

For ground level concentrations at the cloud centre-line

$$C(0,0,0) = \frac{2Q}{(2\pi)^{1/2} u_1 \sigma_x \sigma_y \sigma_z}$$

Continuous Case

For a release at ground level:

$$C(x,y,z) = \frac{Q}{\pi u_1 \sigma_y \sigma_z} \exp - \left[ \frac{1}{2} \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2} \right]$$

where the origin is now the source position, Q is the rate of release and  $u_1$  the windspeed.

On the plume centreline, at the surface, this reduces to:

$$C(x) = \frac{Q}{\pi u_1 \sigma_y \sigma_z}$$

In the above equations, it should be noted that absorption at the surface has been assumed zero, such that the plume is "reflected" at the surface. This may be pessimistic for some cloud materials.

The standard atmospheric dispersion parameters describe the increase in the cloud radius as the cloud drifts downwind. Simple formulae of the type

$$\sigma_y = ax^b \quad \text{and}$$

$$\sigma_z = cx^d$$

have been proposed to describe the increase in standard deviation. Table 4.1 overleaf shows suggested values proposed by TNO for the parameters a, b, c and d valid for conditions where the downwind distance exceeds 100m.

**TABLE 4.1 : ATMOSPHERIC DISPERSION PARAMETERS**

	Parameter /Category	a	b	c	d
very un-stable	(A)	0.527	0.865	0.28	0.90
unstable	(B)	0.371	0.866	0.23	0.85
slightly unstable	(C)	0.209	0.897	0.22	0.80
neutral	(D)	0.128	0.905	0.20	0.76
stable	(E)	0.098	0.902	0.15	0.73
very stable	(F)	0.065	0.902	0.12	0.67

To match the initial source conditions either the cloud size or the initial concentration may be used by selecting a suitable point on the x-axis as the "virtual source" location for the purposes of determining the standard dispersion parameters, since the latter are defined as functions of downwind distance in standard formulations of the Pasquill stability categories.

**Outputs**

The model gives cloud concentrations, both for instantaneous and continuous releases.

**Inputs**

- (i) Released mass
- (ii) Dispersion parameters
- (iii) Windspeed.

**Assumptions and Constraints**

The dispersion is based upon the assumption of Gaussian distributions of turbulence in the atmospheric boundary layer.

**Accuracy**

Subject to a relevant selection of wind speed and stability category short term average concentrations of pollutants may be estimated within at least a factor of two of the experiment. This degree of precision is generally satisfactory for the purposes of an hazard assessment. However, due to limits in the applicability of dispersion coefficients, the methods are generally applied to downwind distances in excess of 100m and less than 100km from the point of discharge.

**Application**

The method determines the concentration distribution of clouds of neutral density.

#### 4.3.3

#### BUOYANT SURFACE RELEASE

**METHOD:** Briggs Plume Rise Model.  
**OUTPUT:** Release height estimate.  
**CONSTRAINTS:** Based upon empirical observations.

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##### The Method

For a surface release of buoyant material, it is not necessarily clear that the material will lift off the surface under the action of buoyancy forces. The effects of turbulence, which may be intense near the ground due to friction effects and obstacles may be dominant. For the cloud to lift off, the lower parts of the cloud edges must move inwards due to the external hydrostatic pressure acting against the spreading influence of the turbulent dispersion. Briggs (1976) has suggested that a criterion may be developed by comparing a characteristic lateral turbulent spreading velocity with a characteristic inward movement associated with buoyancy. This arises from considerations of the drawing in of the cloud sides near the surface as the bulk of the cloud starts to rise.

Briggs takes  $[G H (D_p - D_a)/D_a]^{1/2}$  as the latter value and the friction velocity  $U_f$ , as the former, but other criteria could be devised. Briggs therefore defines a parameter

$$L_p = \frac{G H (D_p - D_a)}{D_a U_f^2}$$

and he finds that lift off occurs when this is greater than about 2.5 for instantaneous releases of roughly hemispherical shape and for continuous releases of roughly semi-cylindrical shape at the ground. It should be noted, however, that the critical value could be different, but in the absence of other information to the contrary, the same value of 2.5 is generally adopted for both cases.

