the Risø puff dispersion model
- computing principles
- set-up procedures
- description of the input and output files

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## 1 INTRODUCTION

The RIMPUFF (Risø Mesoscale PUFF model) is a Lagrangian mesoscale atmospheric dispersion puff model designed for calculating the concentration and doses resulting from the dispersion of airborne materials. The model can cope well with the in-stationary and inhomogeneous meteorological situations, which are often of interest in connection with calculations used to estimate the consequences of the short-term (accidental) release of airborne materials into atmosphere.

The model applies both to homogeneous and inhomogeneous terrain with moderate topography on a horizontal scale of up to 50 km, and responds to changing (in-stationary) meteorological conditions. It can simulate the time changing releases (emission) of airborne materials by sequentially releasing a series of Gaussian shaped puffs at a fixed rate on a specified grid. The amount of airborne materials allocated to individual puffs equals the release rate times the time elapsed between puff releases.

This description pertains to the RODOS (Ehrhardt et al., 1993) integrated nuclear radiation dose version of RIMPUFF. This version is basically the same as the original PC version RIMPUFF, but fast subroutines for calculation of radiation doses from puffs and deposited radionuclides have been added. RIMPUFF has been optimised for real-time calculation of concentrations, time integrated concentrations, deposition and doses of gamma radiation both from radioactive cloud and deposited radionuclides released into the atmosphere.

The RIMPUFF code is equipped with computer-time effective features for stability dependant dispersion parameterisation, plume rise formulas, inversion and ground-level reflection capabilities and wet/dry (source) depletion. It can be applied over moderate complex terrain by using a puff-splitting scheme in connection with external (to RIMPUFF) generated wind fields from separate wind modules (MCF and LINCOM).

The RIMPUFF computer code was originally developed on the Risø Burroughs B7800 (IBM compatible) computer in FORTRAN77. RIMPUFF has later been converted to VAX FORTRAN77 for a VAX 8700 computer. RIMPYFF for RODOS PV 4.0, which is described in this report, is written in HP FORTRAN77 for a HP workstation with UNIX 10.20 operating system.

## 2 PHYSICAL CHARACTERISTICS OF THE RIMPUFF MODEL

### 2.1 Application area of the model

The standard Gaussian plume model is widely used to calculate the atmospheric dispersion of airborne materials. The main advantage of this model is its simplicity. The shortcomings of a standard plume model can be summarised by its ability to handle in-stationary and inhomogeneous flow and turbulence situations very poorly. When dispersion is modelled out to distances larger than say 10 km, these shortcomings become progressively more important. The area over which the plume moves is more likely to display significant inhomogeneities, such as land-water interfaces. Also, as the advection time of the cloud increases, the probability for temporal changes to occur in the flow and turbulence fields is more likely.

Standard Gaussian plume dispersion modelling of inhomogeneous and in-stationary situations is inhibited by the multitude of characteristics that inhomogeneous and in-stationary flow situations can take. Flow models used to handle many of these situations in the standard plume model are often either unreliable and/or time consuming. The quantity and the quality of meteorological data available to drive such model may also vary greatly from site to site.

The RISØ-Mesoscale-PUFF model (RIMPUFF) and its computer code with the same name is designed as a modular system in response to these considerations. The core of the model consists of a bookkeeping algorithm that models a continuous release by a series of consecutively released puffs. At each time step the model/code advects, diffuses and deposits the individual puffs according to local meteorological parameter values and in the recent RODOS version calculates the gamma-radiation dose components from puffs and deposited radionuclides. The momentary concentrations and dose in grid points are calculated from the increment of the time-integrated concentration and from dose rates normalised by the time difference between initial data.

Radionuclide release data and meteorological parameters are handled as a user provided real-time or interactive input database through the Database and manual data input of the RODOS system. The atmospheric dispersion module RIMPUFF is connected to the RODOS database via PAD (Preprocessor for Atmospheric Dispersion) module converting raw meteorological data to form requested for dispersion calculations. Wind and turbulence fields is obtained from the Wind Flow Module (LINCOM or MCF), see the separate model descriptions of these.

## 2.2 Basic principles of the Gaussian puff model

The basic principle for a computational puff-model for simulation of atmospheric dispersion can be understood qualitatively by studying Figure 2.1. The shows an instantaneous top view contour (shaded area) and crosswind concentration distribution of a smoke (radionuclide) plume propagating in the mean wind direction from its point of release. Also, shown is the contour of the average long-term concentration distribution corresponding to an ordinary Gaussian plume model. The middle (b) part shows the case where the short-term averaged plume is represented by means of puff series in which the circles represent individual puffs. The puff model simulates the averaged plume picture by a set of puffs of proper sizes. The lower picture (c) shows the situation for a long-term averaged plume with significantly larger puffs due to meandering of the wind direction over long time.

The concentration distribution in an individual puff is Gaussian in all three dimensions. The standard deviations  $\sigma_y$  and  $\sigma_z$  represent the puff size in crosswind and vertical directions respectively. The standard deviation  $\sigma_x$  in downwind direction used as a mathematical tool and for simplicity the value  $\sigma_x = \sigma_y$  is used and this common value is marked as  $\sigma_{xy}$ . Figure 2.1(b) also suggests that a puff model has the advantage that it makes it possible to account for the short term behaviour of the plume. Where the Gaussian plume model represents a long time averaged concentration pattern, the puff model is capable, in principle, to simulate an updated short term plume picture by means of a corresponding actual wind field, even when this is instationary and inhomogeneous.

## 2.3 Wind field and advection calculations

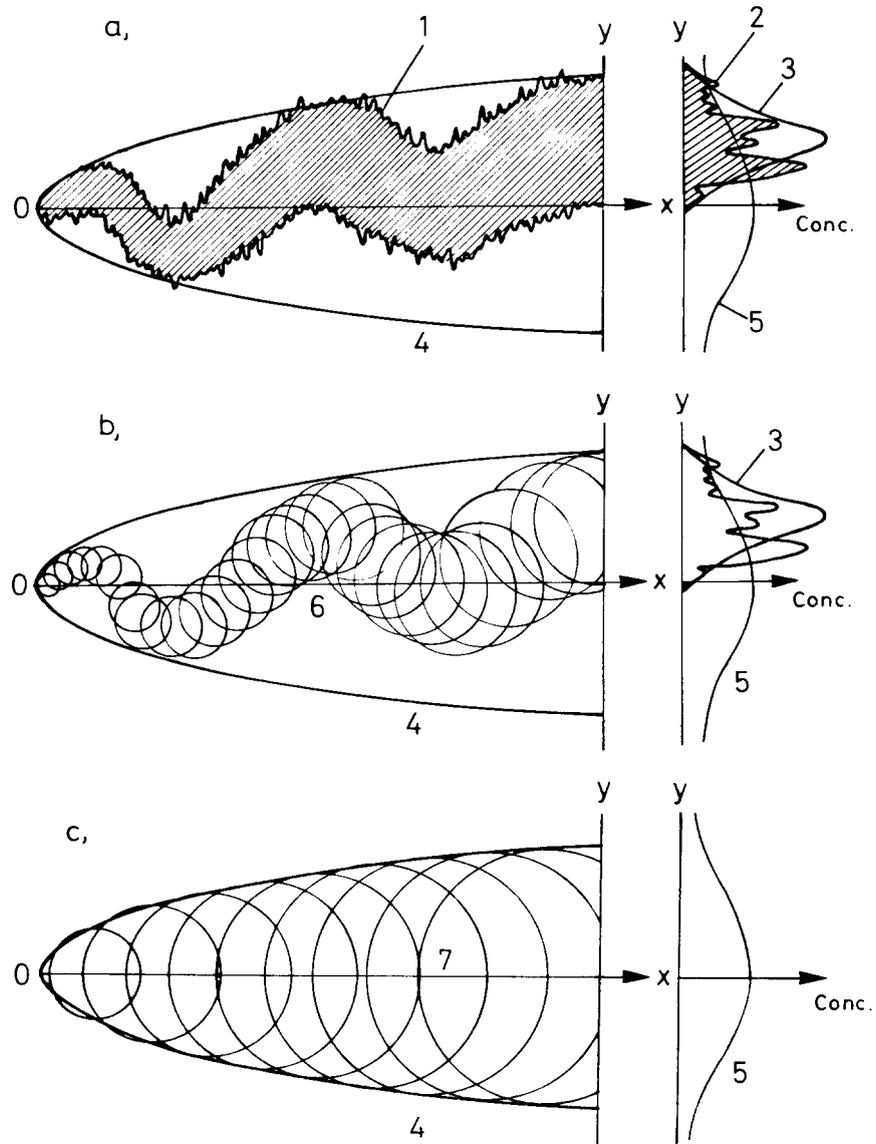
The present puff model uses the actual wind vector (wind direction and wind speed) averaged for time  $t_{av}$  for each puff position. The advection is calculated using the wind vector existing at the puff centre position and the time step used to determine the next position of the puff centre. The wind vector value belongs to the actual height of the puff centre.

The wind vector fields are produced by Wind Flow Module of the ASY subsystem of RODOS, independent of RIMPUFF. These vectors belong to the standard height (usually 10 m). The RIMPUFF model contains a feature to correct the wind speed as a function of height and turbulence parameters.

The individual puffs are advected by the wind field  $\bar{V}$  that in general is a specified function of co-ordinate  $\bar{r}$ , time  $t$  and averaging time  $t_{av}$ . We write

$$\bar{V} = \bar{V}(\bar{r}, t, t_{av})$$

To compute the growth and buoyant lift of all the puffs, it is necessary to have simultaneous specification of the turbulence intensity and/or the atmospheric stability.



**Figure 2.1 Puff simulation of the atmospheric dispersion.** a) Plume behaviour, b) short-term puff simulation, c) long-term averaged puff simulation. 1 - instantaneous plume contour, 2 - instantaneous crosswind concentration distribution, 3 - short term averaged crosswind concentration distribution, 4 - long term averaged plume contour, 5 - long term averaged crosswind concentration distribution, 6 - short term averaged puffs, 7 - long term averaged puffs

RIMPUFF calculates the puff's location on the specified grid by computing their movement during finite time steps.

## 2.4 Plume rise

### 2.4.1 Plume rise due to wind shear

Shear will cause the mean puff height to increase, when the vertical diffusion coefficient,  $\Phi_z$ , increases. Assuming ground reflection and a release height of 0 then the mean height of the puff will be:

$$\langle z_{p0} \rangle = \frac{s_z}{\sqrt{2p}} \int_0^\infty e^{-x} dx = \frac{s_z}{\sqrt{2p}}$$

When the puff height at a given time is  $z_1$  then the height  $z_2$  after one advection step is found from the formula:

$$z_2 = \sqrt{z_1 + \frac{1}{2p} \Delta s_z (2s_{z1} + \Delta s_z)}$$

where

$\Delta s_z$  Increment of  $\Phi_z$  during one advection

$\Phi_{z1}$  Vertical diffusion coefficient at the beginning of the advection step

### 2.4.2 Plume rise due to heat content

Since the succession of puffs resembles a continuous release, the formulas used to determine the effective source height after plume rise is taken from standard plume models (Päsler-Sauer 1985)

The final rise-height for each puff is a function of the atmospheric stability and wind speed at the time of release. The wind speed is adjusted to the release height using an exponential, stability dependant profile.

For the buoyant bent-over plume in neutral conditions, the plume rise  $\Delta h$  in m is given by

$$\Delta h = \frac{1.8^{1/3} x^{2/3}}{\bar{U}} \quad \text{for } x \leq x^*$$

$$\Delta h = 1.8 F_z^{1/3} x^{*2/3} \frac{\frac{2}{5} + \frac{16x}{25x^*} + \frac{11}{5} \left( \frac{x}{x^*} \right)^2}{\left( 1 + \frac{4x}{5x^*} \right)^{-2}} \quad \text{for } > x^*$$

$$F_z = \frac{gQ_h}{\pi C_p \rho_{air} T} = 8.9 \left[ \frac{m^4 / s^3}{joule / s} \right] \frac{\rho_p}{\rho_{air}}$$

where  $x$  is the distance from the source and

$$x^* = 0.43 F_z^{2/5} (\bar{U} \epsilon^{-1})^{3/5}$$

the distance at which atmospheric turbulence begins to dominate entrainment. In this expression  $\epsilon$  is the rate of dissipation of turbulent kinetic energy.

