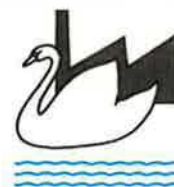


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#9005**

**HER MAJESTY'S
INSPECTORATE OF POLLUTION**



Environmental Protection Act 1990

**Technical Guidance Note
(Dispersion)**

D1

**Guidelines on Discharge Stack Heights
for Polluting Emissions**

HER MAJESTY'S
INSPECTORATE OF POLLUTION



Environmental Protection Act 1990

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**Technical Guidance Note
(Dispersion)**

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**Guidelines on Discharge Stack Heights
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Prepared for publication by Technical Guidance Branch
Her Majesty's Inspectorate of Pollution

Her Majesty's Inspectorate of Pollution

HMIP, currently part of the Department of the Environment, has a key role in protecting and improving Britain's environment. HMIP's responsibilities were increased by the 1990 *Environmental Protection Act*, and it now regulates 200 categories of industry, 5000 major industrial plants and 8000 premises using or storing radioactive material.

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a,b	Coefficients in equation 6
A	U_m/U_b
B	Building width (m)
B_c	Actual concentration of the background pollutant (mg m^{-3})
B_e	Equivalent concentration of the background pollutant for a different discharged pollutant (mg m^{-3})
c_d	Pollutant concentration at stack discharge conditions
c_s	Pollutant concentration at STP (273K, 101.3kPa)
C	Final discharge stack height (m)
D	Pollutant discharge rate (g s^{-1})
d	Discharge stack diameter (m)
G_b	Guideline concentration of the background pollutant (mg m^{-3})
G_d	Guideline concentration of the discharged pollutant (mg m^{-3})
II	Building height (m)
H_m	Maximum H considering all relevant buildings (m)
K	The lesser of building height (H) or building width (B)
M	Discharge Momentum ($\text{m}^4 \text{s}^{-2}$)
M_o	Discharge Momentum for discharges of ambient density from Figure 3 ($\text{m}^4 \text{s}^{-2}$)
m_w	Mean molecular weight of the discharging gases
n	Discharge rate of water droplets (g s^{-1})
P_i	Pollution Index ($\text{m}^3 \text{s}^{-1}$)
Q	Heat released at discharge stack exit (MW)
T	Height of disturbed flow over building – II + 1.5K (m)
T_a	Temperature of the ambient air (K)
T_d	Discharge temperature (K)
T_m	Maximum T considering all relevant buildings
U	Uncorrected chimney height, the lesser of U_b and U_m (m)
U_b	Uncorrected chimney height for buoyancy (m)
U_m	Uncorrected chimney height for momentum (m)
V	Volume flowrate at the discharge conditions ($\text{m}^3 \text{s}^{-1}$)
w	Discharge velocity (m s^{-1})
ρ_a	Density of the ambient air (kg m^{-3})
ρ_d	Density of the discharged gases (kg m^{-3})
x,y,z	Coefficients in equation 15

1.0 Introduction

1.1 This Note is issued by Her Majesty's Inspectorate of Pollution, and is one of a series providing information on technical subjects.

1.2 It lays out a relatively simple, non-specific method of approximately determining the heights of discharge stacks for polluting emissions, which should be adequate in normal circumstances. It is intended for use by Inspectors, Local Authorities, Industry and others who have a need to make such calculations, although it is primarily intended for use with those processes regulated by Local Authorities. Since the height of a stack (which is provided to render an emission harmless), is only one part of BATNEEC, emissions must also be prevented and minimised to meet the requirements of Section 7(2) of the *Environmental Protection Act, 1990*.

1.3 It is intended to complement the Third Edition of the *1956 Clean Air Act Memorandum on Chimney Heights* (Department of the Environment, (1981)). This was produced specifically for dealing with conventional combustion plant of the sort mainly in use at that time. That is, indirect heating and steam raising boilers running on fossil fuels and for which either sulphur dioxide or nitrogen oxides were the major pollutants. The Memorandum should continue to be used for this purpose.

1.4 However, since the Memorandum was produced a much greater variety of types of combustion plant have appeared to which it was never intended to apply; for example, fluidised bed combustors, small generating plant and co-generation systems. Also, there has been an increasing concern over polluting discharges from combustion plant burning non-fossil fuels and from discharges from a wide range of industrial processes of all sizes. The Memorandum has been adaptable, within limits, to deal with some of these other emissions, (see the background report to this document (Hall and Kukadia, (1993)) for a further discussion). However, its use is inappropriate in many cases due to the wide variation in both the types of pollutant and their discharge conditions compared with those for conventional combustion plant. The present guidance is intended to deal with these other discharges.

1.5 Because it can be applied to a wide variety of pollutant discharges, the present guidance is necessarily more complex than the Memorandum. However, it follows the same general procedures as the Memorandum and has some points of similarity, so that previous users of the Memorandum should find many aspects of it familiar.

1.6 Since the main intention of this guidance is to lay out a methodology, only a limited amount of background information is supplied. Similarly, references are limited to those directly relevant to the determination of a discharge stack height. Further details can be found in the background report to this document (Hall and Kukadia, (1993)).

1.7 HMIP are grateful to Warren Spring Laboratory for compiling the information contained in this guidance.

2.0 Basis and Limitations of the Method

2.1 Basis of the method

The calculation method assumes that the discharge stack height is governed by the need to limit local ground level pollutant concentrations below a maximum level that might occur for short periods. By 'local' is meant the region within a distance of about one hundred stack heights where the occasional contribution of a single pollution source to short term pollution levels can be large. It is not intended to deal with long range pollutant transport or to long period pollution levels due to multiple sources, where different considerations apply. The target period is 15-30 mins, but this covers acceptably a range between about five minutes and an hour's duration. The presumption is that human health effects are the major consideration, thus that part of the guidance concerned with guideline concentrations is based solely on this. However, the method could also be used to deal with short term exposure problems for other reasons, provided that acceptable guideline concentrations are known.

2.2 Contribution to long term pollutant levels

Although local short term maximum pollutant concentrations are normally the governing factor in controlling discharge stack heights for health effects, there may be circumstances in which other factors not covered by this document need to be considered. For example, health effects due to long term ambient pollutant concentrations, deposition to the ground of particles containing toxic materials (as with heavy metals or fluorides) or the deposition of nuisance dusts.

2.3 Types of discharge

The method is restricted to controlled, known, steady discharges through stacks directed vertically, where the rate of pollutant discharge is known and where there is a guideline concentration for the pollutant(s). A 'steady' discharge is defined as one with a nominally constant release rate over a minimum time of a few minutes. In cases of short discharge times,

of less than about one minute, the method may still be used (based on the maximum rate of discharge) but may produce a conservative (increased) discharge stack height. The method is not intended for accidental or other uncontrolled discharges, though it may be usable for these purposes under some circumstances.

2.4 Types of pollutant

The method is suitable for both gaseous and small particulate pollutants. The latter are defined as particles of aerodynamic diameter below about 40 μ m.

2.5 Odorous discharges

The method is not suitable in its present form for odorous discharges. The perception of odours is normally to the large excursions in concentration at short time scales (down to time averages of about one second) which occur as a natural part of the dispersion process. Thus the minimum averaged time (of about five minutes) upon which the present method is based is too long for prediction of the dispersion of odours. It is intended to issue further advice on dealing with odorous discharges at a later date.

2.6 Meteorological conditions

Discharge stack heights are based on the worst case experienced in normally occurring meteorological conditions, that is, within the 98%ile envelope of frequencies of windspeed and atmospheric stability. Extreme conditions, for example very strong winds in excess of 20ms⁻¹, have been excluded. This is adequate for determining discharge stack heights in the great majority of cases.

2.7 Topography

The method is restricted to areas around the discharge stack where topographic effects on dispersion are not significant. This is approximately defined as areas where ground slopes are less than 1 in 10. Specialist advice

may be needed in some cases where topography is a problem.

2.8 Maximum discharge stack height

Although the present document will give chimney heights up to 200m, above 100m the stack height derived will only be approximate. At these greater heights it is desirable that stacks be given more individual attention.

3.0 Calculation Procedure

This section sets out the sequence of steps for calculating the discharge stack height. The subsequent sections then deal with each step in detail. The relevant section number is noted in parentheses after each step. There are three main stages in the process. Firstly, determining the size of the polluting discharge and its Pollution Index. Secondly, calculating the discharge stack height. Finally, attention is given to a number of subsidiary matters: absolute minimum stack heights, discharge conditions etc.

The procedure is also laid out in the flow chart, overleaf.

Stage 1: Calculating the Pollution Index (section 4). The steps in this stage are,

- Identify the major pollutants (4.2).
- Determine the guideline concentrations for the pollutants (4.3).
- Correct for background levels of pollution if necessary (4.4).
- Consider combinations of discharged pollutants where they occur (4.5).

2.9 Accuracy

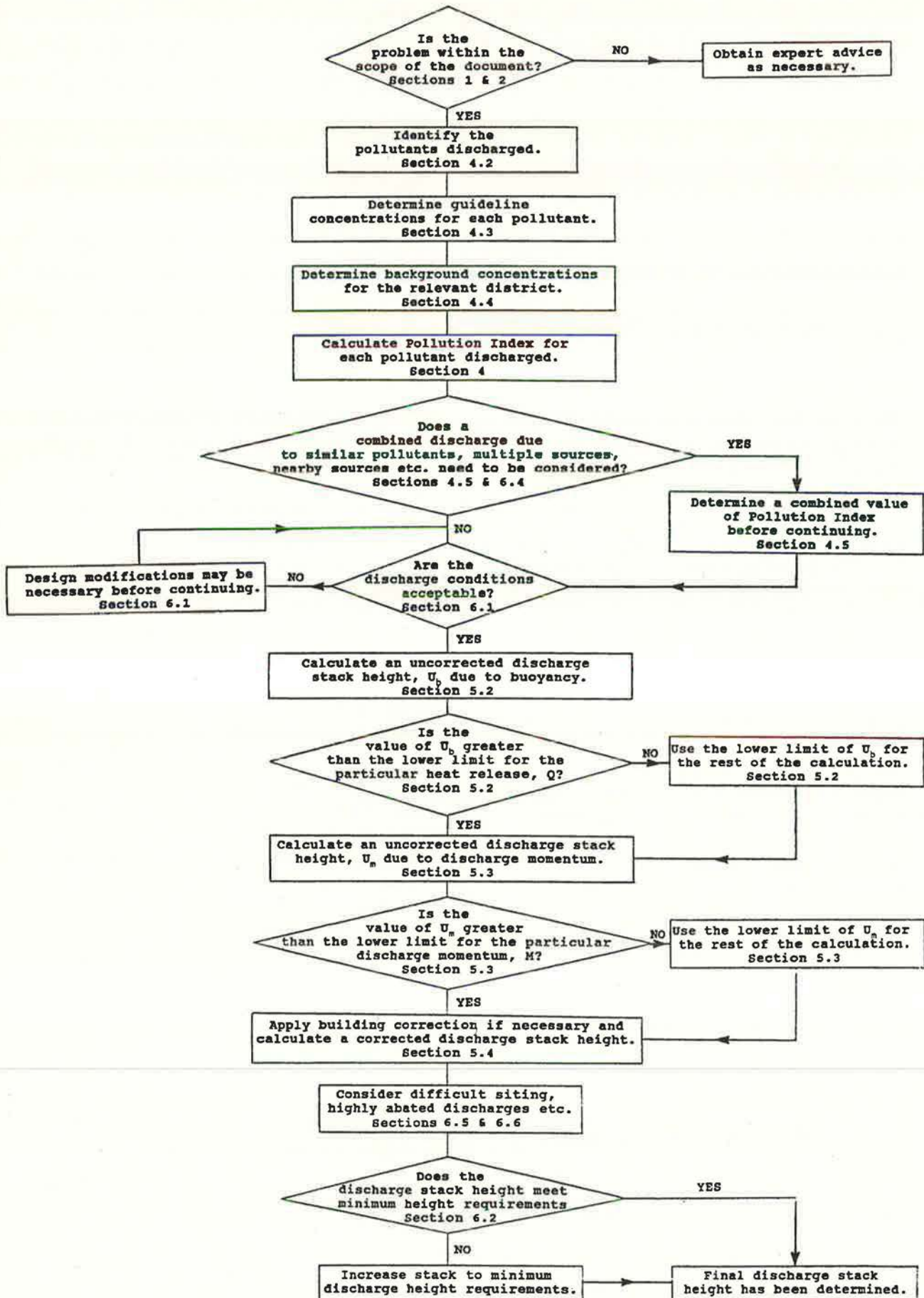
Heights determined using the method should be regarded as a guide rather than a mathematically precise definition of discharge stack height. The conclusion may need to be modified in the light of particular local circumstances or of practical experience.