If the cloud lifts off, the trajectory and dispersion may be predicted using the passive dispersion model or a conventional plume rise formula (e.g. Briggs, 1969) applied with a Gaussian dispersion model such as described above.

**Assumptions**  
**and**  
**Constraints**

If the cloud does not lift off, it can only be treated as a passive tracer using the appropriate dispersion models, e.g. the Gaussian model, for which relevant equations are given above.

#### 4.4 Fires

The radiation effect of fires is normally limited to areas close to the source of the hydrocarbon (say within 200m). In many cases, this means that surrounding communities are not affected. However, there are some types of fire which would have a more pervasive effect. The means by which the various types of fire may be analysed is described below.

Fires may be categorised as follows:

- **Pool fire** (e.g. a tank fire or fire from a pool of fuel spread over the ground or water).
- **Jet fire** from the ignition of jets of hydrocarbons or other flammable materials.
- **BLEVE** (Boiling Liquid Expanding Vapour Explosion) resulting from the overheating of a pressurised vessel by more minor primary fire which causes the vessel to explode and a large and very intense fireball to be produced.
- **Flash Fire** involving the ignition of a vapour cloud which does not explode. That is, the flame speed is not high, but the fire spreads quickly throughout the flammable zone of the cloud.

Fires affect the surrounding environment primarily through the radiated heat which is emitted. If the level of heat radiation is high enough other objects which are flammable may themselves be ignited. Alternatively, living organisms may be burned by heat radiation and thereby suffer either injury or death.

The damage associated with heat radiation may be assessed on the basis of the dose of radiation received. A measure of the received dose is the energy per unit area of the surface exposed to the radiation and the exposure duration. Alternatively, the likely effect of radiation may be estimated by using the power per unit area received. This latter approach is particularly relevant where the equilibrium between the power received and the power absorbed dictates the degree of damage that may encountered.

Simplified models for the assessment of pool, jet, BLEVE and flash fires are given in the following sections. A summary of some potential sources of ignition is given in Appendix 3.

#### 4.4.1

#### POOL FIRES

**METHOD:** Use of classical empirical equations to determine burning rates, heat radiation and incident heat. The intensity is matched to likely damage levels by reference to historic and other data.

**OUTPUT:** Heat intensity and thereby an indication of the potential to cause damage/casualties.

**CONSTRAINTS:** This empirical model for calculating the form of the fire has only been validated for relatively small fires.

#### The Method

The model employed in the estimation of pool fires is derived from those indicated by TNO and involves the use of classical empirical equations to determine burning rates, heat radiation and incident heat. Some of the latter equations are related to hypothetical pool fires of infinitely large radius.

The rate of burning of the liquid surface per unit area for liquids having boiling points above ambient temperature is given by:

$$\frac{dm}{dt} = \frac{0.001 H_c}{C_p(T_b - T_a) + H_{vap}}$$

On the other hand, for liquids with boiling points below room temperature, the expression is:

$$\frac{dm}{dt} = \frac{0.001 H_c}{H_{vap}}$$

The heat flux is given by:

$$q = H_c \frac{dm}{dt} X_E$$

where  $H_c$  is the heat of combustion and  $X_E$  is the fraction of heat produced as radiation.

$X_E$  normally takes a value in the range 0.13 to 0.35; in the absence of better data, the value 0.35 may be used to provide conservative estimates of heat flux for pool fires. When the heat flux at the surface of the pool fire has been calculated, the heat incident upon nearby objects may then be determined. A simplified method assumes that all the heat is radiated from a small vertical surface at the centre of the pool. For a ground pool, the heat incidence at a distance,  $r$ , from the pool centre is given by:

$$I = \frac{T q}{4 \pi r^2}$$

where  $T$  is the transmissivity of the air path and the other parameters are as defined elsewhere. In the absence of good data to the contrary, the transmissivity is set to unity; this gives conservative results.

#### Outputs

The method provides reasonable estimates of radiative flux in the event of a pool fire.

#### Inputs

- (i) Thermophysical properties for the materials of interest
- (ii) Fraction of heat liberated as radiation
- (iii) Transmissivity of the air path to a receiver.