In the neutral surface boundary, i.e. the lowest 20 metres say,  $\epsilon$  at a given height,  $z$ , is related to the friction velocity  $U^*$  by

$$\epsilon = U^{*3} / 0.4z$$

Solving these equations for  $z = \Delta h$ , the theoretical final plume height  $\Delta h_{max}$  for ground releases in neutral conditions becomes

$$\Delta h_{max} \cong 4.5 F_z / \bar{U} U^{*2}$$

Under stable conditions for ground release

$$\Delta h_{max} = 2.4 (F_z / \bar{U} S)^{1/3}$$

Under unstable conditions for ground release

$$\Delta h \cong x^{2/3}$$

The maximum plume rise

$$\Delta h_{max} \cong h_{lid}$$

## 2.5 Dispersion calculations

### 2.5.1 Calculation of concentrations

Growth of the puffs is computed from simultaneous measurements or specifications of the atmospheric turbulence intensity or/and stability in the dispersion area. The height of the inversion cap (through which pollutants is assumed not to pass) and the source height can easily be adjusted. Grid spacing for computation of data may vary from metres to kilometres, and time duration for the release may vary from seconds to hours.

A parameter controls the amount of reflection/absorption of pollutant at the surface of the ground and of the inversion cap. (Total reflection is normally assumed.)

The model calculates the concentration at each grid point by summing the contributions from surrounding puffs at each advection step. The grid concentrations/doses can either accumulate or simply be updated with the latest instantaneous value calculated for time  $t_{av}$ .

The model output consists of time integrated air concentrations and depositions (and radiation dose rates) in grid points at times specified in the input data.

More detailed information on the RISØ puff diffusion model and its use of parameterised puff diffusion is available in (Mikkelsen et al., 1984) and (Mikkelsen et al., 1987).

Once the advection and size of all puffs have been calculated, updated grid concentrations  $\chi(x_g, y_g, z_g)$  are obtained at each grid point  $(x_g, y_g, z_g)$  summing up all the contributions from the puffs in the grid. Assuming Gaussian distributions and total ground and inversion lid reflection the formula for the concentration in a grid point  $(x_g, y_g, z_g)$  from puff number (i) is given by in Bq/m<sup>3</sup>:

$$c_i(x_g, y_g, z_g) = \frac{Q(i)}{(2\pi)^{3/2} (s_{xy}(i))^2 s_z(i)} \times \exp\left[-\frac{1}{2}\left(\left(\frac{x_g - x_c(i)}{s_{xy}(i)}\right)^2 + \left(\frac{y_g - y_c(i)}{s_{xy}(i)}\right)^2\right)\right] \times \exp\left[-\frac{1}{2}\left(\frac{z_g - z_c(i)}{s_z(i)}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2z_{inv} - z_c(i)}{s_z(i)}\right)^2\right]$$

where

- Q(i) Puff inventory in puff no. (i) [activity], which in turn is given by: (Release rate from the source [activity/time]) x (elapsed time between puff-releases [time]) x correction factors).
- $x_c(i), y_c(i), z_c(i)$  Center co-ordinates of puff no. (i).
- $z_{inv}$  Height of the inversion lid
- $\sigma_{xy}(i), \sigma_z(i)$  Puff dispersion parameters in horizontal and vertical directions, respectively ( $\sigma_{xy}(i)$  and  $\sigma_z(i) > 0$ )

### 2.5.2 Dispersion parameters

Expansion with time of a single puff is fundamentally related to the relative diffusion process (figure 2.2). In the surface layer, this is most conveniently described as a function of the local turbulence intensities and downwind distance, see e.g. (Mikkelsen et al., 1987). Therefore, the optimal data set for driving the model should include turbulence intensities. Alternatively, without such data, standard plume dispersion information can be used as e.g. the Pasquill-Turner system (Slade, 1968), shown in figure 2.3 and 2.4 or the Karlsruhe-Jülich system (Bundesminister, 1983). Some of these versions are implemented in the present version of RIMPUFF. Common for all three systems is that the dispersion parameters are a function of downwind

distance. The turbulence intensity is a continuous function of measured meteorological data since the two others are steplike functions of measured meteorological data. Presently a modified version of the Pasquill-Turner system is used with height-dependent dispersion parameters.

The downwind distance dependence of the dispersion parameter can be a linear, a power, a polynomial or other function.

Two typical dispersion class system are shown in tables 3.1 and 3.2.

### 2.5.2.1 Parameterisation schemes

#### *Pasquill-Gifford.*

The well known Pasquill diffusion scheme and its associated dispersion parameters have been among the most frequently applied dispersion schemes all over the world. These schemes are still in use but they are presently often, in particular for real-time assessments, being replaced by so-called "second-generation" dispersion schemes, based on micro-meteorological scaling parameters (Monin-Obukhov similarity theory, see below).

The Pasquill type schemes are limited in use to the conditions of the diffusion experiments from where plume spread information was extracted, i.e. diffusion experiments performed with near ground-level releases and in regions with often low surface roughness (rural areas). The Pasquill dispersion categories were based on surface windspeed measurements (at the 10 m height above ground) and with incoming insolation or cloud cover as a parameter. A is the most unstable case, D corresponds to neutral case, and E and F is the most stable dispersion class.

In RIMPUFF there are 3 parameterisation schemes for sigma parameters: Pasquill, Turbulence intensities and Similarity theory. Pasquill parameterisation RIMPUFF uses a modified Karlsruhe-Jülich system (table 2.3), where the dispersion parameters are described in form

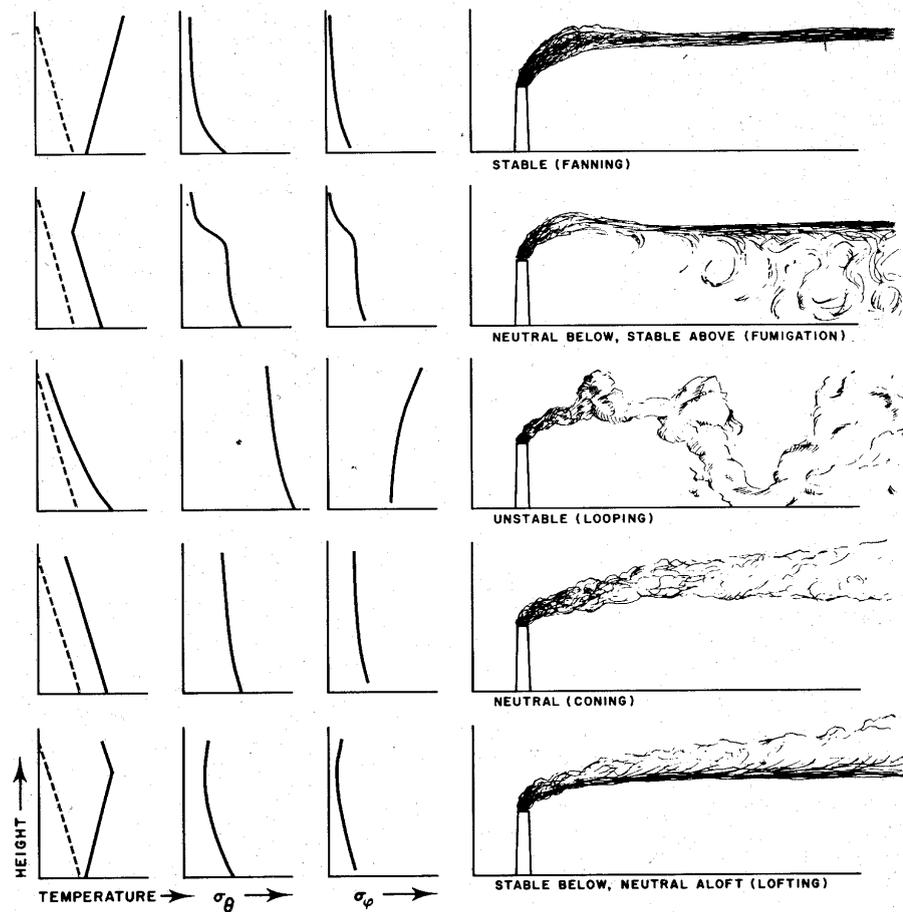
$$s_y = p_y x^{q_y} \quad \text{and} \quad s_z = p_z x^{q_z} \quad (2.1)$$

where x is the downwind distance and  $p_y$ ,  $q_y$ ,  $p_z$ , and  $q_z$  are stability dependent parameters. The formula is assumed to be applicable for  $0.01 < x < 50$  km. However if the downwind distance exceeds 10 km it is assumed that the horizontal dispersion parameter follows the equation:

$$s_y = p10_y x^{0.5} \quad \text{where} \\ p10_y = p_y * 10000^{(q_y - 0.5)} \quad (\text{Source: Jürgen Päsler-Sauer, 1997})$$

From equation (3.1) the sigma values after a given advection step  $X$  and a given (local) stability are obtained by the relations:

$$s_y(x + \Delta x) = (s_y(x)^{\frac{1}{q_y}} + p_y^{\frac{1}{q_y}} \Delta x)^{q_y}$$



**Figure 2. 2 Various types of smoke-plume patterns observed in the atmosphere.** The dashed curves in the left-hand column of diagrams show the adiabatic lapse rate, and the solid lines are the observed profiles. The abscissas of the columns for the horizontal and vertical wind-direction standard deviation  $\Phi_{\theta}$  and  $\Phi_{\varphi}$  respectively, represents a range of about 0E to 25E.

*Wind Fluctuations*

are given advection step )X the relation:

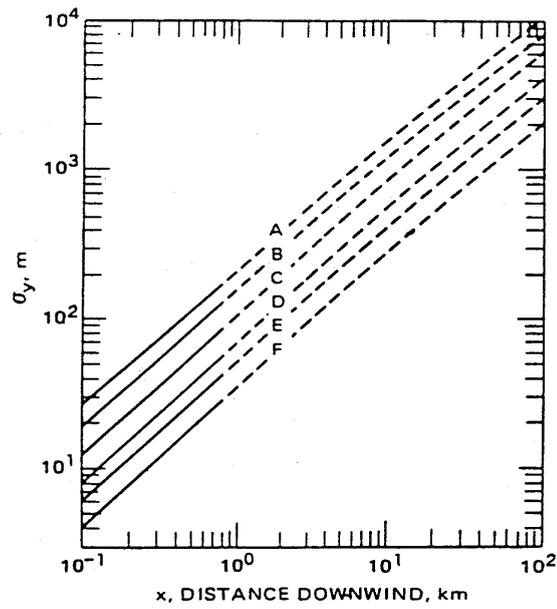
$$s_z(x + \Delta x) = (s_z(x)^{\frac{1}{q_z}} + p_z^{\frac{1}{q_z}} \Delta x)^{q_z}$$

When the horizontal,  $\Phi_2$ , and vertical,  $\Phi_v$ , wind fluctuations given, the sigma values after a

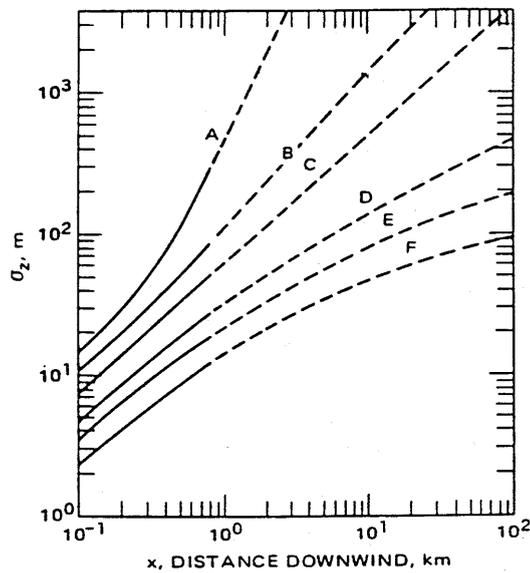
$$s_y(x + \Delta x) = s_y(x) + 0.3 \Delta x s_q \frac{P}{180}$$

$$s_z(x + \Delta x) = s_z(x) + 0.3 \Delta x s_j \frac{P}{180}$$

where  $\Phi_y$ ,  $\Phi_z$  and  $x$  are in meters and  $\Phi_2$  and  $\Phi_v$  in degrees.