Stage 2: Calculating the discharge stack height (section 5). The steps in this stage are,

- Calculate uncorrected discharge stack height for buoyancy, U_b (5.2).
- Calculate uncorrected discharge stack height for momentum, U_m (5.3).
- Calculate final discharge stack height, correcting for the presence of tall buildings if necessary (5.4).

Stage 3: Other considerations (section 6). These are,

- Minimum discharge velocity and other flue exit conditions (6.1).
- Overriding minimum requirements for discharge stack heights (6.2).
- Discharge stack heights for plant with a wide operational range (6.3)
- Multiple sources, nearby sources and combining emissions (6.4).
- Difficult siting (6.5).
- Highly abated emissions (6.6).



Procedure for Determining Discharge Stack Height

4.0 Calculating the Pollution Index

4.1 Definition of the Pollution Index:

The Pollution Index is defined as,

$$\text{Pollution Index, } P_i = \frac{D}{(G_d - B_c)} \times 1000. \quad (1)$$

where,

D is the discharge rate of the pollutant, in g s^{-1} ,

G_d is the guideline concentration of the discharged pollutant, in mg m^{-3} , and

B_c is the background concentration of the discharged pollutant for a particular district/area, or its polluting equivalent, B_e , in mg m^{-3} .

Note that P_i then has units of $\text{m}^3 \text{s}^{-1}$.

The Pollution Index is used subsequently in determining the discharge stack height. It may need to be modified to account for other nearby sources or combinations of emitted pollutants. The details of calculating the Pollution Index and its modification to deal with these other factors are covered in the remainder of section 4.

Guideline concentrations are considered in detail in section 4.3.

Background concentrations are considered in detail in section 4.4.

4.2 Identifying the major pollutant(s) and calculating the Pollution Index:

The major pollutant (or group of pollutants) is that which produces the highest value of the Pollution Index, singly or in combination as appropriate. The discharge stack height is normally calculated using this value of the Pollution Index. It should then also be adequate for effectively dispersing any other pollutants.

Where there is only a single discharged pollutant or a clearly dominant pollutant, calculating the Pollution Index will not be a difficulty. However, in other cases, where there are a number of different pollutants discharged or where there are discharges from a number of adjacent sources, it may not be so clear. This is considered below.

Where there is a discharge from multiple stacks, or from a number of nearby stacks all discharging the same pollutant or type of pollutant, the combined discharge rate of the pollutant from all the sources should be used to calculate the Pollution Index. Alternatively, the Pollution Indices from the different discharges can be summed, the result is the same. The definition of 'nearby' stacks and the procedures for dealing with them are covered in section 6.4.

Where a number of different pollutants of similar type are discharged together, or from a number of nearby sources, it may be necessary to consider a combination of pollutants rather than a single major pollutant. This is dealt with in section 4.5.

The maximum rate of discharge, based on the maximum capacity of the plant, not its normal operational load, should be used to calculate the Pollution Index. In the case where there are multiple units of a similar type, one of which only serves as a standby in case of failure, consideration may be given to omitting the standby from the calculation. In cases of combustion plant where there is a standby fuel option, the discharge stack height should be calculated using the fuel option which produces the largest value of the Pollution Index. In plant with a wide operational range, part load conditions may also need to be considered; this is dealt with in section 6.3. With intermittently operating plant it may also be necessary to consider conditions during start-up or close-down, where pollutant discharge rates may be greater than during normal operation.

For prescribed processes, the relevant Process Guidance Note may assist in determining which pollutants should be examined, although all the discharged pollutants are not always listed. For processes prescribed for control under Part I of the *Environmental Protection Act 1990*,

guidance on emission concentration limits is contained in the relevant notes issued by either the Chief Inspector, HM Inspectorate of Pollution ("IPR" notes) or the Secretary of State ("PG" notes). In calculating the Pollution Index it should normally be assumed that concentrations of the emitted pollutants are at these limit values. However, if the operator is authorised to operate only within lower limit values, then those lower values may be used.

Note that the emission concentration limits in the Process Guidance Notes are given at STP, that is, 273K and 101.3kPa and at specific oxygen levels. In order to calculate the pollutant discharge rates, these must be converted to pollutant concentrations at the stack discharge conditions. This can be done using the conversion equations given in Appendix B.

4.3 Determining the guideline concentration for the pollutant

4.3.1 General

For the present purposes a guideline concentration is one to which the general populace may be safely exposed for continuous periods between about five minutes and up to an hour and which may be repeated intermittently but probably infrequently (that is, for around 10% of the time at most) in the long term. Unfortunately, there is little formal advice on guideline concentrations of this sort and no formal list of guideline concentrations for this purpose, covering the wide range of pollutants of interest, is issued in the UK or ratified for use in the UK. There are a few pollutants for which commonly applied short term guideline concentrations have become settled, based upon either relatively detailed investigation or upon long periods of practical experience. For example, the *Memorandum on Chimney Heights* (Department of the Environment, (1981)) is based upon such commonly applied values for sulphur dioxide and nitric oxide. In other cases it has become common practice to use modified values of guideline concentrations set for other purposes, particularly occupational exposure levels, as yardsticks. In the UK, the main document used for this purpose is the *List of Occupational Exposure Limits* issued by the Health and Safety Executive (EH40). The procedures proposed here follow this common practice.

4.3.2 Available data on guideline concentrations

Table 1 lists those common pollutants for which guideline concentrations could be found for short term exposure of the general populace. The source of information for the guidelines is also indicated. CA refers to commonly applied values as described above. EC refers to limits set for the European Community. WHO refers to values recommended in the recent World Health Organisation(1987) publication, for which short term exposure guidelines are offered. In addition the EC limit for suspended particulate matter is given, though this is a longer term average (the 95%ile of daily means). There is currently no limit value for the smaller, thoracic particulate fraction as defined by the ISO/CEN (1990) convention (that is, the size fraction with a 50% sampling efficiency for particle diameters (d_{50}) of 10 μ m). However, this is currently the subject of consideration by the EC.

4.3.3 Determination of guideline concentration

The following procedure is suggested, where specific specialist guidance has not been sought:

If the pollutant is listed in Table 1, use the guideline concentration listed there.

If the pollutant is not listed in Table 1, use a small fraction of the *Occupational Exposure Limits* published by the Health and Safety Executive. The level commonly used is one fortieth of the Short Term Exposure Limit (STEL). If only a Time Weighted Average (TWA) is given, then a level of one fortieth of the TWA is used. Where the pollutant is scheduled under the COSHH regulations and has a Maximum Exposure Limit (MEL), then a level of one hundredth of the MEL is used.

4.3.4 Lead and other pollutants with longer term guideline concentrations

The present document is concerned with short term exposure levels and is not therefore strictly applicable to pollutants with longer term guideline concentrations. An important example is lead, for which there is an EC annual limit of 2 μ g m⁻³, but no shorter term limit. The document can be used for these materials in two ways. Firstly as a method of screening for their relative importance when discharged in combination with other pollutants. Secondly, as a means of finding upper bound chimney

heights, which will be effective but higher than is necessary. Both uses rely upon the fact that annually averaged concentrations are significantly lower than short term maxima. The second example at the end of the guidance shows such an application.

4.4 Correcting for background pollutant levels

Background levels of some common pollutants are sufficiently high to need accounting for in determining the effective guideline concentration. Table 2 gives a list of background concentrations of those common pollutants of interest which are regularly monitored, with typical upper-bound values for different types of district. If, as a result of local monitoring exercises, local background levels are known more precisely than the typical levels

given in Table 2, those values should be used instead, for determining the effective guideline concentrations. If this is done, values close to the normal upper bounds should be used. The 98%iles of the hourly means are recommended as these values are in common use as upper bounds for other purposes in the air pollution field. If there is no significant background concentration, B_c is zero. Background concentrations of pollutants other than those listed in Table 2 can generally be assumed to be zero, unless there are significant local sources of those pollutants. If the background pollutant is the same as the discharged pollutant, then the actual concentration of the background pollutant, B_c , is used. However, if, as often occurs, the background pollutant is different to the discharged pollutant but of a similar type, then its polluting equivalent concentration to the discharged pollutant, B_c , must be used instead.

Table 1: Short Term Ambient Guideline Concentrations in Use for Some Common Pollutants.

Pollutant	Guideline Concentration		Source ⁺⁺
	ppm	mg m ⁻³ ⁺	
Sulphur Dioxide	0.17	0.44	CA
Nitric Oxide	0.83	1.00	CA
Nitrogen Dioxide	0.10	0.20	EC
Hydrogen Chloride	0.06	0.10	CA
Carbon Monoxide	50	57	WHO
Ozone	0.09	0.18	EC
Formaldehyde	0.08	0.10	WHO
Suspended Particulate Matter*	-	0.30	EC

+ Converted from ppm at 20°C and 1 atmosphere pressure.

++ CA = Commonly applied value
 EC = European Community Limit
 WHO = World Health Organisation Guideline
 (see text for further details).

* Current EC limit for suspended particulate matter, 95%ile of daily means.

The background level of the pollutant should be subtracted from the guideline concentration, as indicated in Equation (1). This modified

guideline concentration should then be used for calculating the Pollution Index. In the case of discharges of combinations of pollutants or of

different but similar types of pollutant to the background pollutant, a more complex procedure is required. This is detailed in section 4.5.4, and demonstrated in the examples.

The background levels listed for lead in Table 2 are averages of weekly means, as this is all the data that is available. It is not entirely appropriate for the present purposes but can be used for upper bound stack height determination (see section 4.3.4, above).

Ozone is included in the list of background pollutants because, though it is normally considered to be a secondary pollutant, some process emissions do contain ozone, usually as a by-product of the process, but sometimes because it is used directly. The levels listed in Table 2 are 98%iles of hourly means.

Background levels for particles are given both for Suspended Particulate Matter and for the thoracic fraction. The thoracic fraction refers to the ISO/CEN (1990) size distribution for particles smaller than $10\mu\text{m}$ (that is, with a 50% sampling efficiency for particle diameters (d_{50}) of $10\mu\text{m}$). Particles discharged from abated plant are most likely to fall within the latter category. The values must be considered as very

tentative, firstly because of the very limited number of sampling sites on which they are based (all that could be found) and, secondly, because the collection characteristics of most of the samplers used for the measurements do not satisfy the requisite sampling conventions very well. It can be seen that the value given in Table 2 for Suspended Particulate Matter in the most polluted category is in excess of the current EC limit. Lower background levels may in fact be more appropriate for many areas of this sort, but it is difficult to justify such lower values without more ambient measurements than presently exist.

With the exception of nitric oxide, the gaseous pollutants listed in Table 2 are relatively stable and are chemically modified over periods of days. Pollutant concentrations therefore tend to be fairly evenly distributed within a given type of district. Nitric oxide, by comparison, has a reaction rate constant of the order of 15-30 minutes for oxidation to nitrogen dioxide. It is therefore more strongly dependent upon local pollution sources, especially the presence of road traffic. Much wider local variations in levels of this pollutant may therefore be expected.

Table 2: Typical Background Levels of Common Pollutants.