#### Assumptions and Constraints

These methods are based upon empirical correlations.

#### Accuracy

Generally considered valid to be for the types of pool fires which might give rise to off-site impacts.

#### Application

This method may be applied to the estimation of effects of pools of fuel which ignite including tank fires and spreading pools on land or water.



#### 4.4.2

#### JET FIRES

**METHOD:** Use of jet dispersion model to determine flame size and radiation formula to determine intensity.

**OUTPUT:** Heat intensities and potential to cause damage/casualties.

**CONSTRAINTS:** Estimated radiation levels close to the base of the flame may be subject to error due to flame lift-off at the source.

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#### The Method

The model employed in estimating thermal radiation effects from jet flames is an extension, developed by the American Petroleum Institute, of the model used for jet dispersion including wind effects (API RP521, "Flare Radiation"). The flame is considered to be in the form of a series of point sources spaced along the centre line of the jet with all sources radiating equal quantities of heat  $q'$ .

The radiation  $I$  from a particular point in the flame to a receptor at distance,  $r$ , can be taken as:

$$I = \frac{X_g q'}{4 \pi r^2}$$

where  $r$  is the distance from the point and  $X_g$  is an emissivity factor dependent on the nature of the combustible material involved in the flame. A value of  $X_g$  of 0.2 is suggested for jet fires. To calculate the power radiated to a receptor point, the flame is represented by selecting a number of locations along its central axis.

These are assumed to be point sources of radiation whose total power output equals that of the flame. The power incident at a

receptor point is then evaluated as the sum of power from all of these points within the flame. A more complex jet dispersion model naturally involves more complex jet shapes and requires the use of a computer program to calculate appropriate "view factors". The latter are the integrals of the visible surface of a particular flame with respect to the various receptors of radiation). Tables of view factors are available but it is not usually considered necessary to use them in an initial hazard analysis because the simpler expressions outlined here generally are adequate for these purposes.

**Outputs**

The calculations produce an estimate of the radiative heat flux which is received at a plane with a defined inclination to the flame.

**Inputs**

- (i) Fuel input rate
- (ii) Length of jet
- (iii) Distance and orientation of receptor

**Assumptions  
and  
Constraints**

It is generally assumed for convenience that the flame will have approximately the same length as an unignited jet. If detailed radiation envelopes are required, the iterative procedures necessary to accomplish the calculations are best conducted by computer.

**Accuracy**

The method is not accurate at the base of a flame if lift-off of the flame occurs. These conditions are likely to arise when high pressure jets are under consideration. For large flames an additional allowance for an extended flame shape due to flame 'thrust' may be needed over and above the estimates based on unignited jets. Conservative estimates are generally obtained if a flame thrust factor of 1.5 times the distance to LFL is used.

**Application**

These simplified methods may be used to estimate radiation levels from jet releases of flammable material.

#### 4.4.3

#### FIREBALLS

**METHOD:** Empirical Correlation of fireball radius based upon work by the American Petroleum Institute.  
**OUTPUT:** Fireball radius and heat flux.  
**CONSTRAINTS:** Applicable to fireballs occurring in the outdoor environment.

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##### The Method

Both the radiation intensity at a distance from the fireball centre and the duration of the fireball can be determined using a very simple calculation. The maximum radius of the fireball is given by:

$$R_f = 2.665 M^{0.327} \text{ (in m.)}$$

where M is the flammable release mass in kilogrammes.

The fireball has a duration of  $t_f$  seconds where

$$t_f = 1.089 M^{0.327} \text{ (in seconds).}$$

The release of energy by combustion is then given by:

$$K = \frac{H_c M^{0.637}}{1.089}$$

So the radiation flux, I, at a distance r is given by:

$$I = \frac{K X_E T}{4 \pi r^2}$$

The fireball duration and diameter expressions used above are those proposed in a recent review of fireball models. (API RP521 "Flare Radiation").

<u>Output</u>	This method gives the radiation intensity at specified distances from the centre of the fireball and permits an estimation to be made of the fireball duration.
<u>Input</u>	Mass of release and heat of combustion.
<u>Accuracy</u>	These methods are based upon empirical correlations which may be updated from time to time in the light of new evidence. The methods are considered to be adequate for an initial hazard assessment using current state of the art techniques.
<u>Assumptions and Constraints</u>	As indicated elsewhere.
<u>Application</u>	These methods may be used to estimate the effect distance and range of fireball impacts within the ranges inherent in the API review API RP 521.