**Figure 2.3 Lateral diffusion coefficients,  $F_y$ , vs. downwind distance for the Pasquill-Gifford-Turner stability categories A,B,...F. (From Gifford, 1976)**



**Figure 2.4 Vertical Diffusion Coefficients,  $F_z$ , vs Downwind Distance for Pasquill-Gifford-Turner Stability Categories A, B,...F (From Gifford, 1976)**

**Table 2.1: Meteorological conditions defining Pasquill’s stability/turbulence classes**

Surface (10 m)	Daytime			Night-time	
wind speed	Incoming solar radiation			Cloudiness	
(m s <sup>-1</sup> )	Strong	Moderate	Slight	≥4/8	≤3/8
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

**Table 4.2 Relation between Pasquill-Gifford Stability and the Standard Deviation of Horizontal and Vertical Wind Directions**

Pasquill Stability Category	$\sigma_{\theta}$	$\sigma_{\varphi}$
A. Extremely unstable conditions	25.0 E	12.0°
B. Moderate unstable conditions	20.0 E	11.0°
C. Slightly unstable conditions	15.0 E	9.0°
D. Neutral conditions	10.0 E	6.0°
E. Slightly stable conditions	5.0 E	3.5°
F. Stable conditions	2.5 E	2.0°

*Similarity- scaling*

The "classical" Pasquill-Gifford parameterisation of plume spread are presently being replaced by so-called "Similarity-scaling" of atmospheric turbulence and diffusion. The basic concept is to base the calculations of plume spread on the physical parameters that governs the ABL turbulence- this is parameters for heat flux  $w_*$ , shear stress  $u_*$ , the inversion height  $z_i$  and the from them derived Monin-Obukhov length  $L$ . With these the A, B, C.. categories have been replaced by the continuous non-dimensional parameter: " $z/L$ ", where  $z$  is the height above the ground (say release height).

The dispersion parameters are calculated from similarity scaling formulas using  $s_y = s_q \bar{u} t F_y(u_*, w_*, L, z_i, z)$  the parameters  $(u_*, L, z_i, w_*)$ , viz.:

$$s_z = s_j \bar{u} t F_z(u_*, w_*, L, z_i, z)$$

In RIMPUFF this is implemented based on the formulas described by Carruthers (Carruthers et al., 1992; Carruthers and Weng, 1993; Schaarschmidt, 1995):

$$s_u^2 = 0.3 w_*^2 + 6.25 T_{W_N}^2(z) u_*^2$$

$$s_v^2 = 0.3 w_*^2 + 4.0 T_{W_N}^2(z) u_*^2$$

**Table 2.3 Karlsruhe-Jülich diffusion coefficients as function of stability category and height of release.**

Height (m)	Stability category	Diffusion coefficients			
		$p_y$	$q_y$	$p_z$	$q_z$
50	A	1.503	0.833	0.151	1.219
	B	0.876	0.823	0.127	1.108
	C	0.659	0.807	0.165	0.996
	D	0.640	0.784	0.215	0.885
	E	0.801	0.754	0.264	0.774
	F	1.294	0.718	0.241	0.662
100	A	0.179	1.296	0.051	1.317
	B	0.324	1.025	0.07	1.151
	C	0.466	0.866	0.137	0.985
	D	0.504	0.818	0.265	0.818
	E	0.411	0.882	0.487	0.652
	F	0.253	1.057	0.717	0.486
180	A	0.671	0.903	0.025	1.5
	B	0.415	0.903	0.033	1.32
	C	0.232	0.903	0.104	0.997
	D	0.208	0.903	0.307	0.734
	E	0.345	0.903	0.546	0.557



The time derivative of  $\Phi_y$  is used to calculate the increment of

$$s_y(t + \Delta t)$$

According to:

$$s_y(t + \Delta t) = s_y(t) + \Delta t \frac{ds_y(t)}{dt}$$

In RIMPUFF the calculation of  $\Phi_{xy}(t+\Delta t)$  and  $\Phi_z(t+\Delta t)$  is based on Carruthers and Weng, 1995. According to Carruthers the length and time scales for turbulence are:

$$\Lambda_w(z) = \left[ \frac{0.6}{z + z_0} + \frac{U / z}{s_w} + \frac{4}{h} \right]^{-1}$$

$$T_L(z) = 1.3 \frac{\Lambda_w(z)}{s_w(z)}$$

An extensive description of the calculation procedure could be found in the references: Carruthers et al., 1992; Carruthers and Weng, 1995; Schaarschmidt, 1995

### 2.5.3 Plume splitting (pentafurcation)

Diffusion in complex terrain often shows evidence of plume splitting and layer decoupling due to channelling and slope flows. Consequently a puff-splitting scheme is applied to model this such that a cluster of new puffs overlays and by that simulate the concentration distribution of the original single puff. When an initially small puff is grown to the size comparable with the grid spacing of the flow model, the puff with  $\sigma_{p1}$  splits horizontally into five new Gaussian puffs with  $\sigma_{p5}$  under the following constraints ( $\sigma_{p1} = \sigma_{xy}$ ):

$$i) \quad \sum \sigma_{p5}^2 = \sigma_{p1}^2$$

$$ii) \quad C_5(0,0) = C_1(0,0)$$

$$iii) \quad \sigma_{p5} = \frac{1}{2} \sigma_{p1}$$

$$iiii) \quad \sum_1^5 Q_{p5}(i)_{p1}$$

This means:

- i) In a horizontal plane and taken about the centroid of the pentafurcated puff (i.e., the radial integrated inertia moment), and of the original puff, the second moments are equal
- ii) The centre concentration at  $(x,y) = (0,0)$  of the pentafurcated and original puff is equal.

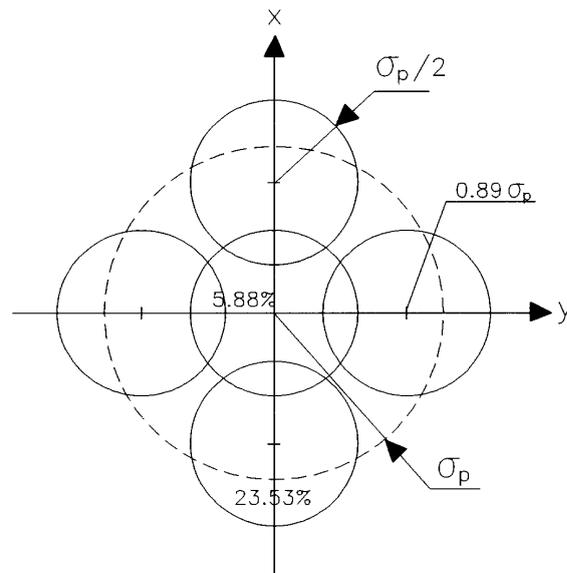
- iii) The sizes of the pentafurcated puffs in the present version all equal one-half times the original puff size. (In common sense this is an arbitrary quantity)
- iiii) In addition, we require mass conservation, i.e. the total amount of matter allocated to the five new puffs must equal the amount of matter first allocated to the original one

Fig. 2.5 shows the corresponding solution to these constraints: one central and four satellite puffs approximate the original single Gaussian puff. The four satellite puffs are positioned with their centroid on each of the four Cartesian coordinates at a distance of  $0.89 \sigma_{p1}$  from the origin. Each of the four satellite puffs carries 23.53 per cent of the total amount of matter. The fifth puff is assigned the remaining 5.88 per cent while still being located at the origin.

Now suppose that the horizontal grid spacing of the flow model is fixed at a size of 500 meters. An original single small puff will then diffuse in size till its horizontal extension reaches 500 m. At this point the puff pentafurcates into five new puffs (see Fig 2.5) each of a size  $\sigma_{p5}$  equal to 250 m. The second order moments (standard deviation) this cluster of pentafurcated puffs will be indistinguishable from the single original puff, and each of the five new puffs can resume a growth rate according to Eq. i), potentially with a new local wind vector and/or level of turbulence. The main point is, however, that once pentafurcated, the four satellite puffs can set off in individual directions in response to the information of divergence now explicitly contained in the flow field.

#### Height of the inversion cap

The height of the inversion cap or the mixing height, varies with stability (Klug, 1968). When the stability changes the height is changed accordingly. For a grid with different stability regions and thus different mixing heights the value at the emission is chosen to apply for all the stability regions at a given puff. The final rise height due to plume rise is not allowed to exceed the mixing height chosen.



**Figure 2. 5 Puff penta-furcation: the original single puff size  $S_p$  is divided into five new puffs, each of the size  $S_p/2$**

$$F_d [Bq m^2 s^{-1}] = V_d [m s^{-1}] X_{z=0} [Bq m^{-3}]$$

**2.6 Deposition**

**calculations**

In assessing the environmental consequences of accidental releases to the atmosphere, estimating the activity deposited on ground surfaces usually plays an important role. One exception is for noble gases, though. Deposition can be separated into dry and wet deposition. The first is caused by interaction of airborne materials with the ground surface. The wet deposition appears due to wash out processes in the atmosphere..

*2.6.1 Dry Deposition*

Dry deposition is calculated using the source depletion concept, i.e. full mixing of airborne materials is assumed without any correction for increased depletion near the ground surface. The dry deposition parameters are chosen for the individual puffs according to type of isotope, atmospheric stability and wind speed and surface roughness.

Dry deposition is in RODOS modelled via a "dry deposition velocity"  $V_d$  [m/s], which typically has a magnitude of ~1 mm/s.

The downward flux  $F_d$  [ $Bq m^2 s^{-1}$ ] is in RODOS given by the deposition velocity  $V_d$  times the ground level concentration  $\Pi$ :

leaving the ground level deposition to be solely determined by these two equal important quantities.

Dry deposition rates are different for vapours and particles, and both are highly controlled by the surface, so different materials have different deposition on different surfaces. Dry deposition for aerosols is a function of friction velocity and wind speed (Thykier-Nielsen and Larsen, 1982).

$$v_d \approx \frac{u_*^2}{\bar{u}}$$

The present version of the model can take the surface type into account. This is done in characterizing each type of surface (urban, rural, forest and water) by its surface resistance, which primarily depends on surface roughness and friction velocity (for a given material) (Hummelshøj (1994), Jensen (1981) and Roed (1990)).

### 2.6.2 Wet deposition

Precipitation (rain, snow, hail...) will scrub a contaminated plume. The rain drops can pick up both gasses and particulates in the plume. The efficiency by which this happens depends on the rain intensity and on the characteristics of the pollutant, for gasses the key parameter is the solubility whereas for particles, the rain out efficiency depends on both volume, shape, density etc.

The effect of rain out is *one of the most important mechanisms* for high ground level contamination.

Wet deposition is modelled similar to dry deposition only with the difference that the deposition velocity here is replaced by a wash-out coefficient  $\gamma$  [ $s^{-1}$ ], the magnitude of which depends on the rain intensity  $I$  [ $mm\ hour^{-1}$ ]:

$$\gamma [s^{-1}] = L I^a$$

where  $L$  ranges between  $\sim 3 \cdot 10^{-5}$  to  $\sim 3 \cdot 10^{-3}$  and with  $a \in [0.5, 1]$  depending on nuclei and particle size.