Type of District	Background Concentrations, mg m^{-3}						
	SO_2^1	NO^1	NO_2^1	Ozone ¹	Lead ²	Particulate ³	
						Thoracic ($d_{50} = 10\mu\text{m}$)	Suspended Particulate Matter
Major city centre/heavy industrial area	0.16	0.40	0.17	0.09	0.5×10^{-3}	0.15	0.4
Highly developed large urban area	0.12	0.25	0.12	0.10	0.25×10^{-3}	0.1	0.2
Urban area of limited size with parkland or largely rural surroundings	0.10	0.15	0.09	0.11	0.1×10^{-3}	0.07	0.1
Partially developed area	0.07	0.10	0.07	0.13	0.05×10^{-3}	0.05	0.07
Rural area with little development	0.05	0.05	0.05	0.15	0.02×10^{-3}	0.03	0.05

1 - 98%ile of hourly means.

2 - Averaged weekly means.

3 - Tentative data - see text.

4.5 Combinations of pollutants

4.5.1 General

In some cases there may be a combination of similar types of pollutant emitted from a single stack, or from a number of stacks either in a multiple stack discharge or from stacks in close proximity. The question then arises as to whether the effects of these similar pollutants may be additive, so that the combination of pollutants should be considered rather than the single major pollutant. There is little formal advice on this subject. The HSE's *List of Occupational Exposure Limits* suggests a method of assessing combinations of pollutants (described as 'Additive Substances'), though it does not propose particular groups of pollutants which should receive this treatment. A similar approach to 'Additive Substances' is adopted here.

4.5.2 Dealing with combinations of discharged pollutants

It is suggested that emissions of different but similar types of pollutants are considered in combination rather than singly, unless there is specific specialised advice to the contrary. Examples of such groups are acid gases and organic solvents. This is done by calculating the Pollution Index for each pollutant in the group (after correcting for background concentrations if necessary, see section 4.5.4) and adding these together to produce a combined Pollution Index for the group. This combined Pollution Index is then used in calculating the stack height. That is,

$$P_i(\text{combined}) = P_i(1) + P_i(2) + P_i(3) \text{ etc,}$$

where $P_i(1)$, $P_i(2)$ etc are the Pollution indices of the different but similar types of pollutants. This combined Pollution Index is then used to calculate the discharge stack height. The examples at the end of this document also show the use of this procedure.

4.5.3 Acid Gases and Nitrogen Oxides

Discharges of combinations of acid gases occur quite commonly from combustion plant, incineration and some industrial processes (brick manufacture, for example). Such discharges should be considered in combination,

as described above. However, emissions of nitric oxide, NO, and nitrogen dioxide, NO₂, which are associated with all combustion processes, should be excepted from combinations of acid gases and treated individually as separate pollutants. Nitric oxide, NO, is known, from previous detailed consideration, to have different physiological effects from most acid gases. Nitrogen dioxide, NO₂, is an acid gas with similar effects to the other acid gases so there is thus a good case, in principle, for its consideration in combination with them. However, it is also the subject of a specific EC short term exposure limit, noted in Table 1, so it should be considered individually.

4.5.4 Correcting for background concentrations of different but similar types of pollutant

Section 4.5.2 describes how discharges of different, but similar types of pollutants should be combined in calculating the Pollution Index. In a similar way, concentrations of different, but similar types of background pollutant to the discharged pollutant must be accounted for in calculating the Pollution Index. Equation (1) requires that the concentration of the background pollutant be subtracted from the guideline concentration of the discharged pollutant, but this cannot be done directly for dissimilar pollutants. It is first necessary to convert the concentration of the background pollutant to its polluting equivalent of the discharged pollutant. This is done by scaling the concentration of the background pollutant by the ratio of the guideline concentrations of the discharged pollutant to that of the background pollutant. That is, the equivalent background concentration, B_e , for a particular discharged pollutant is given by,

$$B_e = B_c \times \left(\frac{G_d}{G_b} \right), \quad (2)$$

where,

B_c is the actual concentration of the background pollutant,
 G_d is the guideline concentration of the discharged pollutant, and
 G_b is the guideline concentration of the background pollutant.

Since this problem arises mainly with the acid gases in relation to existing background levels of sulphur dioxide, SO_2 , values of the ratios of G_d/G_b are listed in Table 3, for a number of commonly discharged acid gases and with sulphur dioxide as the background pollutant. Because of their individual consideration, noted above, nitrogen oxides are omitted from the list.

Table 3: Values of the Conversion Factor, G_d/G_b *

(for determining equivalent background concentrations of some acid pollutants where sulphur dioxide, SO_2 is the background pollutant).

Discharged Pollutant	G_d/G_b
SO_2	1.00
HCl	0.23
HF	0.14
H_2SO_4	0.06
HNO_3	0.57

* See Section 4.5.3 on 'Acid Gases and Nitrogen Oxides'

5.0 Calculating the Discharge Stack Height

5.1 General

The discharge stack height is calculated using the Pollution Index, P_i , as described above, and basic information about the discharge and the surrounding buildings. There are three stages in the procedure. Two uncorrected discharge stack heights are calculated, U_b and U_m , based upon the buoyancy and momentum in the discharge respectively. Then a final stack height is calculated, corrected for downwash due to nearby buildings.

The following basic information on the stack discharge is needed:

(Note that great precision is not required, an accuracy of 10% is sufficient).

The heat release from the stack, Q , in MW. If this is not known, it can be calculated from the other data (see Equations 3,4 and 5);

The temperature of the discharging gases, T_d (Kelvin), if the heat release is not known;

The discharge velocity, w , in m s^{-1} . Note that there are minimum required discharge velocities, see section 6.1.1;

The volume flow rate, V , in $\text{m}^3 \text{s}^{-1}$ (at the discharge conditions), or the stack diameter, d , in m;

If there is liquid water in droplet form present in the discharge, its approximate discharge rate, n , in g s^{-1} ;

If the discharge is not either of combustion gases or mostly of air containing a small proportion of contaminants, then the density of the discharged gases relative to ambient, ρ_d/ρ_a , or their mean molecular weight m_w , will be required.

5.2 Calculating U_b

5.2.1 General

The uncorrected discharge stack height, U_b , is calculated using the Pollution Index, P_i , and the buoyancy of the discharge. For the great majority of cases where the discharging gases are either of combustion products or are mostly of air containing a small proportion of contaminants, the buoyancy is given directly by the heat released, Q (MW), at the stack exit.

The minimum value of heat release for calculating U_b is 0.03 MW (30kW). If the heat release is less than 0.03MW (30kW), do not calculate a value of U_b , pass on to section 5.3 and calculate only a value of U_m .

5.2.2 Calculating the Heat Release

Where the heat release, Q , at the stack exit is not known directly, it can be determined by the most appropriate means outlined below:

Provided that the discharge is either of combustion products or is mostly of air containing a small proportion of contaminants (the most common circumstances) then the heat release, Q , can be found from Fig. 1, which gives it as a function of the volume rate of discharge and the temperature of the discharging gases, T_d (K). Alternatively, it can be calculated using,

$$Q = \frac{V \left(1 - \frac{283^*}{T_d} \right)}{2.9} \text{ (MW)}, \quad (3)$$

where,

V is the total volume rate of discharge of gases, in m^3s^{-1} , at the discharge conditions, and

T_d (K) is the temperature of the discharging gases.

* The ambient temperature is assumed to be 10°C (283K).

In the relatively unusual case where the discharging gases are not either combustion gases or mostly air containing a small proportion of contaminants, the equivalent heat release of the buoyant discharge is given by,

$$Q = \frac{V \left(1 - \frac{\rho_d}{\rho_a} \right)}{2.9} \text{ (MW)}, \quad (4)$$

where ρ_d and ρ_a are respectively the densities of the discharging gases (at the discharge conditions) and of ambient air.

Alternatively, if the mean molecular weight, m_w , of the discharging gases and their temperature are known, the equivalent heat release of the buoyant discharge is given by,

$$Q = \frac{V \left(1 - \frac{m_w}{29} \frac{283}{T_d} \right)}{2.9} \text{ (MW)}, \quad (5)$$

The calculated heat release should include only sensible heat, it should not include the latent heat of condensation of any water vapour that may be present. If the discharge contains liquid water droplets, the calculated heat release should be reduced by,

$$0.0023n \text{ (MW)},$$

where n is the rate of discharge of water droplets in g s^{-1} . This is the heat loss in the discharge due to the loss of the latent heat of evaporation of the liquid water. If n is less than 13 g s^{-1} (equivalent to a heat loss of 0.03MW), then the heat loss may be ignored.

If the discharging gases are denser than air by virtue of a low discharge temperature, a high molecular weight, or by the discharge of a large amount of liquid water, calculate the equivalent heat release (which will be negative), using equations 3, 4, or 5, above. If this is between zero and -0.03MW (-30kW) do not calculate a value of U_b , instead pass on to section 5.3, below, and calculate only a value of U_m . If the equivalent heat release is less than -0.03MW, specialist advice should be sought on the dispersion of heavier than air gases. The *Workbook on the Dispersion of Dense Gases* (Britter and McQuaid, (1988)) may be of assistance. Increasing the heat release in the discharge may be effective in alleviating problems of this sort.

5.2.3 Calculating U_b

U_b can be found from Fig 2, which shows it plotted as a function of P_i and the heat release. Alternatively it can be calculated using,

$$U_b = 10^a \cdot P_i^b, \quad (6)$$

where,

for $Q \leq 1$ MW, $a = -1.11 - 0.19 \cdot \log_{10} Q$,

$$b = 0.49 + 0.005 \cdot \log_{10} Q;$$

and

for $Q > 1$ MW, $a = -0.84 - 0.1 \cdot \exp(Q^{0.31})$,

$$b = 0.46 + 0.011 \cdot \exp(Q^{0.32}).$$

The limits of application of equation (6), for U_b , are:

U_b ; min 1m, max 200m.
Heat release ; min 0.03MW,
max 100MW.
 P_i ; min 50, max 10^7 .

5.2.4 Minimum values of U_b

Note that Fig.2 shows minimum values of U_b associated with particular heat releases, irrespective of the value of P_i . These override lower calculated values of U_b . The minimum discharge stack heights can also be calculated from,

$$\text{if } Q \leq 1 \text{ MW, then} \\ \text{minimum } U_b = 1.95 \cdot Q^{0.19}, \quad (7)$$

$$\text{if } Q > 1 \text{ MW, then} \\ \text{minimum } U_b = 1.7 + 0.25 \cdot Q^{0.9}. \quad (8)$$

The lowest value of U_b for any heat release is 1m.

Fig. 2 also shows a shaded area for values of P_i around 10^7 and beyond. For discharges of this scale, the height of the discharge stack is no longer a relevant parameter for pollution control, irrespective of the heat release in the discharge, except as a means of the discharge clearing its immediate surroundings. Pollution levels then depend, amongst other things, upon the height of the mixing layer and the degree to which the discharge plume may penetrate this layer. They are controlled by emission limits not by discharge stack height. The present document is not applicable to this region.

5.3 Calculating U_m

5.3.1 General

The uncorrected discharge stack height U_m is calculated using the Pollution Index, P_i , and the discharge momentum, M .

5.3.2 Calculating the discharge momentum, M

The discharge momentum, M , is defined as,

$$M = \frac{\rho_d}{\rho_a} \cdot V \cdot w, \quad (9)$$

which is equivalent to,

$$M = \frac{\rho_d}{\rho_a} \cdot \frac{\pi w^2 d^2}{4} \quad (10)$$

where,

ρ_d and ρ_a are the densities of the discharging gases (at the discharge conditions) and the atmosphere, respectively,

w is the discharge velocity in m s^{-1} ,
 d is the diameter of the discharge stack in m,

V is the volume rate of discharge, in $\text{m}^3 \text{s}^{-1}$, at the discharge temperature.

The discharge momentum then has units of $\text{m}^4 \text{s}^{-2}$.

Provided that the discharge is of combustion products or is mostly air containing a small proportion of contaminants, the discharge momentum, M , may be found more simply from,

$$M = \frac{283}{T_d} \gamma \cdot w, \quad (11)$$

or from,

$$M = \frac{283}{T_d} \cdot \frac{\pi w^2 d^2}{4}, \quad (12)$$

depending upon the information available on the discharge.