#### 4.4.4

#### FLASH FIRES

**METHOD:** The gas dispersion models described previously are applied directly  
**OUTPUT:** Extent of flash fire  
**CONSTRAINTS:** As for dispersion models

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##### The Method

It is generally assumed that a flash fire spreads throughout that part of the vapour cloud which is above LFL. There is, however, little information on the effects of a flash fire on people. The dispersion calculations presented previously may be used to establish UFL and LFL contours. Subject to ignition of the cloud, the conservative assumption is generally made that all of the people outside buildings, but in areas between these contours are considered, to be killed; of the people inside buildings, a fraction,  $f$ , may be assumed to be killed. In an initial hazard assessment and in the absence of other information,  $f$  is usually taken to be zero.

For a more detailed analysis, the effects of the vapour cloud igniting taking into account the various atmospheric conditions which may be encountered at several different times after release should be examined.

##### Outputs

This method yields the extent of potential flash fires and provides broadly conservative estimates of the expected fatalities.

##### Inputs

- (i) Cloud density profile from previous dispersion calculations.
- (ii) Flammability limits.

##### Assumptions and Constraints

The method assumes that significant overpressures do not occur and includes only an approximate assumption about the magnitude of the potential impacts.

<u>Accuracy</u>	Not known but considered to be adequate for the purpose of an initial hazard analysis.
<u>Application</u>	This method is applicable to flash fire scenarios which may be encountered in open terrain.

#### 4.4.5

#### FIRE DAMAGE

**METHOD:** Fire damage estimates are based upon correlations with recorded incident radiation flux and damage levels

**OUTPUT:** Indication of damage as a function of incident radiation

**CONSTRAINTS:** Since damage estimates are based upon empirical evidence the damage response characteristics should be updated as and when new evidence comes to light.

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#### The Method

Various tables have been created to set up criteria for damage to people and property from fire. Sometimes they are expressed in terms of radiation intensity and sometimes as a power dosage. The effect on buildings, natural surroundings and equipment is measured in terms of the likelihood of ignition, particularly if wooden structures or buildings are in the vicinity. Spontaneous and flame-induced ignition values can be considered for various levels of radiation. The radiative or incident fluxes recorded in Tables 4.2 overleaf are related to the levels of damage and impact upon people, including plant personnel, based upon observations arising from actual incidents and large fires.

#### Outputs

The method provides estimates of fire damage, fatalities and injuries.

#### Inputs

(i) Estimates of thermal flux at selected receptor points using appropriate fire models described in previous sections.

TABLE 4.2 : DAMAGE CAUSED AT VARIOUS INCIDENT LEVELS OF THERMAL RADIATION

INCIDENT FLUX (kW/m <sup>2</sup> )	TYPE OF DAMAGE CAUSED
37.5	Sufficient to cause damage to process equipment. 100% lethality.
25	Minimum energy required to ignite wood at infinitely long exposures. (non piloted). 100% lethality.
12.5	Minimum energy required for piloted ignition of wood, melting plastic tubing. 100% lethality.
4	Sufficient to cause pain to personnel if unable to reach cover within 20s; however, blistering of skin (1st degree burns) is likely. 0% lethality.
1.6	Will cause no discomfort for long exposure

Assumptions  
and  
Constraints

At the lower levels, where time is required to cause serious injury to people, there is often the possibility to escape or take shelter.

Accuracy

The accuracy of the incident flux damage relationships is considered to be adequate for initial hazard assessments and within the estimation of hazardous incidents.

Application

The correlations of thermally induced damage or injury may be applied to hazard assessment.



#### 4.5 Explosions

An explosion is a sudden release of energy in a material, its violence depending on the rate of energy release. Considering explosions in the most general sense the types involved in hazardous installations may include the release of both physical or chemical energy.