#### *Deposition Parameters*

In the present version of the RIMPUFF module the following values of the deposition parameters are used:

Isotope group	Group name	Basic dry-deposition parameter [m/s]	Wet-deposition parameter [s <sup>-1</sup> ]
1	Noble gases	-	-
2	Iodine elementary	0.01	8.0E-5×Λ <sup>0.6</sup>
3	Iodine organic	0.0005	8.0E-7×Λ <sup>0.6</sup>
4	Aerosols	0.001	8.0E-5×Λ <sup>0.8</sup>

**Table 1.4 Isotope groups and deposition parameters.**

Remark: The dry- and wet-deposition parameters are the same as those used within the RODOS prototype system. Λ is the rain-intensity in mm/h.

## 2.7 Gamma dose calculations

RIMPUFF includes modules for calculating external gamma doserates both from airborne and deposited radioactivity. A more detailed description of the gamma dose calculations is available in (Thykie-Nielsen, 1993 and 1995).

### 2.7.1 Gamma doserate from puffs

The method for calculation of gamma dose rates in a given receptor point from a Gaussian puff for each gamma radiation energy is based on the solution of the equation below:

$$d(QE_{\gamma}, \sigma_y, \sigma_z, H, R_{xy}) = 2K\sigma_{en} E \int_{x=-\infty}^{\infty} \int_{y=0}^{\infty} \int_{z=-\infty}^{\infty} \frac{B(\mathbf{m})}{4\mathbf{p}^2} e^{-\mathbf{m}} \mathbf{c}(x, y, z) dx dy dz \quad [\text{Gy/s}]$$

where

- Q activity in one puff [Bq]
- E<sub>γ</sub> energy of gamma radiation [MeV]
- σ<sub>y</sub> crosswind puff dispersion parameter [m] (σ<sub>x</sub> = σ<sub>y</sub>)
- σ<sub>z</sub> vertical puff dispersion parameter [m]
- H height of the puff center [m]
- R<sub>xy</sub> distance of the puff centre base point (x = y = 0, z = -H) from the receptor point [m]
- K constant, 1.6 × 10<sup>-13</sup> [Gy/s/MeV/kg]
- σ<sub>en</sub> energy absorption coefficient for air [m<sup>2</sup>/kg]

B	build up factor
$\mu$	linear attenuation factor for air [ $\text{m}^{-1}$ ]
r	distance of the volume $\text{dxdydz}$ from the receptor point located at the distance $R_{xy}$ from the puff centre base point

$X(x,y,z)$  the concentration in point  $x,y,z$  [ $\text{Bq}/\text{m}^3$ ] due to formula

$$c(x, y, z) = \frac{Q}{(2p)^{3/2} s_y^2 s_z} \exp\left(-\frac{x^2}{2s_y^2}\right) \exp\left(-\frac{y^2}{2s_y^2}\right) \exp\left(-\frac{z^2}{2s_z^2}\right)$$

For all lines of all radionuclides this calculation should be done and the dose components should be summed.

As such a computation is very time consuming the used method is the following.

The equation for the doserate was solved for different sets of para-meters ( $\sigma_y$ ,  $\sigma_z/\sigma_y$ , H,  $R_{xy}$  and  $E_\gamma$ ) by numeric volume integral method. The calculated and tabulated data are used for fast calculation of cloud gamma doses. The calculation method is described in Chapter 3.

### 2.7.2 Gamma doserate from deposited activity

Dose rates of isotopes accumulated on the ground surface due to dry and wet deposition are calculated from the amount of deposited activity and dose constants for a semi-infinite plane source. Details of the calculations are described in Chapter 3.4.1.

### 3 COMPUTING PRINCIPLES

This chapter describes the principles used in the present (RODOS 4.0) version of the RIMPUFF computer code. As the real-time computing requires fully fixed set of all parameters except the real-time data (i.e. source term and meteorological data) all parameters should be fixed either in the code or at set-up of the computer programme. All parameters have a default value except site dependent parameters.

The main requirements for the present version were:

- maximum computing time for one set of real time data in continuous mode: 300 s
- number of grid cells for the calculations: 41 in x and 41 in y direction
- maximum grid spacing: 2000 m
- maximum number of additional receptor (detector or reference) points: 100

The computational tasks of the recent version of the RIMPUFF model are shown in Fig. 3.1.

The RIMPUFF code version R4.0 is the computer code of the Dispersion Module. This module is a part of the Analyzing Subsystem of the RODOS system.

The real time input data are:

- meteorological data and
- source data

The flow chart for the central part of RIMPUFF is shown in Fig. 3.2.

Meteorological data corrected for topography are produced by Wind Flow Module. Source data are provided by the RODOS System in the Data Subsystem. Automatic real-time computing requires the existence of meteorological data, but source data are only requested in case of radionuclide release from the source.

#### 3.1 Meteorological data

For each meteorological station time series of observations related to atmospheric stability, wind speed and - direction plus rain intensity are evaluated by the Meteorological Preprocessor Module (it is recently the PAD - Preprocessor for Atmospheric Dispersion) and together with topographical data in the Wind Flow Module. The minimum time step for new meteorological data set is 600 s. The meteorological data set contents:

Input	Computation	Output
(a) Time variable data - Meteorological (windfield, stability and precipitation data) - Release data (b) Time independent data - Grid (receptor) data - Constants for calculations	- Generation of puffs and advection of puff centres with windfield - Calculation of size and radionuclide inventory of individual puffs - Calculation of concentration and deposition - Calculation of gamma doses	- Time integrated radionuclide concentrations and gamma dose rates in grid (receptor) points - Positions, size and inventory of puffs at the border of calculation grid (data for MATCH module)

**Figure 3.1** Computational structure of the RODOS version of the RIMPUFF module

- date and time of the data set
- numerical value of
- wind field
- stability field
- inversion layer thickness
- rain field.

The number of data set for each field equals with number of grid points.

The meteorological data files content a flag to indicate the availability of data. This flag is:

- 1 data available is available as field
- 1 data is available as constant value for the field
- 0 data are not available.

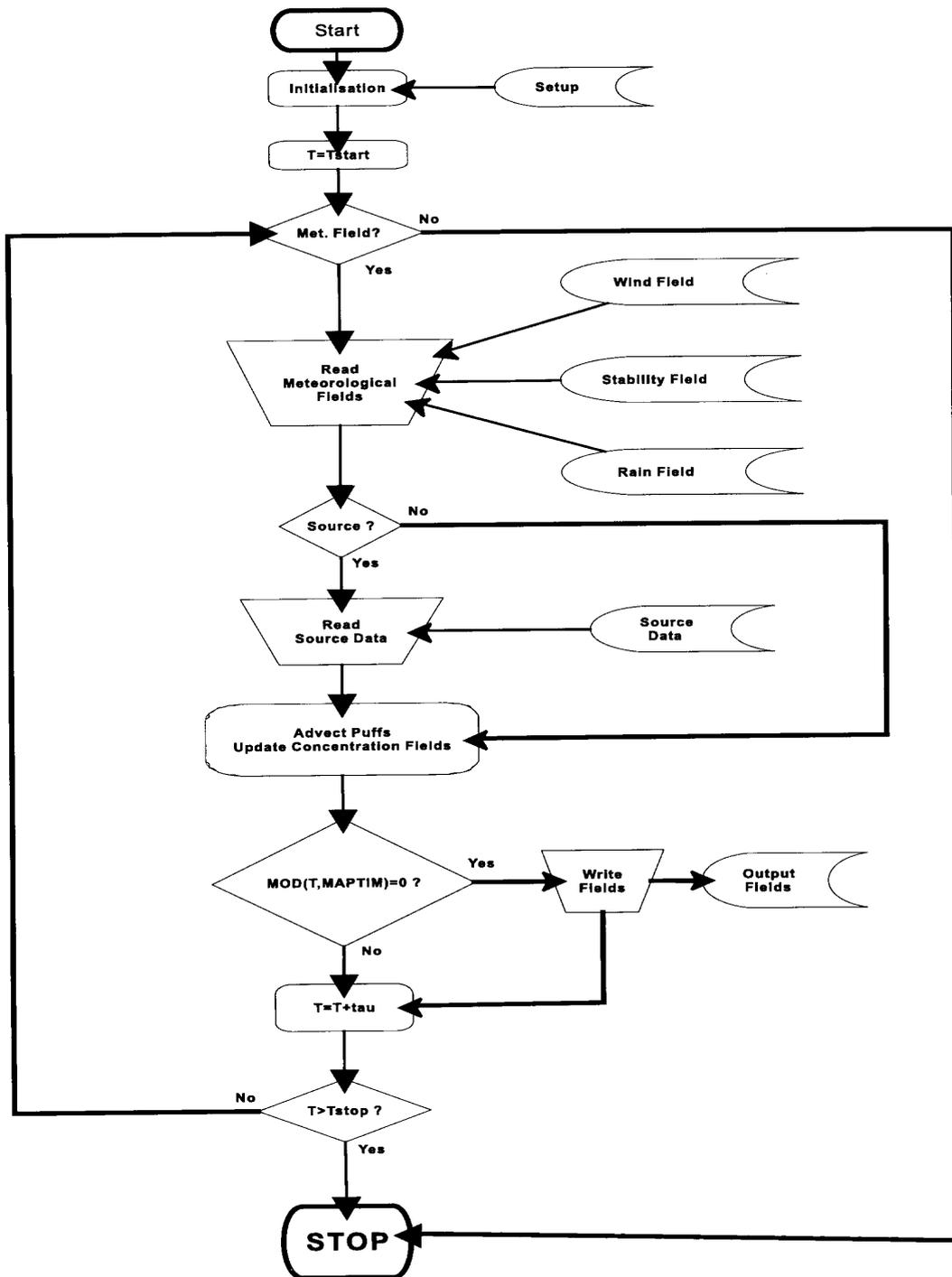


Figure 3.2 Flow chart for the central part of RIMPUFF in case of Hand Generated Data Exercise/Simulation).

Remark: In case of real time calculations there is no total time limitation

## 3.2 Source data

The radionuclide source data are taken from the RODOS Data Subsystem for each computing period (600 s or more). The source data file contents all released radionuclides including pure alpha and beta emitters and the heat content of the release.

The source data set contents:

- date and time of the data set
- numerical value of release of radionuclides.
- heat content of the release.

Specification of released radionuclides:

- Mass number of radionuclide
- Standard abbreviation of the nuclide name including possible form of radioiodine (aerosol, elementary)
- Release rate in Bq/s for each radionuclide

## 3.3 Geometrical and related time parameters

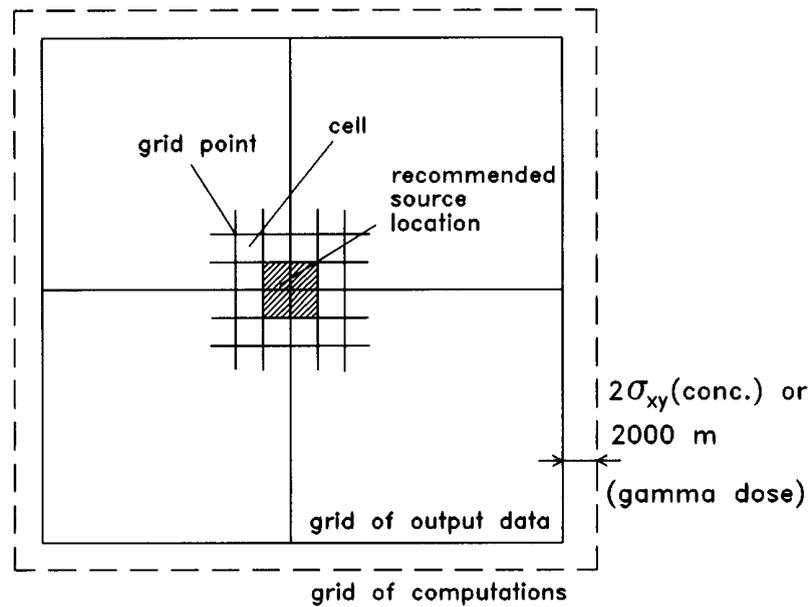
### 3.3.1 Grid system

Computation is made for grid points of the area considered (Fig. 3.3). In the present version the number of grid points both in x and y directions is 41, i.e. the grid size is 41 x 41 grid points. In such a case there exist 40 x 40 grid cells. Having a distance of 1000 m between neighbouring grid points, the size of computed data field is equal to 40 x 40 km. The real computation area exceeds the area of output data grid area to exclude the errors due to edge effect. This additional distance in case of concentration calculations is equal to  $2\sigma_{xy}$  and in case of gamma dose rate calculations is 2000 m.