Alternatively, the discharge momentum can be found with the aid of Fig. 3, which gives it for discharges at ambient temperature of air containing a small proportion of contaminants or for combustion products (or for discharges at ambient density otherwise) as a function of stack diameter, d , and discharge velocity, w . The momentum of discharges at other temperatures or densities can be found quickly by using Fig. 3 to find the value for a discharge at ambient temperature (assumed to be 10°C) or density and multiplying by the ratio of ambient/discharge temperature or density. That is,

$$M = M_0 \cdot (283/T_d), \text{ or} \quad (13)$$

$$M = M_0 \cdot (\rho_d/\rho_a), \quad (14)$$

where M_0 is the discharge momentum obtained from Fig. 3.

For the common case of combustion gases discharged within the temperature range 100-150°C, the ambient/discharge temperature or density ratio can be taken as 0.7 to adequate accuracy. Thus the discharge momentum can be found very quickly by taking a value from Fig. 3 and multiplying by 0.7.

5.3.3 Calculating U_m

Knowing M and P_i , the discharge stack height U_m can be found from Fig. 4, which gives U_m from M and P_i . Alternatively, it can be calculated using,

$$\log_{10} U_m = x + (y \cdot \log_{10} P_i + z)^{0.5}, \quad (15)$$

$$\text{where, } x = -3.7 + (\log_{10} M)^{0.9},$$

$$y = 5.9 - 0.624 \log_{10} M,$$

and

$$z = 4.24 - 9.7 \log_{10} M + 1.47 (\log_{10} M)^2 - 0.07 (\log_{10} M)^3$$

The limits of application of Eqn 15, for U_m , are:

U_m ; Min 1m, Max 200m.
Discharge Momentum; Min 1, Max $2 \cdot 10^4$.
 P_i ; Min 50, Max 10^7 .

5.3.4 Minimum values of U_m

Note that there are minimum values of U_m marked on Fig. 4 for particular values of the discharge momentum, M , irrespective of the value of P_i . These override lower calculated values of U_m . Minimum discharge stack heights can be calculated from,

$$\text{minimum } U_m = 0.82M^{0.32} \quad (16)$$

The lowest value of U_m for any value of M is 1m.

5.4 Calculation of final discharge stack height, C , corrected for nearby buildings

5.4.1 General

The procedure described and the notation used here is similar to that used in the earlier (1981) Memorandum, except that it has been modified to account for the two different uncorrected discharge stack heights, U_b and U_m , used in the present, more widely applicable, method.

Notation;

U = Uncorrected discharge stack height, the lesser of U_m or U_b .

$A = U_m/U_b$. If there is no value of U_b , or if $U_b > U_m$, then $A = 1$.

H = Building height (measured to the ridge or other highest point, ignoring lift or tank rooms and other protrusions less than 1% of the roof area).

B = Building width (measured at right angles to a line joining the discharge stack and the nearest point).

K = The lesser of building height (H) or building width.

T = Height of disturbed flow over building = $H + 1.5K$.

T_m = Maximum T considering all relevant buildings.

H_m = Maximum H considering all relevant buildings.

C = Final corrected discharge stack height.

5.4.2 Determination of Building Height, Width and Distance from the Stack

The general principles of determining building height, width and distance from the stack, and of dealing with buildings of complex shape, are similar to those outlined in the earlier (1981) Memorandum. For convenience, two of the figures from the Memorandum outlining these principles are reproduced again here as Figs 5 and 6.

5.4.3 Effective Heights and Widths of Trees, Lattice Towers and Porous Structures

Difficulties can sometimes arise in assessing the effective height and width of trees and other dense foliage, of lattice towers and supporting structures and of other porous structures. Trees and dense foliage should be taken as having their actual height, but an effective width of half their actual maximum width. Lattice towers etc., and other porous structures should be taken as having their actual height, but a width equivalent to the solid fraction of the structure. Thus, for example, a tower having 20% solidity should be taken as having an effective width of one fifth of its actual width.

5.4.4 Discharge stack heights needing a building correction

Note a value for U, which is the smaller of U_b or U_m . If the buoyancy in the discharge is less than 0.03MW (30kW) and there is no value of U_b , take U as equal to U_m . Consider all buildings within a range of $5U_m$ and note the tallest. If U is greater than 2½ times the height of the tallest building, then there is no building correction and U is the value of the final discharge stack height, C.

If U is less than 2½ times the height of the tallest building within a range of $5U_m$, then a correction to the discharge stack height for building effects is required.

5.4.5 Correction for single, wide buildings

For the commonly occurring case where there is a single dominant building which is wider than

it is high, the final discharge stack height, C, is given by,

$$C = H + 0.6\{U + (2.5H - U)(1 - A^{-U/H})\} \quad (17)$$

If there is no value of U_b , or if $U_b > U_m$, then $A = 1$ and the equation above reduces to

$$C = H + 0.6U, \quad (18)$$

which is the same as the correction in the earlier (1981) Memorandum.

The building height correction, plotted as C/H against U/H for various values of A, is shown graphically in Fig.7.

5.4.6 Multiple buildings and tall buildings

In cases other than for single, wide buildings, as above:

1. List all the relevant buildings, that is those within a distance of $5U_m$, and record H and B for each building.
2. Evaluate K for each building (the lesser of H or B).
3. Calculate T for each building ($T = H + 1.5K$).
4. Find H_m (the largest value of H).
5. Find T_m (the largest value of T).
6. If U is greater than T_m , then $C = U$ and no correction to the discharge stack height is required.
7. Otherwise calculate the corrected discharge stack height, C, using,

$$C = H_m + (1 - H_m/T_m)[U + (T_m - U)(1 - A^{-U/H_m})]. \quad (19)$$

If there is no value of U_b , or if $U_b > U_m$, then $A = 1$ and the equation above reduces to,

$$C = H_m + U(1 - H_m/T_m), \quad (20)$$

which is the same as the correction in the earlier (1981) Memorandum.

The building height correction, plotted as C/H_m against U/H_m , is shown graphically in Figs. 8, 9, and 10 for values of H_m/T_m of 0.6, 0.8 and 0.9. Fig. 7 corresponds to a similar plot for H_m/T_m of 0.4. The building height correction for intermediate values of H_m/T_m can be found

by linear interpolation between the figures.

5.4.7 Final discharge stack heights

Calculated discharge stack heights should be rounded up to the nearest metre.

6.0 Other Considerations

6.1 Minimum discharge velocity and other stack discharge conditions

6.1.1 Discharge velocity

A minimum discharge velocity is required in order to prevent the discharged plume suffering from aerodynamic downwash and flowing down the outside of the discharge stack, thereby reducing its effective height. The following minimum discharge velocities are recommended. Velocities are given for specific values of both heat release and discharge momentum. Use whichever gives the greater velocity.

For the heat release;

For a heat release below 0.1MW, 10m s^{-1}

For a heat release above 1MW, 15m s^{-1}

For a heat release between 0.1MW and 1MW,
pro rata

For the discharge momentum;

For a discharge momentum below 10, 10m s^{-1}

For a discharge momentum above 100, 15m s^{-1}

For a discharge momentum between 10 and 100,
pro rata

6.1.2 Stack Discharge Conditions

Discharges should be vertically upwards and unimpeded by cowls or any other fixture on top of the stack. However, the use of coning or of flame traps at the tops of stacks is acceptable. In the case of discharge stacks (whether single or multiple stack) with shrouds or casings around the stack(s), the stack(s) alone should extend above the shroud or casing. This extension should be at least 50% of the shroud or casing's greatest lateral dimension.

6.2 Overriding minimum requirements for discharge stack heights

The final corrected discharge stack height may

need to be increased to satisfy the requirements listed below;

6.2.1

Irrespective of the pollutant discharge, there are minimum discharge stack heights based on the heat release and the discharge momentum.

These are noted in sections 5.2 and 5.3, and on Figs. 2 and 4.

6.2.2

No discharge stack should be less than 3m above the ground or any adjacent area to which there is general access. For example, roof areas and elevated walkways.

6.2.3

A discharge stack should never be less than the calculated uncorrected stack height.

6.2.4

A discharge stack should never be less than the height of any building within a distance of $5U_m$.

6.2.5

A discharge stack should be at least 3m above any opening windows or ventilation air inlets within a distance of $5U_m$.

6.2.6

Some Process Guidance Notes recommend minimum discharge stack heights, irrespective of the scale of the process. These requirements should normally override calculations made with the present document.

6.3 Discharge stack heights for plant with a high turndown ratio or a wide range of discharge conditions

Some types of plant operate over a high turndown ratio or over a wide range of throughput, with an associated wide variation in

the stack discharge conditions. In these cases part load conditions may produce the more severe pollution problems. This can occur where reduced loading is associated with a substantial reduction in the heat release or discharge momentum. It may then be advisable to calculate discharge stack heights at low load as well as at maximum capacity. The highest calculated discharge stack should be used.

6.4 Multiple sources, nearby sources and combining discharges

6.4.1 General

It is common to find a number of different pollutant sources discharged either together from a multiple stack discharge or from discharge stacks in close proximity. This section provides guidance in dealing with these multiple emissions. It is assumed in what follows that the discharge stacks are of similar heights, which is good practice for stacks in close proximity. Discharge stacks close together of markedly dissimilar heights are only acceptable in restricted circumstances. These are considered in section 6.4.5.

For convenience, a summary of the rules for combining discharges is given in Table 4.

6.4.2 Multiple-stack discharges

Dealing with these is quite straightforward, the combined emissions being treated as a single discharge. The pollutant discharge is treated in the same way as with combinations of pollutants, described in section 4.5. Values of the Pollution Index for the individual discharges are added together as appropriate. The heat release, Q , and discharge momentum, M , of the combined emission is also found by summing the respective values for the individual discharges. The discharge stack height is calculated using these combined values of Pollution Index, heat release and discharge momentum.

6.4.3 Discharge stacks in close proximity

This is defined approximately as stacks within a distance $U_m/2$ of one another. If the discharge stacks are within a distance of three stack diameters of one another, they can be treated as a single discharge, as in the case of multiple discharge stacks, above. For discharge stacks

further apart, but within a distance of $U_m/2$, the pollutant discharges should be considered as a single discharge, values of the Pollution Indices for the discharges being added together as appropriate. In the same way, the heat release, Q , may be considered as a single discharge and values for the individual stacks summed. The discharge momentum, M , however, should not be summed, the individual values of U_m should be calculated and the largest value of U_m used in the final stack height calculation.

6.4.4 Nearby sources

For discharge stacks at distances between $U_m/2$ and $5U_m$ apart, the pollutant discharges should be considered as a single discharge, values of the Pollution Index for the stacks being added together as appropriate. The heat release and the discharge momentum should be taken individually and stack heights calculated on this basis. The tallest height calculated should be applied to all the discharge stacks unless the conditions in 6.4.5, below, are satisfied.

Discharge stacks at distances beyond $5U_m$ apart should be treated individually.

6.4.5 Discharge stacks of dissimilar heights close together

This is not good practice unless the Pollution Index of the lower discharge is small compared with that of the higher discharge. As far as the lower discharge is concerned, the taller nearby discharge stack has the same effect as a tall building and should be treated as such. Thus low discharge stacks should be at a greater distance than $5U_m$ (calculated from the Pollution Index of the lower discharge) from taller stacks. Even at this distance, there may be localised pollution problems due to plume downwash when the plume from the lower discharge runs into the taller stack.

6.5 Difficult siting

6.5.1 General

Discharge stack heights on some sites may need further consideration, despite satisfying the building height correction in section 5.4. This applies particularly if there are tall buildings in the vicinity but beyond the range of $5U_m$.

6.5.2 Courtyard wells and nearly enclosed spaces

Low discharge stacks should not be situated in

courtyard wells or in nearly enclosed areas, where ventilation rates can be poor, unless the pollutant discharge is small. As a rough guide, discharges in enclosed spaces less than $20U_m$ across and where the building heights are more than 20% of the spacing between them should be treated with caution. In such circumstances it may be better if the discharge is set above the surrounding buildings using the building height correction in section 5.4.

6.5.3 Nearby tall buildings

Buildings taller than the discharge stack but at

distances beyond $5U_m$, may cause plume meandering. As a rough guide, any building taller than the discharge stack within a distance of five building heights may have this effect. In these circumstances consideration should be given to any problems that might result from intermittent plume downdraughts. There may also be problems due to the plume running into the taller building.