Where chemical energy is involved, there are two main types of explosions which are of importance to the process industries. These are deflagrations, in which the flame front travels relatively slowly through the combustible material, and detonations, in which the flame front becomes coupled with a shock wave which is travelling faster than the speed of sound into the combustible gases. A deflagration may turn into a detonation, if the source of ignition is strong, or if the combustible gases are in a confined or semi-confined area and a sufficient 'run up' distance is available.

It should be noted that an explosion is one of the two possible results of ignition in a flammable release, the other being a flash fire. The probability split between the two events is a matter for these analyst's judgement. Typically, for those situations where a delayed ignition could occur a reasonable assumption, in the absence of data of the contrary, is that approximately 15% of the releases could result in explosion characteristics, with the remainder being in the form of flash fires.

One major consideration in analysing explosions is to consider whether the explosion is essentially confined or whether it is unconfined. An explosion within a vessel is obviously confined and the effects of these are treated separately below.

By definition, an unconfined explosion is one in which a gas cloud is formed on flat ground with no significant structures or obstructions which would tend to restrict the expansion of the burning cloud. An explosion of a vapour cloud in this manner is referred to as an Unconfined Vapour Cloud Explosion (UVCE).

A confined explosion may also be encountered when there is a significant amount to 'obstruction' of the expansion of the burning gas or vapour cloud in more than one dimension (i.e. more than by the surface on which the gas has spread). Typically, a confined explosion may occur in built up areas particularly where buildings or structures are present.

A number of attempts have been made to analyse the behaviour of flammable mixtures under explosion conditions to provide a general theoretical interpretation of such processes. These have not been very successful largely because of the uncertainties in adequately describing the condition of the explosible gas mixtures prior to ignition and the complex coupling between turbulence, shock waves and flame speed. A more pragmatic approach is to adopt correlation methods based on field studies with well defined explosible materials. The correlation methods are adopted in this manual.

An explosion within a vessel manifests its effects by the properties and fragments which it produces. An approximate method for estimating the sizes, velocities and distances reached by such projectiles has been included in this section for completeness.

#### 4.5.1

#### EXPLOSION CORRELATION

**METHOD:** Correlation of damage produced with energy of explosion.  
**OUTPUT:** Distances to various levels of damage caused by a vapour cloud explosion.  
**CONSTRAINTS:** Should not be extrapolated for very large or very small clouds.

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##### The Method

Hemispherical cloud explosions arise from ground level ignition in unconfined areas, and there are two methods of estimating the effects. The first is to estimate the damage levels directly and the second to find the overpressure and other parameters, and estimate damage from them.

The damage radius  $R(S)$  is given by

$$R(S) = C(S)(NE_e)^{1/3}$$

where  $C(S)$  is an experimentally derived constant defining the level of damage based upon work by the Dutch State Mines (DSM) Company. It varies from 0.03 for heavy damage to 0.4 for light glass damage and light injury.  $E_e$  is the total energy of the explosion and  $N$  is the yield factor or the proportion of the energy,  $E_e$ , which is available for pressure wave propagation.

##### Outputs

The method gives the distances to various defined levels of damage. Using the notation above, these are typically:

$R(1)$  for  $C(1) = 0.03$  Heavy damage to  
buildings and to  
processing equipment  
 $R(3)$  for  $C(3) = 0.15$  Glass damage causing  
injury  
 $R(4)$  for  $C(4) = 0.4$  10% glass damage

TABLE 4.3 : EXPLOSION LIMIT VALUES FOR VARIOUS CHARACTERISTIC TYPES OF DAMAGE

C(S)	LIMIT VALUE ( $\text{mJ}^{-1/3}$ )	CHARACTERISTIC DAMAGE
C(1)	0.03	Heavy damage to buildings and to processing equipment
C(2)	0.06	Repairable damage to buildings and facade damage to dwellings
C(3)	0.15	Glass damage causing injury
C(4)	0.4	Glass damage about 10% of panes

Inputs

In finding damage levels directly, it is assumed that the total amount of combustible material in the explosive part of the cloud and the heat release per unit mass of the material are known. The product of these gives the total energy  $E_e$  of the explosion.