The recommended location of the source is one of the four centre cells, in this case a minimum of computation distance is about 20 km from the source.

The separation (distance) between the grid points is significant only for the spatial resolution and is thus not related to the accuracy of the calculated concentrations.

To essential information on concentrations/doses may be "hidden" between grid points near the source region especially in case of short release at stable meteorological conditions. Therefore a special feature is included into the RIMPUFF code. The user can specify a number of additional receptor (detector or reference) points of special interest, for these points the calculations shall be done additionally.

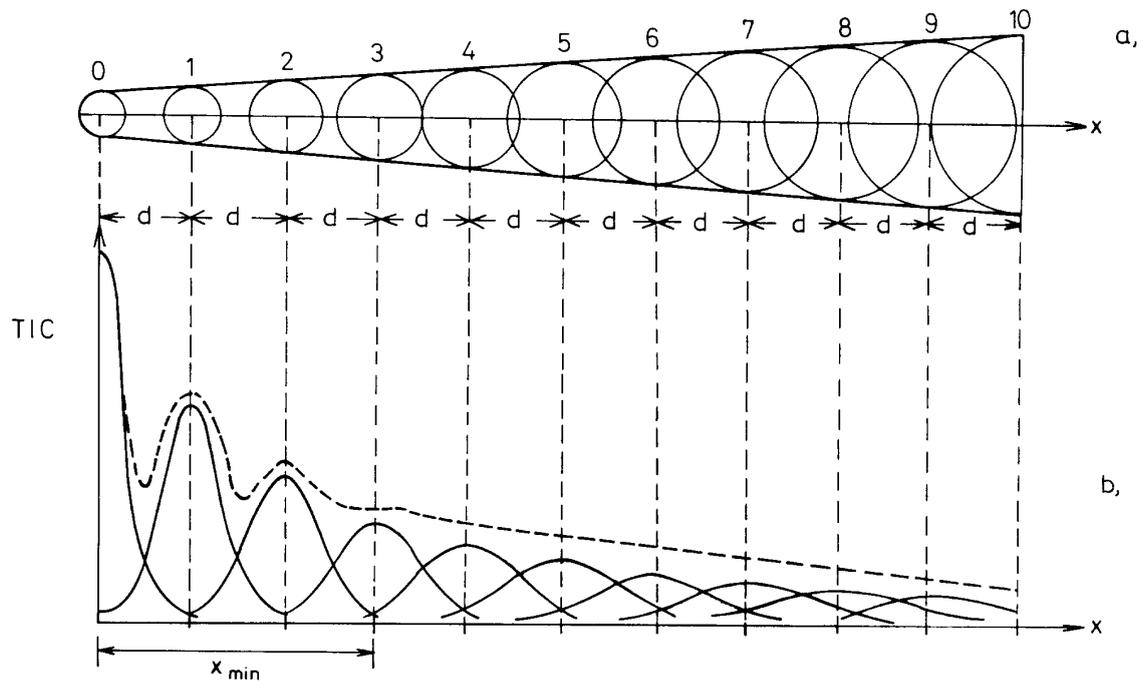


**Figure 3.3 The grid system of computations**

### 3.3.2 Time between puff-releases and advection time

The accuracy by which the puff-model calculates the grid concentrations has been tested by comparison with the Gaussian plume, both models driven by a constant wind field. These tests show that the release rate should be large enough or advection time should be short enough for the puffs of given initial size to "overlap" each other, thus producing a smooth concentration profile. When the puffs expand during their advection downwind, we have a situation as shown in Fig. 3.4. It should be noted that at unchanging wind direction the distance between puff positions to be used for concentration calculation and the smoothness of the spatial distribution of concentrations are equally influenced by the time between puff releases and by the advection time. Beyond the distance  $x_{min}$ , the profile remains smooth and similar to the continuous plume of the plume model, as long as the wind direction does not change.

If we ask what is that neighbour puffs almost fully overlap we see (Fig. 3.5) that requirement given below for TAU (release rate for puffs) and/or  $t_{adv}$  (advection time between two successive computations) should be fulfilled



**Figure 3.4 Advection of puffs with increasing size.** Initially small puffs released at small rate and/or advected for a relatively (to puff size) downwind distance  $d$  have to travel the distance  $x_{min}$  before they expand to a size where they effectively overlap. (a) - puff positions, (b) - time integrated concentration (TIC) as function of the downwind distance  $x$

$$TAU \leq \frac{2s_p(x)}{U}$$

where:

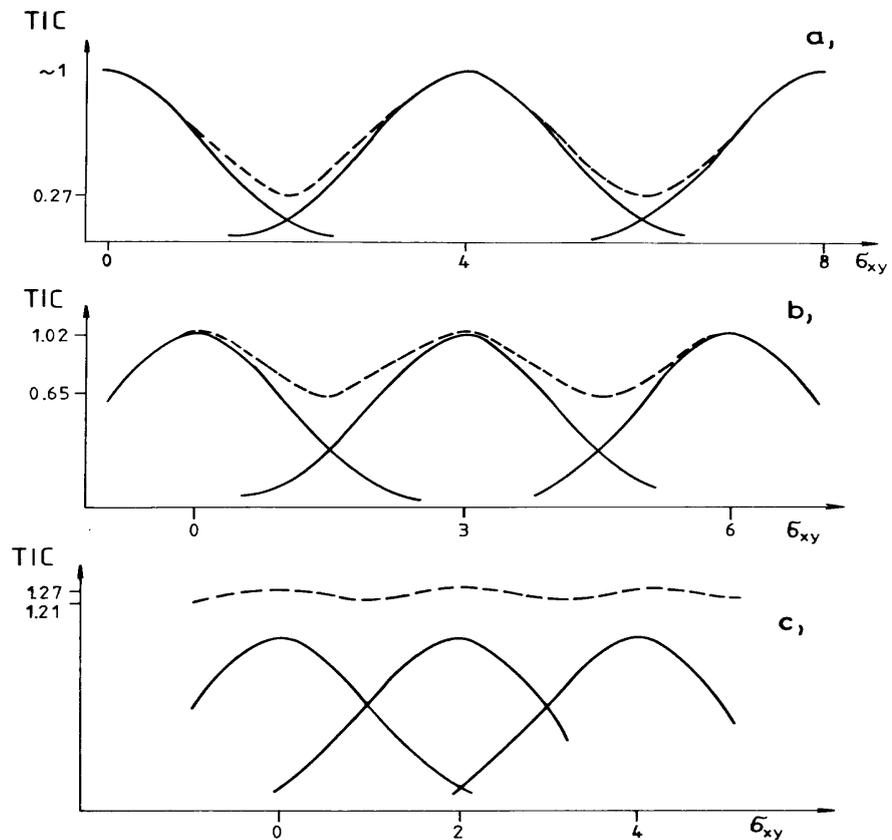
$\sigma_{xy}$  horizontal dispersion coefficient [m]

$u$  wind speed [m/s]

$x$  length of the puff's trajectory from the source [m]

The inequality gives an upper limit on advection time  $t_{adv}$  and/or TAU, if we want the puffs to overlap after some travel. Thus it is now seen that  $x$  is interpreted as the downwind distance, where puffs born with a certain size and rate of release cover each other effectively. In given version of RIMPUFF the default value of TAU (release rate for puffs) is equal to 300 s and  $t_{adv}$  (advection time between two successive computations) is equal to 20 s. It means, that the trajectory length between two successive computations at a wind speed of 5 m/s is equal to 100 m, i.e. one tenth of the grid distance and the requirement of the overlapping is fulfilled if  $\sigma_{xy} > 50$

m. At lower wind speed the situation is even better but at higher wind speed the overlapping is less.



**Figure 3.5** Time integrated concentration as a function of puff positions in  $\sigma_{xy}$  units. (a) - 4 units, (b) - 3 units and (c) - 2 units. Continuous line - contribution from one puff, dotted line - sum of contributions. The maximum and minimum values are given as well.

When selecting the time parameters the following conditions must be taken into account:

- 1) NTADV ( $t_{adv}$ ) must be an integer in s
- 2) TAU (release period) must be an integer multiple of NTADV  
i.e. NTADV # TAU
- 3) ITSP (averaging time for wind observations) must be an integer multiple of TAU

4) MAPTIM (time between output of concentrations etc.) must be an integer multiple of ITSP

Further it must so that:

$$NTADV \leq \frac{\text{Min}(\Delta X_{\text{DetMin}}, 2 s_{xy}, \Delta G_{\text{Max}})}{U}$$

where

$$\Delta G_{\text{Max}} = 2 \sqrt{\Delta x^2 + \Delta y^2}$$

$\Delta x = \Delta y$  grid spacing

$\Delta X_{\text{DetMin}}$  minimum distance between detector points

U wind speed

As the calculation time is proportional to  $\frac{1}{\text{TAU} \times \text{NTADV}}$  and precision of calculation (smoothness of distributions) is determined by NTADV the most economical from point of view of calculation time is the choice of TAU equal to ITSP. Such a case is shown in Fig 3.6 (a) for two puffs released at the beginning of the first and second period of ITSP and travelling during two periods of ITSP. For wind directions changing significantly for two sequential ITSP periods can be remarked some uncovered by puffs area between two trajectories. The coverage can be significantly improved releasing two puffs during ITSP period as shown in Fig. 3.6 (b) and Fig. 3.7. In Fig. 3.8 show the dose (time integrated concentration) distributions for case of one (a), for two (b) and for four (c) and very large number (dotted line in c) of puffs released during one ITSP period. The dotted line describes the real situation in case of continuous release and therefore if we need dose distributions to be compared to measured one in real-time mode release of more puffs (4 or 5) during one ITSP period is recommended.