Particular attention should be given to the possibility of contaminating nearby ventilation inlets.

Table 4: Summary of Rules for Combining Discharges from Nearby Stacks. (Section 6.4)

Spacing Between Stacks	Pollution Index P_i	Heat Release Q	Discharge Momentum M
Spacing < 3d	Sum Values	Sum Values	Sum Values
$3d < \text{Spacing} < U_m/2$	Sum Values	Sum Values	Use Individual Values
$U_m/2 < \text{Spacing} < 5U_m$	Sum Values	Use Individual Values	Use Individual Values
$5U_m < \text{Spacing}$	Use Individual Values	Use Individual Values	Use Individual Values

6.6 Highly abated emissions

Some plant operates with high levels of emission abatement and, as a result, quite low discharge stack heights may be calculated for the residual pollutant discharge during normal operation. In such circumstances consideration should be given to three matters,

- 1) Whether serious local pollution problems might result from occasional malfunction or deterioration of the abatement equipment, during which period a much larger pollutant emission may occur.
- 2) Whether some secondary aspect of the emission, for example a visible plume due to a relatively high water content or a low level of residual odour, may in fact be the major pollutant rather than the small abated residue of what would normally have been the major pollutants.

- 3) Whether, particularly in the case of some types of incineration plant, any sort of emergency stack is fitted to the plant, which will bypass the abatement equipment in the event of some sort of plant failure. This would result in an unabated emission being discharged.

In these circumstances an increased discharge stack height may be desirable. There is a good case for ensuring that stack heights for highly abated discharges are sufficient for the discharge to pass well clear of its immediate surroundings. This would be sufficient to avoid the most severe local pollution problems likely to arise. To achieve this for wide buildings, the minimum required discharge stack height is 1.5 times the tallest of the adjacent buildings. Otherwise the minimum height should be $T+1.5K$, as noted in section 5.4.4.

Appendix A

References

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Appendix B

Some Conversion Factors

Length

inches \times 0.0254 \rightarrow metres (m)

feet \times 0.305 \rightarrow metres (m)

Mass

lb \times 0.454 \rightarrow kilogramme (kg)

lb \times 454 \rightarrow gramme (g)

Calorific value

Btu lb⁻¹ \times 0.556 \rightarrow kilocalorie kilogramme⁻¹ (kcal kg⁻¹)

Btu lb⁻¹ \times 2326 \rightarrow joules kilogramme⁻¹ (J kg⁻¹)

kcal kg⁻¹ \times 4187 \rightarrow J kg⁻¹

Btu ft⁻³ \times 8.9 \rightarrow kcal m⁻³

Btu ft⁻³ \times 37260 \rightarrow J m⁻³

Energy

Btu \times 1055 \rightarrow joules (J)

therm \times 1055 \times 10⁵ \rightarrow J

kcal \times 4187 \rightarrow J

Joules second⁻¹ \rightarrow Watts (W)

Millions of Btu h⁻¹ \times 0.293 \rightarrow MW

Mass Flowrate

lb h⁻¹ \times 0.126 \rightarrow gramme second⁻¹ (g s⁻¹)

kg h⁻¹ \times 0.278 \rightarrow g s⁻¹

To convert concentration in ppm to mgm^{-3} , (approximately)

$$\text{mg m}^{-3} = \text{ppm} \cdot \left(\frac{m_w}{24} \right) \cdot \left(\frac{293}{T} \right),$$

where, m_w is the molecular weight of the pollutant and T (K) is the temperature. Ambient pressure is assumed.

To convert temperature in $^{\circ}\text{C}$ to Kelvin, K

$$T (\text{K}) = T (^{\circ}\text{C}) + 273$$

To convert pollutant concentration, c (mgm^{-3}) at STP, (that is, 273K and 101.3 kPa) and a given oxygen content, $O_2(\%)$ to the equivalent value at stack discharge conditions,

$$c_d = c_s \cdot \left(\frac{273}{T_d} \right) \cdot \left(\frac{100 - H_2O_{(d)}}{100} \right) \cdot \left(\frac{20.9 - O_{2(d)}}{20.9 - O_{2(s)}} \right),$$

where, d denotes discharge conditions

s denotes conditions at STP

$H_2O_{(d)}$ is the % moisture content in the stack

Further information can be found in Clayton (1992).

The discharge rate, D , of the pollutants at stack discharge conditions is then given by,

$$D (\text{g s}^{-1}) = \frac{(V \cdot c_d)}{1000},$$

where, V is the discharge volume flowrate from the stack.

Appendix C

Examples

Example 1: Determine the minimum discharge stack height for a cremator installed in an isolated building.

Information Required:

Building dimensions, 40m × 15m × 12m high to the ridge
 Discharge gas temperature, 200°C (473K)
 Volume discharge rate of gases (dry), 2.68 m³ s⁻¹ at 200°C (473K)
 Gas discharge velocity, 16 m s⁻¹
 Stack oxygen (dry), 18.5%
 Moisture in Discharge 4.0%

From the Secretary of State's *Guidance on Crematoria*, PG5/2 (1991) amended in 1992, the emission concentration limits for the following are:

Hydrogen Chloride (HCl)	200 mg m ⁻³
Carbon Monoxide (CO)	100 mg m ⁻³
Suspended Particulate Matter (SPM)	80 mg m ⁻³

at conditions of STP i.e. 273K, 101.3kPa and 11% oxygen (dry).

Maximum discharge rates of other pollutants at discharge conditions are taken to be:

Sulphur Dioxide (SO ₂)	0.160 g s ⁻¹
Nitrogen Dioxide (NO ₂)	0.020 g s ⁻¹
Nitric Oxide (NO)	0.070 g s ⁻¹

District: A highly developed large urban area is assumed.

Stack Height Calculation

1. It is important to note that the emission concentration limits, c , for the pollutants given in the Process Guidance Note are at conditions of STP and 11% oxygen (dry). These must be converted to gas concentrations and hence discharge rates at stack discharge conditions. This can be done by using the equations in Appendix B,

$$c_d = c_s \cdot \left(\frac{273}{T_d} \right) \cdot \left(\frac{100 - H_2O_{(d)}}{100} \right) \cdot \left(\frac{20.9 - O_{2(d)}}{20.9 - O_{2(s)}} \right)$$

where d denotes discharge conditions,
 s denotes conditions at STP,
 H_2O is the % moisture content in the stack and
 O_2 is the % oxygen in the stack

The discharge rate of the pollutants is then given by,

$$\text{Discharge Rate (g s}^{-1}\text{)} = \frac{(V \cdot c_d)}{1000}$$

where V is the discharge volume flowrate.

Thus for hydrogen chloride,

$$c_d(\text{HCl}) = 200 \cdot \left(\frac{273}{473}\right) \cdot \left(\frac{100-4}{100}\right) \cdot \left(\frac{20.9-18.5}{20.9-11}\right) = 26.86 \text{ mg m}^{-3}$$

Therefore,

$$\text{Discharge Rate (HCl)} = \frac{(2.68 \times 26.86)}{1000} = 0.072 \text{ g s}^{-1}$$

Similarly, the discharge rates for the other pollutants are,

Carbon Monoxide (CO)	0.036 g s ⁻¹
Suspended Particulate Matter (SPM)	0.029 g s ⁻¹

2. The guideline concentrations (from Section 4.3.2, Table 1) for the discharged pollutants are as follows:

SO ₂	= 0.44 mg m ⁻³
NO ₂	= 0.20 mg m ⁻³
HCl	= 0.10 mg m ⁻³
NO	= 1.00 mg m ⁻³
CO	= 57 mg m ⁻³
SPM	= 0.30 mg m ⁻³

3. Estimated background concentrations, B_c, of the relevant common pollutants (from Section 4.5, Table 2) for a highly developed large urban area are as follows:

SO ₂	= 0.12 mg m ⁻³
NO ₂	= 0.12 mg m ⁻³
NO	= 0.25 mg m ⁻³
SPM	= 0.20 mg m ⁻³

The background concentration, B_c, for the acid gas SO₂ needs to be expressed as an equivalent concentration, B_e, of the other discharged acid gas, HCl. This can be calculated using Table 3 and Equation (2).

The equivalent background concentration, B_e, of HCl corresponding to the existing background concentration, B_c, of SO₂ is given by Equation (2),

$$B_e = B_c \times \left(\frac{G_d}{G_b}\right)$$

For a discharge of HCl and a background concentration of SO₂,

$$G_d/G_b = 0.23.$$

Thus, the SO₂ is equivalent to a background concentration of HCl of,

$$B_e(\text{HCl}) = 0.12 \times 0.23 = 0.028 \text{ mg m}^{-3}.$$

4. Calculation of the Pollution Index corrected for background levels of pollutants.

The equation for the Pollution Index (Equation (1)) is given in Section 4.1 as,

$$\text{Pollution Index, } P_i = \frac{D}{(G_d - B_c)} \times 1000.$$

where, in the case of HCl, $B_c = B_e$.

Thus,

$$P_i(\text{SO}_2) = \frac{0.16}{0.44 - 0.12} \times 1000 = 500 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{NO}_2) = \frac{0.02}{0.2 - 0.12} \times 1000 = 250 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{HCl}) = \frac{0.072}{0.1 - 0.028} \times 1000 = 1000 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{NO}) = \frac{0.07}{1.00 - 0.25} \times 1000 = 93 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{CO}) = \frac{0.036}{57 - 0} \times 1000 = 0.63 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{SPM}) = \frac{0.03}{0.3 - 0.2} \times 1000 = 300 \text{ m}^3 \text{ s}^{-1}.$$

The Pollution Indices for the acid gases (excluding NO_2 and NO) are summed while the Pollution Indices for NO_2 , NO , CO and SPM are considered separately for the reasons given in Section 4.5.

Therefore, for the acid gases,

$$\begin{aligned} P_i(\text{TOTAL}) &= P_i(\text{SO}_2) + P_i(\text{HCl}) \\ &= 500 + 1000. \\ &= 1500 \text{ m}^3 \text{ s}^{-1}. \end{aligned}$$

This value of the Pollution Index is larger than those for NO_2 , NO , CO or SPM . It is, therefore, used for determining the discharge stack height.

5. Calculation of U_b

Substituting relevant values into Equation (3) from Section 5.2 gives the heat release as,

$$Q = \frac{2.68 \left(1 - \frac{283}{473}\right)}{2.9} = 0.4 \text{ MW}$$

The uncorrected discharge stack height due to buoyancy U_b is determined using Equation (6) from Section 5.2,

$$U_b = 10^a P_i^b$$

where, for $Q = 0.4$ MW, $a = -1.03$ and
 $b = 0.49$.

So, $U_b = 10^{-1.03} \cdot (1500)^{0.49}$.

Thus, **$U_b = 3.4$ m.**

The minimum value of U_b required for a heat release of 0.4MW is 1.64 m (from Section 5.2, Equation (7)). Thus U_b is taken as 3.4 m.

6. Calculation of U_m

The discharge momentum, M , is determined using Equation (9) from Section 5.3,

Therefore,

$$M = \frac{283}{473} \times 2.68 \times 16 = 25.7 \text{ m}^4 \text{ s}^{-2}$$

The uncorrected chimney height, U_m , due to momentum is calculated using Equation (15) from Section 5.3,

$$\log_{10} U_m = x + (y \cdot \log_{10} P_i + z)^{0.5},$$

where,

$$\begin{aligned} x &= -2.34, \\ y &= 5.02 \text{ and} \\ z &= -6.71. \end{aligned}$$

So, $\log_{10} U_m = -2.34 + (5.02 \times \log_{10}(1500) - 6.71)^{0.5}$.

Thus, **$U_m = 5.0$ m.**

The minimum value of U_m required for a discharge momentum of $25.7 \text{ m}^4 \text{ s}^{-2}$ is 2.3 m (from Section 5.3, Equation (16)). Thus U_m is taken as 5.0 m.

7. Calculation of Final Discharge Stack Height, C

The uncorrected discharge stack heights due to buoyancy and momentum are now used to determine a final discharge stack height correcting for the building in which it is to be installed.