Assumptions and Constraints

If the total energy available for explosion,  $E_e$ , is greater than  $5 \times 10^{12}$  joules, there is almost no information on damage effects. For lower values  $E_e$  there is sufficient data to make an estimate of damage. It is assumed that a proportion  $N$  of the energy  $E_e$  is available. This is called the yield factor and is further assumed to be the product of two terms designated by  $N_c$  and  $N_m$ .  $N_c$  is the proportion of yield loss due to the continuous development of fuel concentration and  $N_m$  represents the mechanical yield of the combustion.  $N_c$  and  $N_m$  can be chosen according to the analyst's judgement; correspondingly, the values usually taken for  $N_m$  are 33%. Typically,  $N_c$  is taken to be 30% for isochoric combustion and 18% for isobaric.

Accuracy

It is generally considered that the correlation methods when applied to vapour cloud explosions will tend to yield a conservative estimate of damage.

**Application**

This method may be used to provide an estimate of effect distances for a range of explosion severities for flammable clouds of hydrocarbons containing upto  $5 \times 10^{12}$  joules of energy or approximately 100 tonnes of material.

#### 4.6 Effects of Toxic Releases

For an assessment of major hazards, we are concerned with the acute toxic effects of short-term exposure at high concentrations and not the long-term chronic effects, which arise from long-term exposure at lower concentrations. Toxic gases and vapours cause damage to living organisms by a variety of physical and chemical mechanisms, many of which are not fully understood. Much of the data on the acute effects of toxic materials have been derived from controlled experiments on animals. The effect on humans has only been corroborated through the fortunately very limited experience we have in this matter, usually from occupational exposures resulting from inplant accidents.

The effects of acute exposure to toxic gases or vapours includes: mild irritation, severe irritation, injury, irreversible injury and lethal effects. Some of these are manifest immediately in the exposed person, while some may be manifested as a delayed response to an accidental release. Both the exposure concentration and time of exposure are important in determining the acute toxicity effects. This may be repressed in terms of a dose/response relationship.

An approximate quantitative measure of the ability of a chemicals to produce the most acute toxic manifestation, ie. death (through inhalation), is the lethal concentration (LC50) at which 50% of the exposed population would not be expected to survive over the exposure period. For an atmospheric release of hazardous gases and vapours, inhalation is the main route of exposure causing acute toxic effects. In some hazard analysis cases, it may be appropriate to specify a non-lethal injury level of exposure for a given period as the limiting exposure criteria. Or, alternatively, a useful exposure limit to adopt may be in the NIOSH/OSHA, Immediately Dangerous to Life of Health (IDLH) value (1978) for a 30 minute exposure.

The effect of a toxic gas is dependent upon the concentration of the toxic compound in the atmosphere and the time for which individuals may be exposed to that concentration. Both of these parameters are dependent upon the nature of the release and the dispersion of gas downwind.

For an instantaneous, or near instantaneous release of hazardous material, a cloud may pass over a population relatively quickly. However, acutely toxic concentrations could be encountered even for this relatively short period. In the case of a continuous release, relief from the exposure would not be experienced for some time unless some form of safeguard action is taken; as a result, lower concentrations may give rise to detrimental effects. For this reason, it is essential to consider toxic effects by using the predictions of concentration/time profiles provided by the dispersion models given in the recent sections of this manual.

For toxic vapour cloud calculations, there is no definitive lower limit of concentration such as the LFL in the case of a flammable gas, because toxic effects depend upon the time of exposure as well as the concentration experienced. To avoid calculations at negligible concentrations, it is useful to specify a level of interest or concern, based upon the toxic parameters of the material involved and the anticipated duration of the exposure. The parameters may be adjusted by the analyst to suit the specific situation under examination. Care should be taken to adjust the time step used in assessing toxic impacts to be compatible with the size of the cloud in order to avoid unnecessary calculations.

#### 4.6.1

#### EFFECTS OF VAPOUR CLOUD OF TOXIC GAS

**METHOD:** Combining the dispersion models, frequency data, population data and dose response relationship to determine expected toxic impacts.

**OUTPUT:** Proportion of population affected in various weather conditions.

**CONSTRAINTS:** The validity of this approach has not been fully developed for all toxic materials due to the paucity of relevant experimental data.