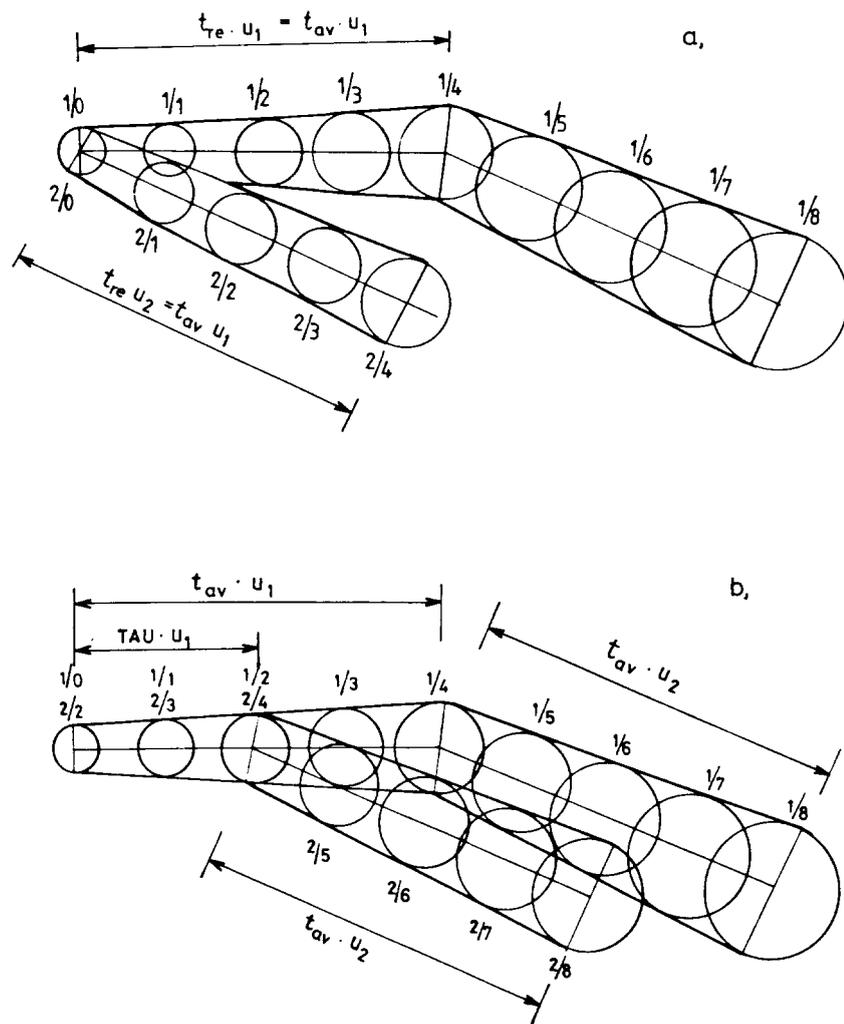
### 3.4 Minimum grid concentration of interest (CHEMIN)

An approach is to limit the integration of contributions from a puff to the area which contains a certain fraction of the puff mass, e.g. 95 %. The idea is to limit the integration of the puff contribution to air concentration and deposition to the horizontal distance  $R_{\text{max}}$  from the puff center. At  $R_{\text{max}}$  is the concentration reduced to the fraction CHEMIN of the center concentration.

The procedure to calculate  $R_{\text{max}}$  is as follows:

$$X_{\text{center}} = \frac{Q}{(2p)^{2/3} s_{xy}^2 s_z}$$

The center concentration of a puff is :

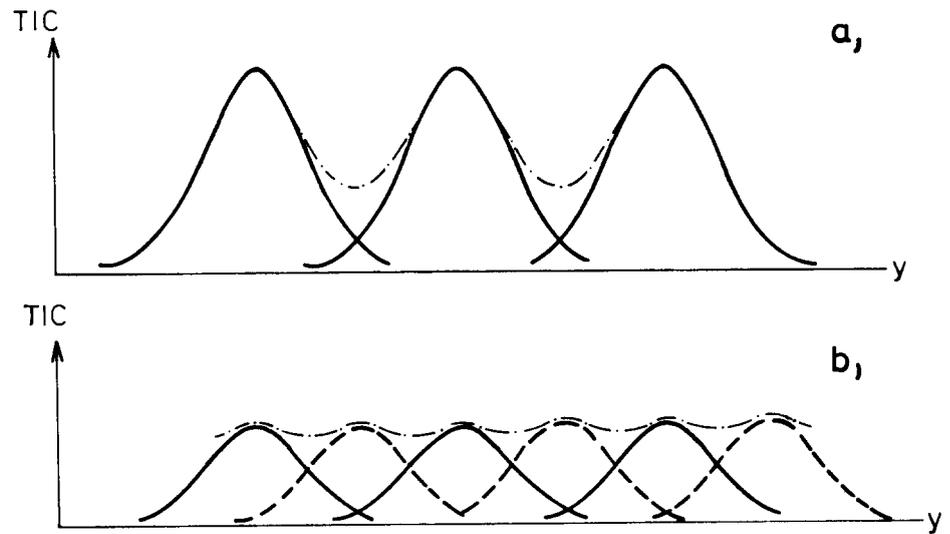


**Figure 3.6** Distribution of the puff positions used at calculations in case a) one puff is released during  $t_{av}$  and b) two puffs are released during  $t_{av}$

where

- $O_{center}$  Center concentration of puff
  - $Q$  Source term
  - $\Phi_{xy}$  Horizontal dispersion parameter
  - $\Phi_z$  Vertical dispersion parameter
- $R_{max}$  is found from:

$$C_{min} X_{center} = X_{center} e^{-\frac{R_{max}^2}{2s_{xy}^2}}$$



**Figure 3.7 Crosswind distribution of the dose** (time integrated concentration) in case a) one puff is released during  $t_{av}$  and b) two puffs are released during  $t_{av}$

where

$$C_{min} = CHEMIN \quad (0.0 < CHEMIN < 1.0)$$

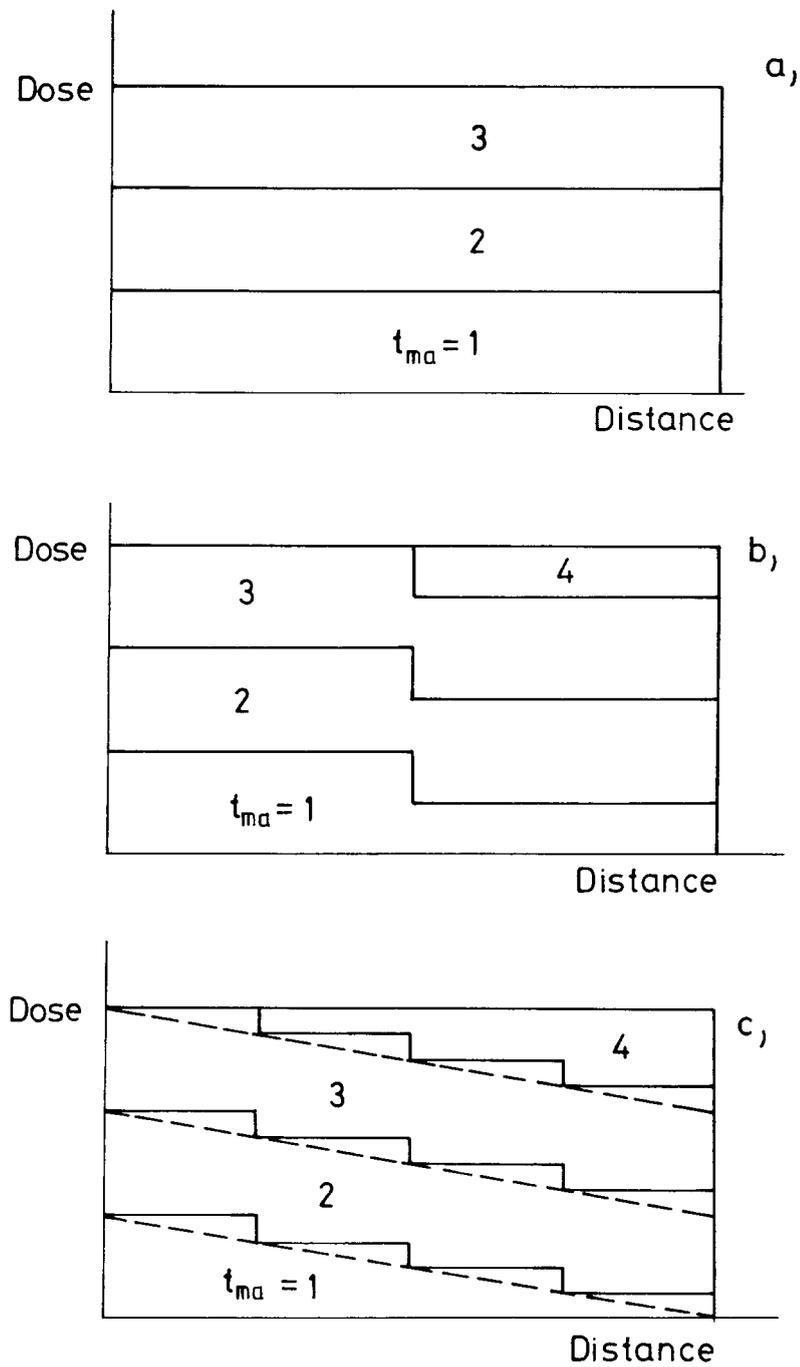
From the equation given above can be found that

$$R_{max} = s_{xy} \sqrt{-2 \ln(C_{min})}$$

Realistic values of CHEMIN this gives the following values of  $R_{max}$  :

CHEMIN	$R_{max}$ (unit: $\Phi_{xy}$ )	Mass of Puff within distance $R_{max}$ from the puff center
0.00001	4.799	1.0000
0.0001	4.292	1.0000
0.001	3.717	0.9998
0.01	3.035	0.9976
0.1	2.146	0.9681

From the table is concluded that CHEMIN = 0.001 is a reasonable choice taking account of almost all the mass within the puff using a reasonable CPU time.

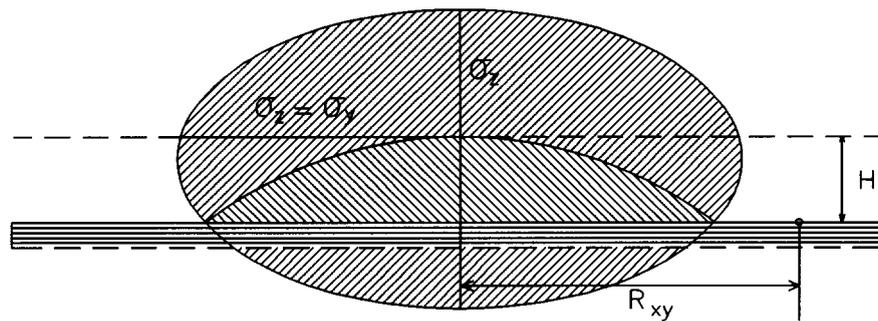


**Figure 3.8 Downwind distribution of the dose** (time integrated concentration) in case a) one puff is released during  $t_{av}$  and b) two puffs are released during  $t_{av}$  c) four puffs and very large number of puffs (dotted line) are released during  $t_{av}$

Gamma dose rate calculations

3.4.1 Gamma dose rate from a puff

Geometric arrangement for these calculations is illustrated in Fig.3.9. It is assumed that the ground surface is totally reflecting. Due to symmetry both the semi-infinite (with reflection) and the infinite (without ground reflection) dose models give the same gamma-dose rate at ground level.



**Figure 3.9 Geometric arrangement at the calculation of the gamma dose rate from Gaussian puff**

Using formula given in par. 2.7.1 for gamma dose rate from a point source and numerical integration method for full puff (Thykier-Nielsen, 1995) a data base containing the dose rates due to 1 MeV/s energy release was precalculated using the following set of numerical data:

- Q            1 Bq MeV/E<sub>γ</sub> where E<sub>γ</sub> is given in MeV (for the present case Q=5; 2; 1 and 0.5 Bq, respectively)
- E<sub>γ</sub>        0.2; 0.5; 1 and 2 MeV
- B            Capo's polynomials and Risø data for energy 0.2 MeV, from (Hademann-Jensen and Thykier-Nielsen, 1980)  
For B outside the range of approximation, i.e.,  
0 ≤ μr ≤ 7 for E<sub>γ</sub> = 0.2 MeV  
0 ≤ μr ≤ 20 for E<sub>γ</sub> > 0.2 MeV the last acceptable value has been used.
- σ<sub>y</sub>        range from 10 - to 2000 m (8 values)
- σ<sub>z</sub>        given as a function of σ<sub>y</sub> for a range of σ<sub>y</sub>/σ<sub>z</sub>, ie. the asymmetry factor, from 0.4 to 40 (11 values)
- H            range from 10 to 500 m (8 values)

$R_{xy}$	up to a distance where the dose rate decreases below 1% of dose rate at $R_{xy}=0$	
$\sigma_{en}$	data by Storm 1967 reproduced in (Lauridsen, 1982)	
$\mu$	for air data interpolated from (Thyker, 1978). The numerical values are:	
	0.2 MeV - $1.60 \times 10^{-2} \text{ m}^{-1}$	0.5 MeV - $1.14 \times 10^{-2} \text{ m}^{-1}$
	1.0 MeV - $8.30 \times 10^{-3} \text{ m}^{-1}$	2.0 MeV - $5.70 \times 10^{-3} \text{ m}^{-1}$

A precalculated database for radionuclides was also created using the photon energies and yields for isotopes as given in (Lauridsen, 1982). This isotope library contains the energy release rate for unit activity in 4 energy groups. These energy groups were taken around the nominal photon energies as follows:

Group	E nominal (MeV)	Energy range (MeV)
1	0.2	$\leq 0.35$
2	0.5	$> 0.35 \dots 0.75$
3	1.0	$> 0.74 \dots 1.5$
4	2.0	$> 1.5$

Using the isotope library and the dose rate values precalculated for the set of parameters mentioned above the dose module within the RIMPUFF works in the following way.