The correction due to single, wide buildings is given by Equation (17) in Section 5.4 as,

$$C = H + 0.6\{U + (2.5H - U)(1 - A^{-U/H})\},$$

where, $H = 12$ m,
 $U = 3.4$ m (the lesser of U_b and U_m), and
 $A = U_m/U_b = 5.0/3.4 = 1.5$.

Therefore, **$C = 16$ m** (rounded up to the nearest metre).

The final discharge stack height required is 16 m (4 m above the building).

Example 2: Determine a minimum discharge stack height for a furnace heated by gas oil and used for the manufacture of lead glass.

Information Required:

Building dimensions 50m × 30m × 20m high

Discharge gas temperature, 300°C (573K)

Discharge volume of gases (dry), 6.3 m³ s⁻¹ at 300°C (573K)

Gas discharge velocity, 15m s⁻¹

Stack oxygen (dry), 6.7%

Moisture in Discharge, 8.2%

From the Secretary of State's *Guidance on the Manufacture of Lead Glass*, PG 3/4 (1991) the emission concentration limits for the following are:

Hydrogen Fluoride	(HF)	5 mg m ⁻³
Hydrogen Chloride	(HCl)	30 mg m ⁻³
Sulphur Dioxide	(SO ₂)	750 mg m ⁻³
Nitrogen Dioxide	(NO ₂)	240 mg m ⁻³
Nitric Oxide	(NO)	960 mg m ⁻³
Lead	(Pb)	2 mg m ⁻³
Suspended Particulate Matter (SPM)		100 mg m ⁻³

at conditions of STP ie. 273K, 101.3kPa and 8% oxygen (dry).

District: A heavy industrial area is assumed.

Stack Height Calculation

1. It is important to note that the emission concentration limits for the pollutants given in the Process Guidance Note are at conditions of STP and 8% oxygen (dry). These must be converted to gas concentrations and hence discharge rate at stack discharge conditions. This can be done by using the equations in Appendix B,

$$c_d = c_s \cdot \left(\frac{273}{T_d} \right) \cdot \left(\frac{100 - H_2O_{(d)}}{100} \right) \cdot \left(\frac{20.9 - O_{2(d)}}{20.9 - O_{2(s)}} \right)$$

where d denotes discharge conditions

s denotes conditions at STP

H₂O is the % moisture content in the stack

O₂ is the % oxygen in the stack

The discharge rate of the pollutants is then given by,

$$\text{Discharge Rate (g s}^{-1}\text{)} = \frac{(V \cdot c_d)}{1000}$$

where V is the discharge volume flowrate

Thus for hydrogen fluoride,

$$c_d(HF) = 5 \cdot \left(\frac{273}{573} \right) \cdot \left(\frac{100 - 8.2}{100} \right) \cdot \left(\frac{20.9 - 6.7}{20.9 - 8} \right) = 2.41 \text{ mg m}^{-3}$$

Therefore,

$$\text{Discharge Rate (HF)} = \frac{(6.3 \times 2.41)}{1000} = 0.015 \text{ g s}^{-1}$$

Similarly, the discharge rates for the other pollutants are,

Hydrogen Chloride	(HCl)	= 0.091 g s ⁻¹
Sulphur Dioxide	(SO ₂)	= 2.275 g s ⁻¹
Nitrogen Dioxide	(NO ₂)	= 0.728 g s ⁻¹
Nitric Oxide	(NO)	= 2.910 g s ⁻¹
Lead	(Pb)	= 0.006 g s ⁻¹
Suspended Particulate Matter (SPM)		= 0.310 g s ⁻¹

2. The guideline concentrations (see Section 4.3.2 and Table 1) for the discharged pollutants are as follows:

HF	=	0.063 mg m ⁻³
HCl	=	0.10 mg m ⁻³
SO ₂	=	0.44 mg m ⁻³
NO ₂	=	0.20 mg m ⁻³
NO	=	1.00 mg m ⁻³
Pb	=	0.0038 mg m ⁻³
SPM	=	0.30 mg m ⁻³

3. Estimated background concentrations, B_c of common pollutants (from Section 4.5, Table 2) for a heavy industrial area are as follows:

SO ₂	=	0.16 mg m ⁻³
NO ₂	=	0.17 mg m ⁻³
NO	=	0.40 mg m ⁻³
Pb	=	0.0005 mg m ⁻³
SPM	=	0.40 mg m ⁻³

The background concentration, B_c, for the acid gas SO₂ needs to be expressed as an equivalent concentration, B_e, of the other discharged acid gases (in this case HF and HCl). This can be calculated using Table 3 and Equation (2).

$$B_e = B_c \times \left(\frac{G_d}{G_b} \right),$$

For the background pollutant SO₂, G_d/G_b (for HF) = 0.14, and
 G_d/G_b (for HCl) = 0.23.

Thus, the SO₂ is equivalent to a background concentration of HF of,

$$B_e(\text{HF}) = 0.16 \times 0.14 = 0.022 \text{ mg m}^{-3}.$$

Similarly, the SO₂ is equivalent to a background concentration of HCl of,

$$B_e(\text{HCl}) = 0.16 \times 0.23 = 0.037 \text{ mg m}^{-3}.$$

Typical background levels of suspended particulate matter for this type of district are already in excess of the guideline concentration. It is likely that local values may in fact be lower for this specific case and this could be found by ambient monitoring. Otherwise, either an excessive discharge of SPM must be accepted or further particulate abatement would be required.

4. Calculation of the Pollution Index corrected for background levels of pollutants.

The equation for the Pollution Index is given in Section 4.1 as,

$$\text{Pollution Index, } P_i = \frac{D}{(G_d - B_c)} \times 1000$$

where $B_c = B_e$ for HF and HCl.

Thus,

$$P_i(\text{HF}) = \frac{0.015}{0.063 - 0.022} \times 1000 = 366 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{HCl}) = \frac{0.091}{0.1 - 0.037} \times 1000 = 1444 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{SO}_2) = \frac{2.275}{0.44 - 0.16} \times 1000 = 8125 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{NO}_2) = \frac{0.728}{0.2 - 0.17} \times 1000 = 24270 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{NO}) = \frac{2.91}{1.00 - 0.40} \times 1000 = 4850 \text{ m}^3 \text{ s}^{-1}.$$

$$P_i(\text{Pb}) = \frac{0.006}{0.0038 - 0.0005} \times 1000 = 1820 \text{ m}^3 \text{ s}^{-1}.$$

The Pollution Indices for the acid gases (excluding NO_2 and NO) are summed. The Pollution Indices for NO_2 , NO and Pb are considered separately for the reasons given in Section 4.5.

Therefore,

$$\begin{aligned} P_i(\text{TOTAL}) &= P_i(\text{HF}) + P_i(\text{HCl}) + P_i(\text{SO}_2) \\ &= 366 + 1444 + 8125 \\ &= 9950 \text{ m}^3 \text{ s}^{-1}. \end{aligned}$$

The value of the Pollution Index is greatest for NO_2 . It is, therefore, used for determining the discharge stack heights.

5. Calculation of U_b

Substituting relevant values in Equation (3) from Section 5.2 gives the heat release as,

$$Q = \frac{6.3 \left(1 - \frac{283}{573}\right)}{2.9} = 1.1 \text{ MW}$$

The uncorrected discharge stack height due to buoyancy U_b is determined using Equation (6) from Section 5.2.

Therefore,

$$U_b = 10^a \cdot P_i^b.$$

For $Q = 1.1 \text{ MW}$, $a = -1.12$, and
 $b = 0.49$.

So, $U_b = 10^{-1.12} \cdot (24270)^{0.49}$.

Thus, **$U_b = 10.7 \text{ m}$**

This value of U_b is higher than the lower limit of 1.97 m (obtained using Equation (8) from Section 5.2) for $Q = 1.1 \text{ MW}$. Therefore, 10.7 m is used for the rest of the calculation.

6. Calculation of U_m

The momentum flux, M , is determined using Equation (9) from Section 5.3 to give,

$$M = \frac{283}{573} \times 6.3 \times 15 = 47 \text{ m}^4 \text{ s}^{-1}$$

The uncorrected chimney height, U_m , due to momentum is calculated using Equation (15) from Section 5.3,

$$\log_{10} U_m = x + (y \cdot \log_{10} P_i + z)^{0.5},$$

where,

$$x = -2.11,$$

$$y = 4.86, \text{ and}$$

$$z = -8.2.$$

So $\log_{10} U_m = -2.11 + (4.86 \times \log_{10}(24270) - 8.2)^{0.5}$.

Thus, **$U_m = 32.4 \text{ m}$**

This value of U_m is greater than the lower limit of 2.8 m (from Section 5.3, Equation (16)). Therefore, a value of 32.4 m is used for the rest of the calculation.

7. Calculation of Final Discharge Stack Height, C

The uncorrected discharge stack heights due to buoyancy and momentum are now used to determine a final discharge stack height correcting for the building in which it is to be installed.

The correction due to single, wide buildings is given by Equation (17) from Section 5.4 as,

$$C = H + 0.6\{U + (2.5H - U)(1 - A^{-U/H})\},$$

where,

$$H = 20 \text{ m,}$$

$$U = 10.7 \text{ m (the lesser of } U_b \text{ and } U_m), \text{ and}$$

$$A = 32.4/10.7 = 3.0$$

Therefore,

$$\mathbf{C = 37 \text{ m}}$$
 (to the nearest metre).

The final discharge stack height required is 37 m (17 m above the building).

Appendix D Figures 1–10

Figure 1 Heat Released at Discharge Stack Exit from Temperature and Discharge Volume. For Combustion Products or Contaminated Air.

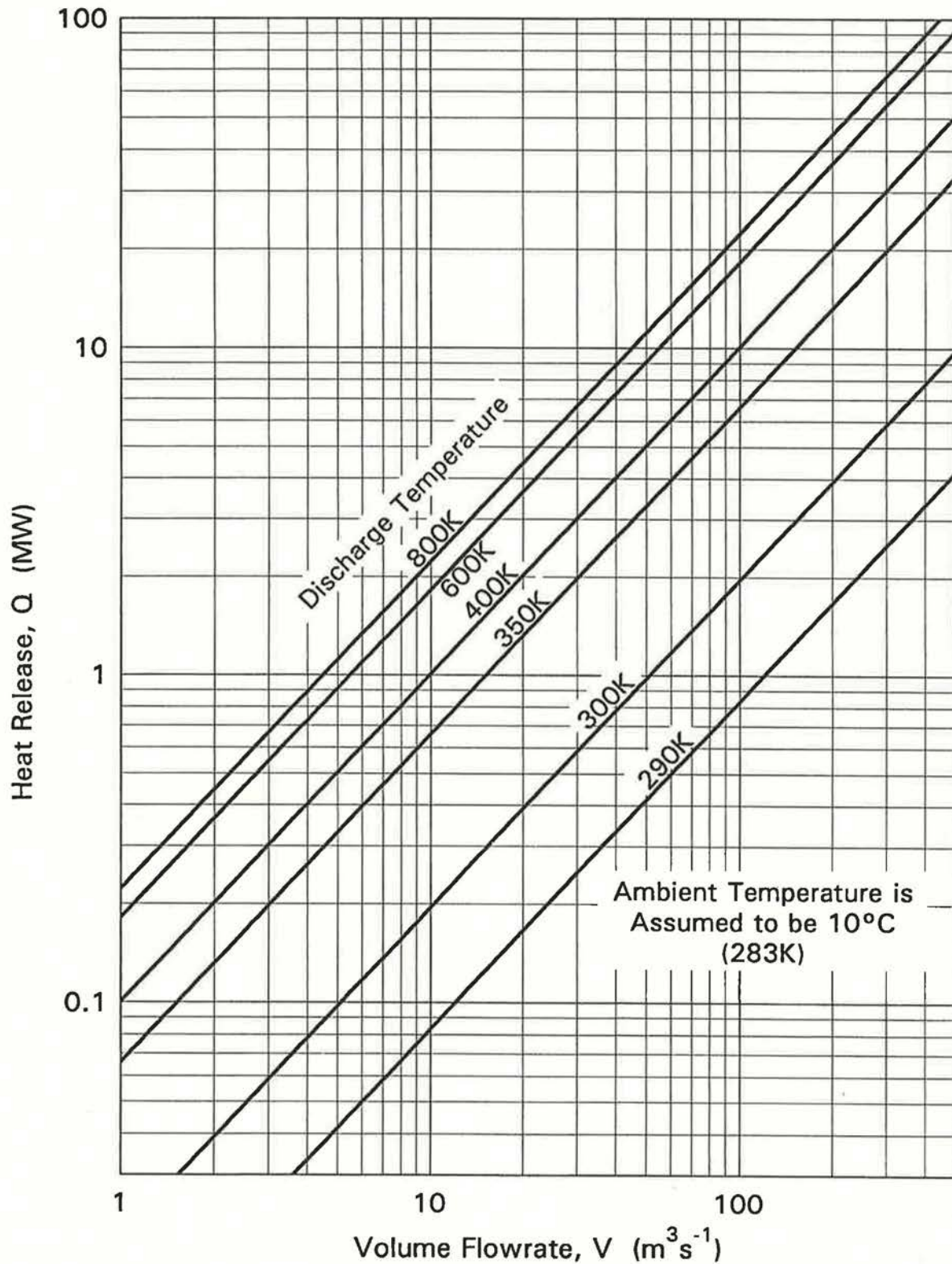


Figure 2 Uncorrected Discharge Stack Height, U_b , from P_i and Heat Released at Discharge Stack Exit