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##### The Method

The early effects during the rapid discharge of material are not usually included in the toxicity calculations because these regions should be confined within the plant boundaries for most cases. Toxic effects during these stages are assumed to have little significance for the overall toxic impact. The only toxic effects which are usually calculated are for the subsequent dense vapour cloud dispersion phase or Gaussian dispersion as appropriate. By calculating the concentration profile in relation to the development of the cloud, the toxic load can be estimated. The results are integrated across the cloud to find the toxic effect at distances,  $d$ , from the release point.

Where sufficient information is available, a convenient way of expressing the effect of an exposure to toxic gases is to relate the concentration of exposure to the duration of that exposure using what is known as a probit function. A probit is a probability unit,  $Pr$ , and has the form

$$Pr = A_t + B_t \ln (C^n t_e)$$



where  $A_t$ ,  $B_t$  and  $n$  are parameters which are dependent upon the nature of the toxic material

$C$  is the concentration of exposure

$t_e$  is the duration of exposure

$A_t$ ,  $B_t$  and  $n$  are chosen so that the value of  $Pr$  is a Gaussian distributed random variable with a mean value of 5 and a variance of 1. It provides a measure of the percentage of the population who would be expected to be adversely affected in a toxic release of known concentration and duration of exposure. The probit may be related to the percentage death probability by using the transformation given in Table 4.4 overleaf.

In theory, the method of probit calculations is applicable to all toxic materials, but difficulties may arise in practice. The derivation of probit functions for human lethality is restricted by the shortage of appropriate toxicity data upon which to base a reliable judgement for the values of the parameters forming the probit expression.

Normally, the exposure time should be set equal to the release duration. However, even in emergency situations, where considerable confusion may prevail, an exposure duration of more than 30 minutes would probably be unrealistic since potential victims would tend to take avoiding or mitigating actions within this time.

To evaluate the probit,  $C^n t_e$  must be calculated at positions of interest. This can involve lengthy computation and the following simple approaches are suggested. The object of these procedures is to evaluate the distance from the release at which the toxic effect would have a value of 50%. The probit will then have a value of 5 and would equate to the LC(50) for the defined exposure time;

**For a continuous release:**

$$\frac{\exp (5.0 - A_t)}{B_t} = C^n t_e$$

where  $t_e$  is the exposure time

A value of  $C$  is then obtained from which the radius to 50% fatality may be estimated using the models described in Section 4.3 of this manual.

**For an instantaneous release:**

As the cloud passes over the population, the concentration at any given point will vary. In order to make the calculation tractable, the average concentration may be calculated along the centre-line of the cloud. Assuming that the cloud radius does not change during the passage of the cloud over the locations of interest the average centre-line concentration is given by:

$$C = 0.585 C(x, o, o, t)$$

where  $C(x, o, o, t)$  may be calculated using the models in Section 4.3.

The duration of exposure,  $t_e$  may then be given by:

$$t_e = \frac{(R^2 - x^2)^{1/2}}{u_1}$$

where  $R$  is the cloud radius at the location of interest.

Toxicity data for some commonly used chemicals are given in Appendix 4.

TABLE 4.4 : TRANSFORMATION OF PERCENTAGES TO PROBITS  
IN TOXICITY CALCULATIONS (Finney, 1971)

%	0	1	2	3	4	5	6	7	8	9
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.26	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.58	7.65	7.88	0.09

**Outputs**

This method gives the probability of experiencing a lethal dose (or injurious dose) of the substance in question at a given distance from a source, taking dispersion conditions into account.

**Input**

- (i) Toxicity parameters for the material under consideration.
- (ii) Concentration/time profiles of released material.

**Assumptions and Constraints**

Many assumptions are required for this model and it should be noted that the resulting estimates are intended to yield an indication of the effect distances associated with specified toxic hazards. The calculations of dispersion and toxic effect are interlinked; for complex situations access to suitable computing facilities would be required.

**Accuracy**

This method is considered to have an accuracy no better than a factor 2.

**Application**      This method may be used to estimate approximate effect distances in the event of a toxic gas or vapour release. These calculations may be based upon Probit relationships, LC(50), IDLH or other relevant dose criterion for the toxic pollutant of interest.