For a puff with actual values of  $\sigma_y$ ,  $\sigma_y/\sigma_z$ , H and  $R_{xy}$  (the latter related to the grid point of interest) an interpolation is made within the precalculated database in each energy group. Then the dose rate for an isotope is simply the sum of the 4 interpolated values multiplied by the energy released in the energy group in 1 s. The latter quantity is calculated based on the precalculated isotope library and the actual inventory of the puff for the isotope specified.

Outside the range of parameters used in precalculations the semi-infinite dose model is applied. The algorithm of turning to the semi-infinite model is as follows:

- if  $\sigma_y > 2000 \text{ m}$
- if  $H > 500 \text{ m}$
- if no precalculated dose rate exists for the actual radial distance of the receptor point
- if  $\sigma_z > H_{inv}$ , ie., the height of the inversion layer.

Dose conversion factors for cloud gamma dose rates calculated by the semi-infinite model were taken from (Jacob, et al, 1990).

### 3.4.2 Gamma dose rate from deposited activity

The dose rates of isotopes accumulated on ground surface due to dry and wet deposition are calculated from the amount of deposited activity and dose constants for semi-infinite plane source in every advection time step. Decay of isotopes as well as production of daughter elements on ground surface are taken into account. The list of isotopes for which calculations can be made is

$$\frac{dQ_i(t)}{dt} = -\lambda_i Q_i(t) + \lambda_i f_{ji} \sum_{j=1}^{i-1} Q_j(t) - G_i(t) Q_i(t)$$

given in Appendix.

Daughter element production on the ground is taken into account. Activity of mother and daughter elements as solutions to coupled differential equations of the type:

where

- t travel time
- $Q_i(t)$  amount of isotope no. i at time t
- $f_{ij}$  branching ratio for decay of isotope no. i leading to the formation of isotope no. j
- $\lambda_i$  decay constant for isotope no. i
- $G_i(t)$  production/depletion function for isotope no. i.
- i isotope no. The first isotope in a decay chain has no. 1, the next no. 2 and so on.

As an example, consider a single airborne isotope with no daughter

$$G_i(t) = \lambda_{i,rain}$$

products, subject to a constant wet deposition:

where  $\lambda_{i,rain}$  is the wet deposition constant for isotope no. i

Then

$$\frac{dQ_i(t)}{dt} = -\lambda_i Q_i(t) - \lambda_{i,rain} Q_i(t)$$

which gives

$$Q_i(t) = Q_i^0 e^{-(\lambda_i + \lambda_{i,rain})(t-t_0)}$$

where

$$Q_i^0 = Q_i(t = t_0)$$

Considering a single isotope decaying in a time interval  $\Delta t = t - t_0$  to daughter product, then amounts of mother and daughter product will be:

$$Q_M = Q_{M0} e^{-\lambda_M \Delta t}$$

$$Q_D = Q_{M0} \frac{\lambda_D}{\lambda_D - \lambda_M} (e^{-\lambda_M \Delta t} - e^{-\lambda_D \Delta t}) + Q_{D0} e^{-\lambda_D \Delta t}$$

where

$Q_{M0}$  and  $Q_{D0}$  activity of mother and daughter element respectively at time  $t_0$

$Q_M$  and  $Q_D$  activity of mother and daughter element respectively at time  $t$

$\lambda_M$  and  $\lambda_D$  decay constant of mother and daughter element respectively

Continuous deposition is calculated in discrete steps, i.e. it is assumed to happen in the middle of each advection time step. The dose rate is also calculated for this point of time. The dose conversion factors are taken from (Jacob, et al, 1990).

## 4 Set-up and data parameters

Remark: This description gives an overview of internal structure of the RIMPUFF module. Despite that most of listed parameters are fixed for the RODOS user they are described just for information of the user about the RIMPUFF features. The file names are used only internally and therefore in given context they are used only for better understanding of the internal structure.

Steps of the set-up procedures (See in User's Manual for the Atmospheric Dispersion Module: MET\_RODOS, RODOS(WG2)-TN(98)-05

- Prepare the grid size for your calculations. (In RODOS the grid size is 41x41 grad units with 0.5, 1 or 2 km mesh size)
- Define the lower left corner of the grid in UTM-co-ordinates.
- Define the co-ordinates of the source
- Define the co-ordinates of the detector points
- Landuse matrix (surface roughness and deposition velocities)

The RIMPUFF module uses the source provided by RODOS system and the meteorological fields (wind, stability and precipitation) produced by the other modules of the Local Scale Model Chain.

- Set up the RIMPAR parameters.
- Set up the WINPAR parameters.

### 4.1 User defined input

The user defined input data are specified in the RODOS input windows. All other steering parameters are supplied by the model chain or derived from these. Thus the user does not have to create any input files when running the RIMPUFF module inside the RODOS system.

In stand-alone mode, outside RODOS, RIMPUFF may use the so-called detector points. The positions of these points are specified in RIM-DET.DAT.

In the description of the input parameters, default values are given in parenthesis in **bold** style. In the case that no default value exist, there is written (**no**).

#### 4.1.1 Steering parameters

The input parameters could be divided into 3 groups:

- a. Those which could be defined directly by the user through RODOS input windows
- b. Those which come from the meteorological preprocessor

- c. Those which are derived from the parameters given above or set at fixed values for RODOS

4.1.2 User Specified Input Parameters

**CHEMIN** REAL Minimum relative concentration of interest.  
 Use a realistic value, e.g. as described in 3.5.2 . A very low value will increase computing time drastically (the contributions of the puffs will be integrated over the whole grid !).

**(0.001)**

**ISMODE** INTEGER Stability index mode  
 directing the computation of lateral and vertical standard deviation of each puff **(1)**

The following values of ISMODE are permitted for RIMPUFF:

ISMODE	Sigma-Y	Sigma-Z
1*	Pasquill Turner {A,B...F}	Pasquill Turner {A,B...F}
2	Pasquill Turner {A,B...F}	Vertical direction deviation
3	Lateral direction deviation	Pasquill Turner {A,B...F}
4	Lateral direction deviation	Vertical direction deviation
5*	Similarity Approach	Similarity Approach
6*	German-French Commission	Similarity Approach

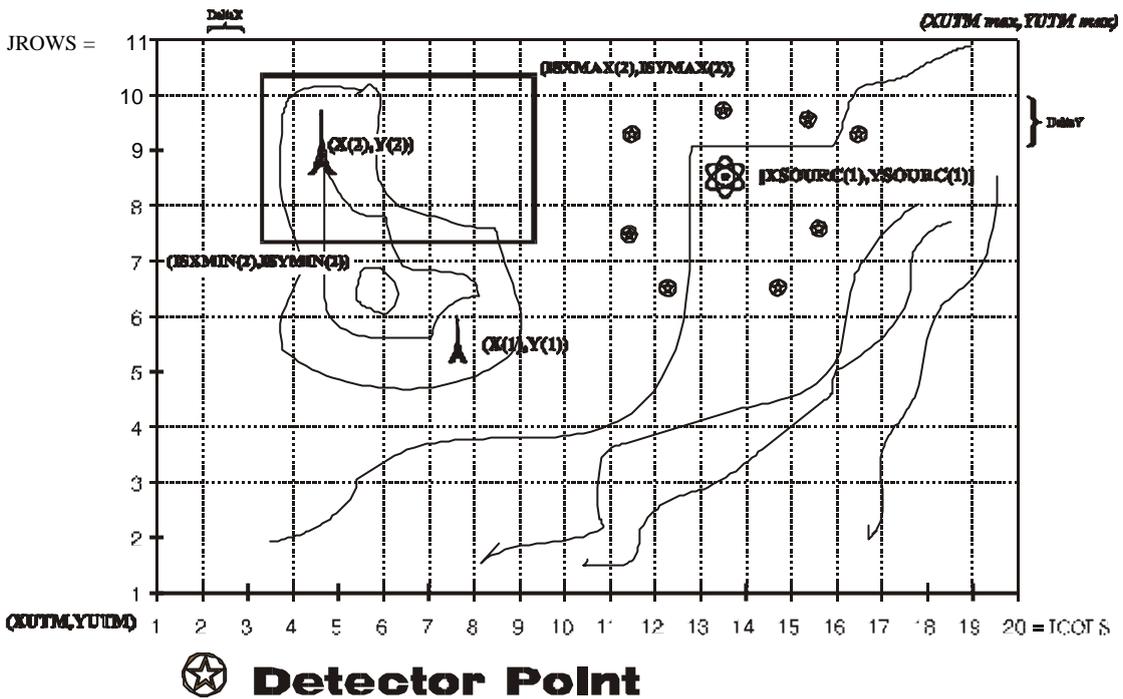
\*Remark: At version RODOS 4.0 only 1, 5 and 6 ISMODE are permitted

The present dispersion coefficients for the modified Pasquill Turner categories are given in table 2.3.

**IPENTPF** INTEGER 1 or 0  
 1: Pentafurcation of puffs (Use only for very complex terrain)  
 0: No pentafurcation

**SYMPEN** REAL Minimum  $\sigma_{xy}$  value for pentafurcation in m **(300)**

<b>IDETPKT</b>	INTEGER	<p><b>1</b> or <b>0</b></p> <p><b>1</b> : Doses/Concentrations in specific detector points are calculated and written on the output file for each MAPTIM.</p> <p><b>0</b> : NO calculation of Doses/Concentrations in detector points (<b>0</b>).</p> <p>Data for detector points</p> <p>If IDETPKT = 1 then the data for the detector points (Fig. 4.1) should be given in the file <b>RIMDET.DAT</b> using UTM co-ordinates.</p>
<b>IOUTDET</b>	INTEGER	<p><b>1</b> or <b>0</b></p> <p><b>1</b> : Create files with concentration/doses in air for the detector points.</p> <p>The following files are created:</p> <p>OUTP_A.DAT: Time integrated concentration in air</p> <p>OUTP_D.DAT: Concentration on the ground</p> <p>OUTP_GP.DAT: Gamma doses from puffs</p> <p>OUTP_GD.DAT: Gamma doses from deposited material</p> <p><b>0</b> : No files with concentration/doses in detector points. (<b>0</b>)</p>
<b>IOUTDET</b>	INTEGER	<p><b>1</b> or <b>0</b></p> <p><b>1</b> : Create files with concentration/doses in air for the detector points.</p> <p>The following files are created:</p> <p>OUTP_A.DAT: Time integrated concentration in air</p> <p>OUTP_D.DAT: Concentration on the ground</p> <p>OUTP_GP.DAT: Gamma doses from puffs</p> <p>OUTP_GD.DAT: Gamma doses from deposited material</p> <p><b>0</b> : No files with concentration/doses in detector points. (<b>0</b>)</p>



**Figure 4.1 Grid system layout.** The positions of the source, the grid points and meteorological towers are shown.

<b>IdryField</b>	INTEGER	<b>0 or 1</b>
		<b>1:</b> Take account of land-use when calculating dry-deposition.
		<b>0:</b> The dry deposition rates are independent of surface type ( <b>0</b> ).