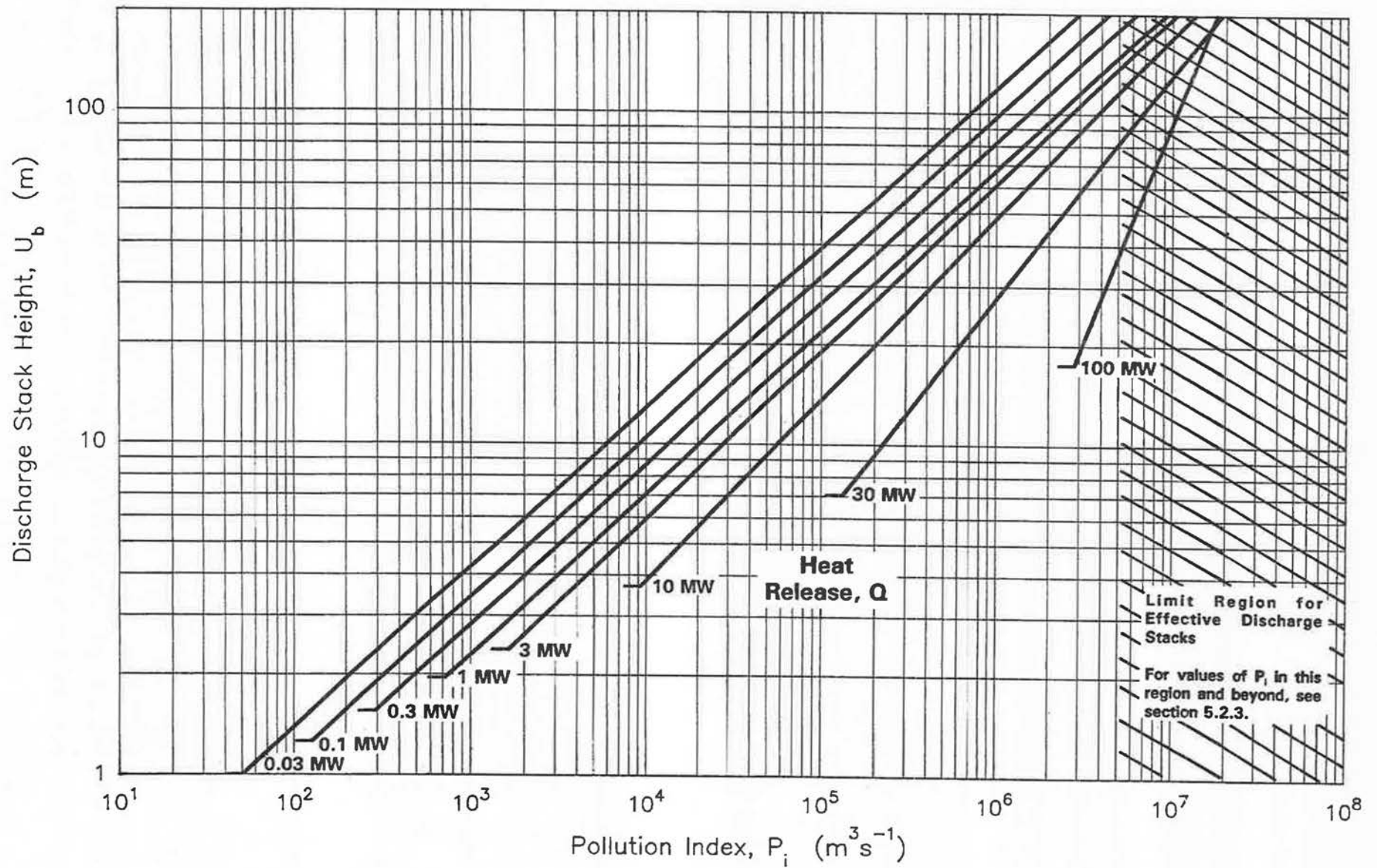


Figure 3 Discharge Momentum at Stack Exit from Stack Diameter and Discharge Velocity. For Discharges of Combustion Products or Contaminated Air at Ambient Temperature.

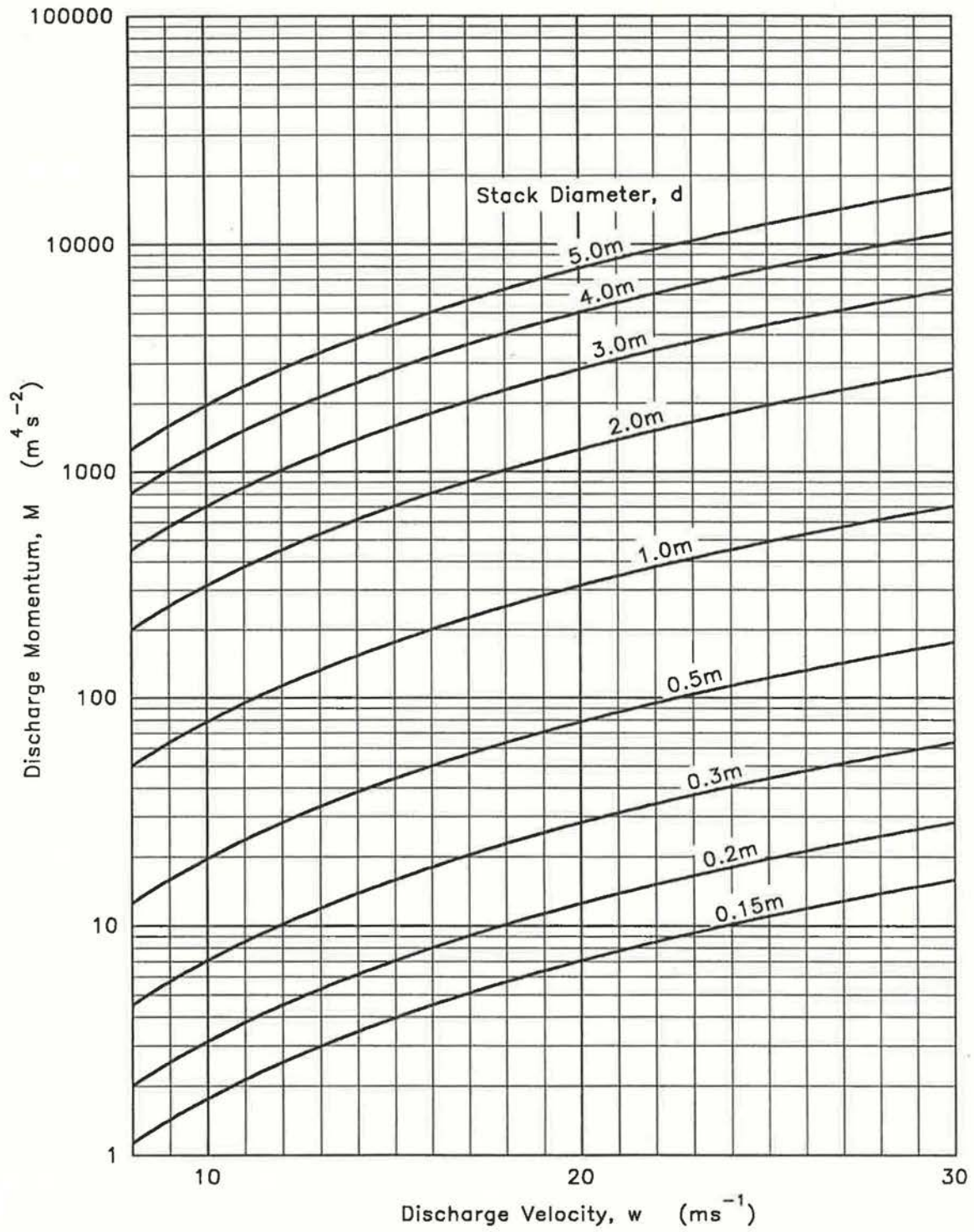


Figure 4 Uncorrected Discharge Stack Height, U_m , from P_i and Discharge Momentum