*4.1.3 Input parameters provided by the Model Chain*

*Grid Parameters and Source Location*

The following parameters have to be defined in RIMPUFF:

<b>ICOLS</b>	INTEGER	Number of columns in the concentration grid 1 # ICOLS # 41 ( <b>41</b> )
<b>JROWS</b>	INTEGER	Number of rows in the concentration grid 1 # JROWS # 41 ( <b>41</b> )
<b>DELX</b>	REAL	Horizontal grid size (m) ( <b>1000</b> )

<b>DELY</b>	REAL	Lateral grid size (m) ( <b>1000</b> )
<b>KOORD</b>	INTEGER	Selector for coordinate system = 0 : Grid units = 1 : UTM-coordinates ( <i>recommended</i> )
<b>Iz_UTM</b>	INTEGER	UTM zone used for the grid DEFAULT value: <b>32</b>
<b>XUTM_R</b>	REAL	X coordinate for lower left corner of grid in the UTM coordinate system. Unit: km DEFAULT value: <b>0.0</b>
<b>YUTM_R</b>	REAL	Y coordinate for lower left corner of grid in the UTM -coordinate system. Unit: km DEFAULT value: <b>0.0</b>
<b>XSOURC</b>	REAL	X-coordinate of source in km in the UTM-coordinate system <b>(no, site specific!)</b>
<b>YSOURC</b>	REAL	Y-coordinate of source in km in the UTM-coordinate system <b>(no, site specific!)</b>

From LSMC is calculated:

Icols = NCOLS

Jrows = NROWS

KOORD = 1                   !UTM coordinate system

Iz\_UTM = IZUTM           !LSMC provides the UTM zone

Delx = DXCELL

Dely = DYCELL

XUTM\_R = Xori/1000.

YUTM\_R = Yori/1000.

NRMULT = NSRC       ! No. of sources (from LSMC)

```

Xsourc(1) = XSRC(1)/1000.    ! from LSMC
Ysourc(1) = YSRC(1)/1000.    ! from LSMC

NFX      =   ICOLS
NFY      =   JROWS
    
```

#### 4.1.4 Source Specification

Based on the source data provided by the RODOS system, an internal source file for RIMPUFF is generated. This file contains the time series of releases from source no. 1 (only one source is permitted in this version of the RIMPUFF module).

```

<Start of 1. Release Sequence [s]>, <Duration of 1. Release Sequence [s]>
<Release height [m]>, <Heat content of source [kW]>
<Fraction of Iodine, Elementary>, <Fraction of Iodine, Organic>, <Fraction
of Iodine, Aerosol>
<isotope no.>, <Release of Isotope [Bq/s]>
<isotope no.>, <Release of Isotope [Bq/s]>
<isotope no.>, <Release of Isotope [Bq/s]>
.....
-1, 0.
<Start of 2. Release Sequence [s]>, <Duration of 2. Release Sequence [s]>
<Fraction of Iodine, Elementary>, <Fraction of Iodine, Organic>, <Fraction
of Iodine, Aerosol>
<isotope no.>, <Release of Isotope [Bq/s]>
<isotope no.>, <Release of Isotope [Bq/s]>
<isotope no.>, <Release of Isotope [Bq/s]>
.....
-1, 0.
.....
.....
<End of all Release Sequences [s]>, -1
    
```

The isotope numbers are those given in Appendix.  
 Please note the following:

Supposing the release times are: t1, t2, t3 etc.

and the durations of the releases are: tdel1, tdel2, tdel3 etc.

Then it should be so that

t1 + tdel1 # t2

t2 + tdel2 # t3

etc.

The numbers of the isotopes specified for the given release scenario is provided through an internal file called RIMISO.DAT . The format of the file is:

<isotope no.>

<isotope no.>

<isotope no.>

.....

-1

The file is a free field ASCII file.

Maximum **15** isotopes could be specified. The isotope number should be taken from the list given in Appendix.

Meteorological Data

From LSMC the following fields are provided:

Boundary layer height:     ABL\_GR = hmixG

Wind field:                 UGR = UGRD

                              VGR = VGRD

Rain fields:                RainGr = preciG

Depending on stability mode (ISMOD) the following stability data are given:

ISMOD = 1 :                 istab = istabG

ISMOD = 5 : Friction velocity:     Ustar\_grd = UstarG

Inverse Monin-Obukhov Length:   smoli\_grd = SmoliG

All these fields are given for each meteorological data step:

ITSP = idtupd \* 60   ! time between met data in seconds

Further the surface roughness field is given as:

Zrough\_grd = zrgh

4.1.5 Deposition

The present version of the RIMPUFF module use the deposition parameters given in p. 2.6

#### 4.1.6 Puff Advection

The data relevant for puff advection are:

**NTADV**      INTEGER      Number of seconds between each advection step (**20**)

**TAU**      INTEGER      Number of seconds between puff releases.  
 TAU must be an integer multiple of NTADV (**300**) Remember that max. number of puffs in the grid any time must be less than 675. To obtain reasonable computing times the number of puffs must be less than 100

In the RIMPUFF module they are calculated from time interval for meteorological data, as follows:

```

If (900.LE.ITSP) THEN
AU = ITSP/3
ELSE
TAU = ITSP
EndIf
  
```

```

NTADV = Min(TAU/10,60)
  
```

Further the reflection factor should be specified:

**REFLEC**      REAL      Reflection factor for doses/concentrations from each puff.  
 0.0 # REFLEC # 1.0  
 (**1.0**) (full reflection)

In the RIMPUFF module is used:

**REFLEC**      = **1.0** i.e. full reflection

#### 4.1.7 Dose parameters

Air concentrations at ground level are always calculated. RIMPUFF contains the following parameters for specification of the types of calculations to be performed:

<b>DEPMOD</b>	INTEGER	Switch for deposition. DEPMOD = 0 : No deposition DEPMOD = 1 : Dry and wet deposition (1)
<b>IGAMMOD</b>	INTEGER	Calculation of gamma doses from puffs = 0: No calculation of gamma doses from puffs = 1: Calculation of gamma doses from puffs (1)
<b>IGAMDEP</b>	INTEGER	Gamma doses from deposited activity 0 : No gamma doses from deposited activity 1 : Gamma doses from deposited activity (1)
<b>MAPTIM</b>	INTEGER	Number of seconds between the output of concentration- and wind-fields to printer and disk-file. At each MAPTIM the dose rate is calculated as an average over the last advection step.

In the RIMPUFF module the following values are used:

<b>DEPMOD</b>	= 1: Dry and wet deposition
<b>IGAMMOD</b>	= 1: Calculation of gamma doses from puffs
<b>IGAMDEP</b>	= 1 : Gamma doses from deposited activity
<b>MAPTIM</b>	= MAPTM ( from LSMC)

Note that RIMPUFF calculates gamma doses in air. The “so-called” gamma dispersion factors are calculated by the interface to the RODOS system.

#### 4.1.8 Other steering parameters

<b>Iexit_table</b>	= 1 : Table of puffs leaving the grid area, to be used in connection with the <b>MATCH</b> model.
<b>IWSFOLD</b>	= 0 : No modification of wind speed according to vertical concentration distribution.

#### 4.1.9 Source Data

The source data are transferred to RIMPUFF via the file **RIMSRC.DAT** using the internal RIMPUFF isotope numbers from the list given in Appendix.

#### 4.1.10 Source geometry

**SIGYIN** = 1.0 : Initial value of sigma-y in meters. Must be  $\geq 1$  m (**1**)

**SIGZIN** = 1.0 : Initial value of sigma-z in meters. Must be  $\geq 1$  m (**1**)

4.1.11 Wind Sped profile

RIMPUFF normally uses a wind sped profile derived from similarity theory. However, when using Pasquill categories the wind speed at height h (h > 10

$$u_h = u_{10} * \left(\frac{h}{10}\right)^{p_u}$$

m) is calculated from:

where u<sub>10</sub> is the wind speed at 10 m height (Päsler-Sauer, 1985b).

Values are taken from the values given below:

Wind speed profile used at calculation of the wind speed shear

Stability	A	B	C	D	E	F
p <sub>u</sub>	0.07	0.13	0.21	0.34	0.44	0.44

Detector points

Detector points is provided to RIMPUFF via the file RIMDET.DAT

The format of this file is:

**NDET**

```
< X-coordinate for point no. 1 > , < Y-coordinate for point no. 1 >
< X-coordinate for point no. 2 > , < Y-coordinate for point no. 2 >
.....
< X-coordinate for point no. NDET > , < Y-coordinate for point no.
NDET>
```

where

**NDET**

INTEGER Number of detector points for dose/concentration calculations

$$0 < \text{NDET} \# 200 \text{ (0)}$$

The coordinates should be given in **metres**, using UTM or similar coordinate system..

Basic data files for isotopes

A sub-directory contains files with data for the isotopes used in RIMPUFF. The files are:

ACTIDA.DAT                      Decay chain data for actinides

Flib.dat	Decay chain data for fission products
Rpgamdata.DAT	Gamma dose constants for isotopes
Rpisodata.DAT	Basic isotope data

These data can not be changed by the user !

## 4.2 Description of the grid files

RIMPUFF's output is primarily 2 dimensional data matrices which are provided to the RODOS system via a post-processor. The values are concentrations/doses in the lower left **corner** of each grid mesh.

The common principle for output files used in real-time mode that only the time integrated values are included into the output files of Dispersion Module, all momentary values can be calculated as a difference for period  $i$  and  $i+1$ .

For debugging purposes, it is however possible to get output on the so-called GRD files.

If **IOUTGRD=1** then the following ASCII .GRD files are created:

Conc_<Isn>_<t>.GRD:	concentrations in air at ground level
Depos_<Isn>_<t>.GRD:	concentrations of deposited material
Gampuf_<Isn>_<t>.GRD:	gamma doses from puffs
Gamdep_<Isn>_<t>.GRD:	gamma doses from deposited activity
Gampuf_Inst_<Isn>_<t>.GRD:	gamma dose rates from puffs

*Isn* is the Isotope name (see Appendix 1).

*t* is the time in format *yyyymmddhhiiss* , where

*yyyy* is the year

*mm* is the month

*dd* is the day

*hh* is the hour

*ii* is the minute

*ss* is the second

The layout of the files is:

DSAA

<Number of X-values> <Number of Y-values>

<Minimum X-value for Grid> <Maximum X-value for Grid>

<Minimum Y-value for Grid> <Maximum Y-value for Grid>

<Minimum Z-value for Grid> <Maximum Z-value for Grid>

$\langle Z[I,J], I=1,IMAX, J=1,JMAX \rangle$

where  $Z[i,j]$  are the concentrations or doses in the grid points.

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**APPENDIX List of isotopes selectable for RIMPUFF runs**

No.	Isotope	No.	Isotope
1	Na-24	33	Te-132
2	Co-58	34	Te-133m
3	Co-60	35	Te-133
4	Kr-85m	36	Te-134
5	Kr-85	37	I-129
6	Kr-87	38	I-131
7	Kr-88	39	I-132
8	Rb-86	40	I-133
9	Rb-88	41	I-134
10	Sr-89	42	I-135
11	Sr-90	43	Xe-133
12	Sr-91	44	Xe-135
13	Sr-92	45	Xe-138
14	Y-90	46	Cs-134
15	Y-91	47	Cs-136
16	Zr-96	48	Cs-137
17	Zr-97	49	Cs-138
18	Nb-95	50	Ba-140
19	Mo-99	51	La-140
20	Tc-99m	52	Ce-141
21	Ru-103	53	Ce-143
22	Ru-105	54	Ce-144
23	Ru-106	55	Pr-143
24	Rh-105	56	Nd-147
25	Sb-127	57	Np-239
26	Sb-129	58	Pu-238
27	Te-127m	59	Pu-239
28	Te-127	60	Pu-240
29	Te-129m	61	Pu-241

No.	Isotope	No.	Isotope
30	Te-129	62	Am-241
31	Te-131	63	Cm-242
32	Te-131m	64	Cm-244

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