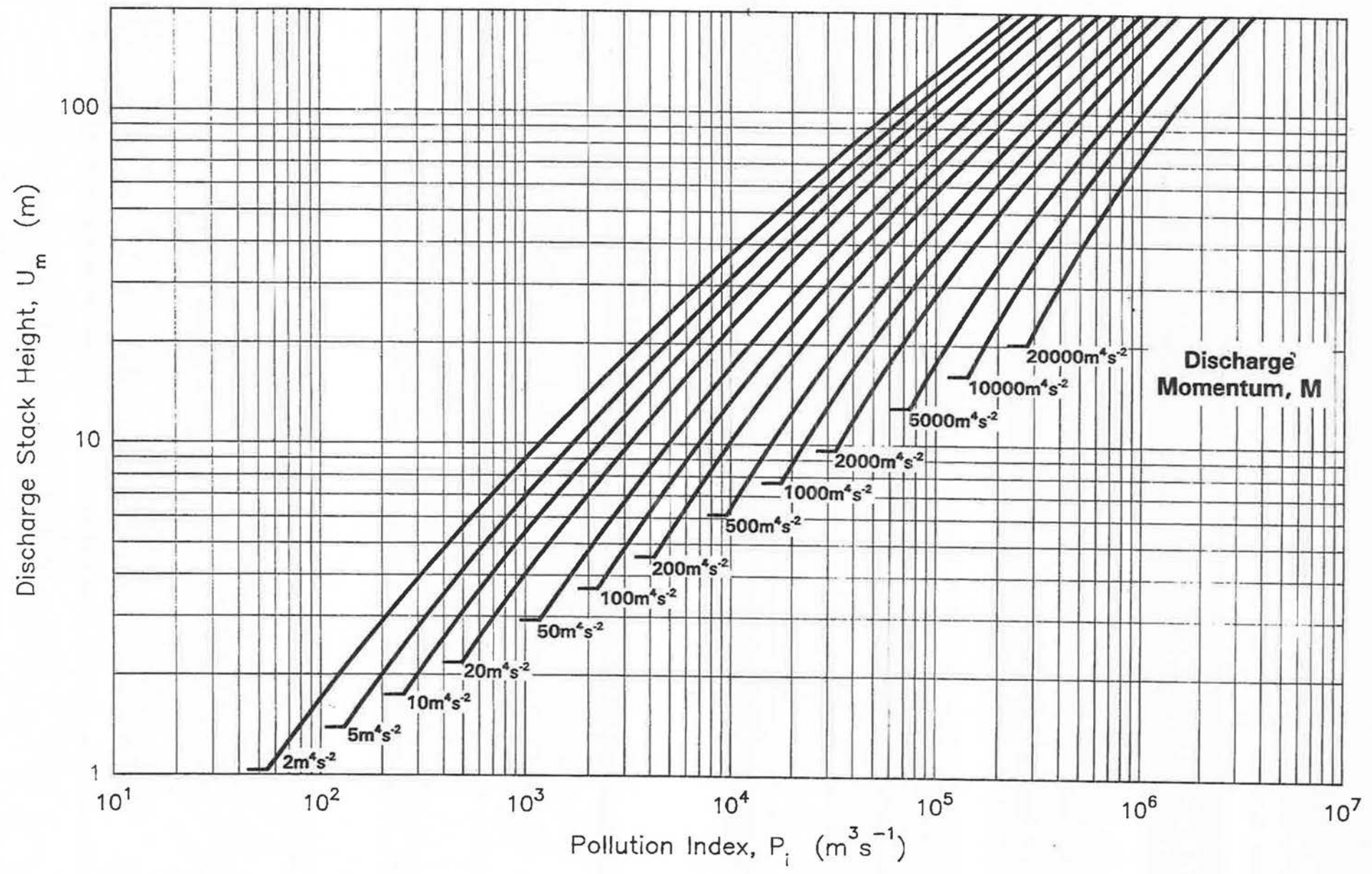


Figure 5 Method of Determining Heights and Widths of Buildings of Complex Shape

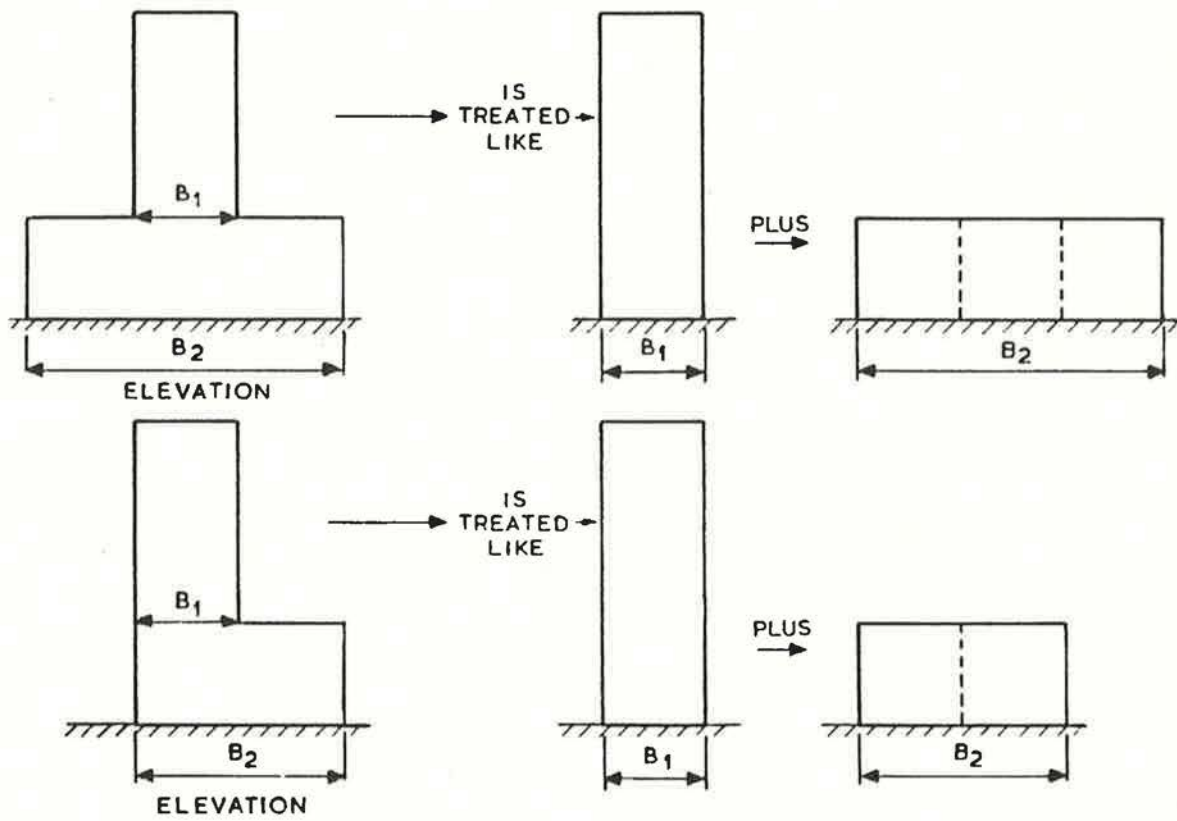


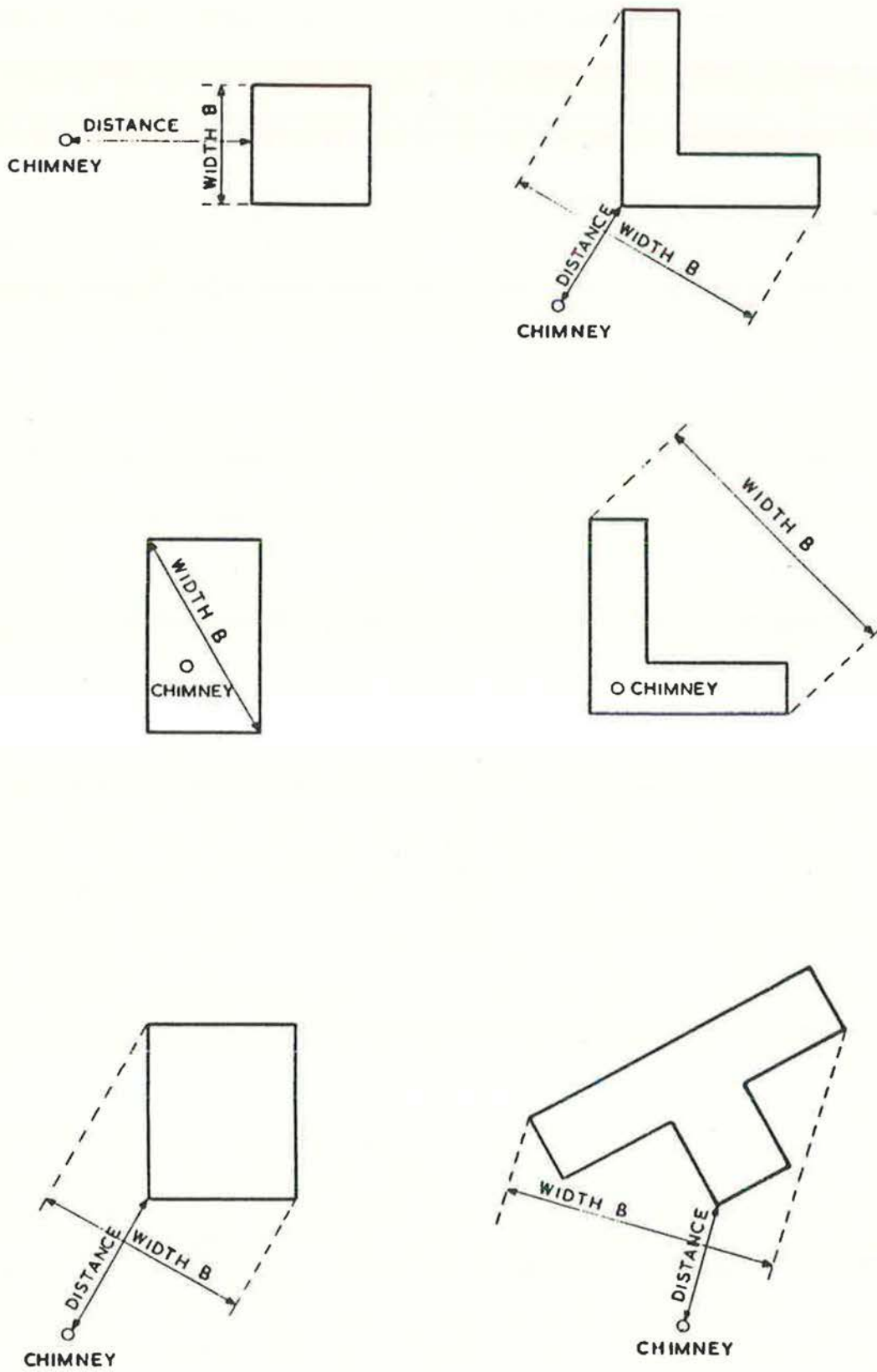
Figure 6 Method of Determining Chimney Distance and Building Width

Figure 7 Discharge Stack Height Correction for Low, Wide Buildings
 ($H_m/T_m \leq 0.4$, Eqn. 17)

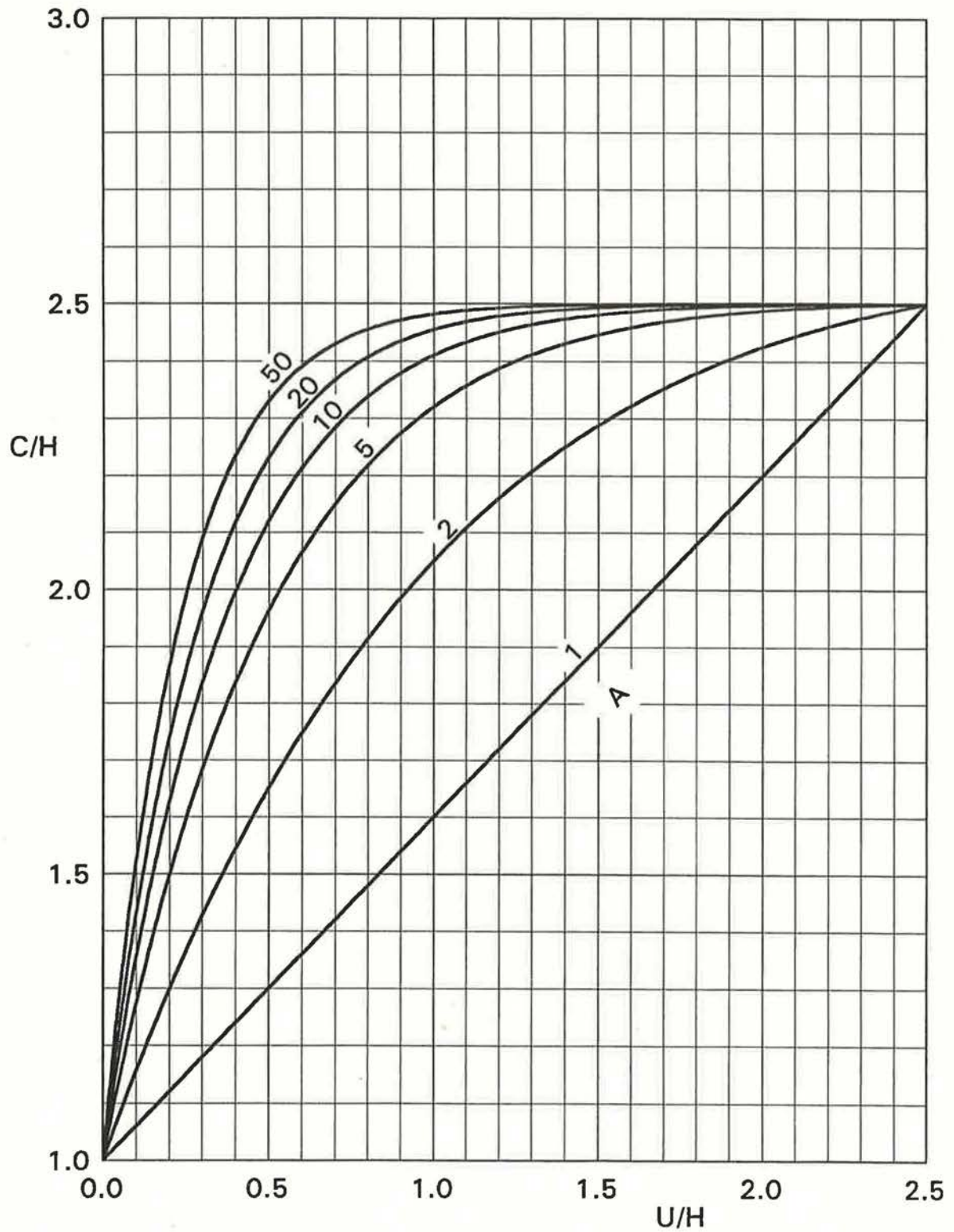
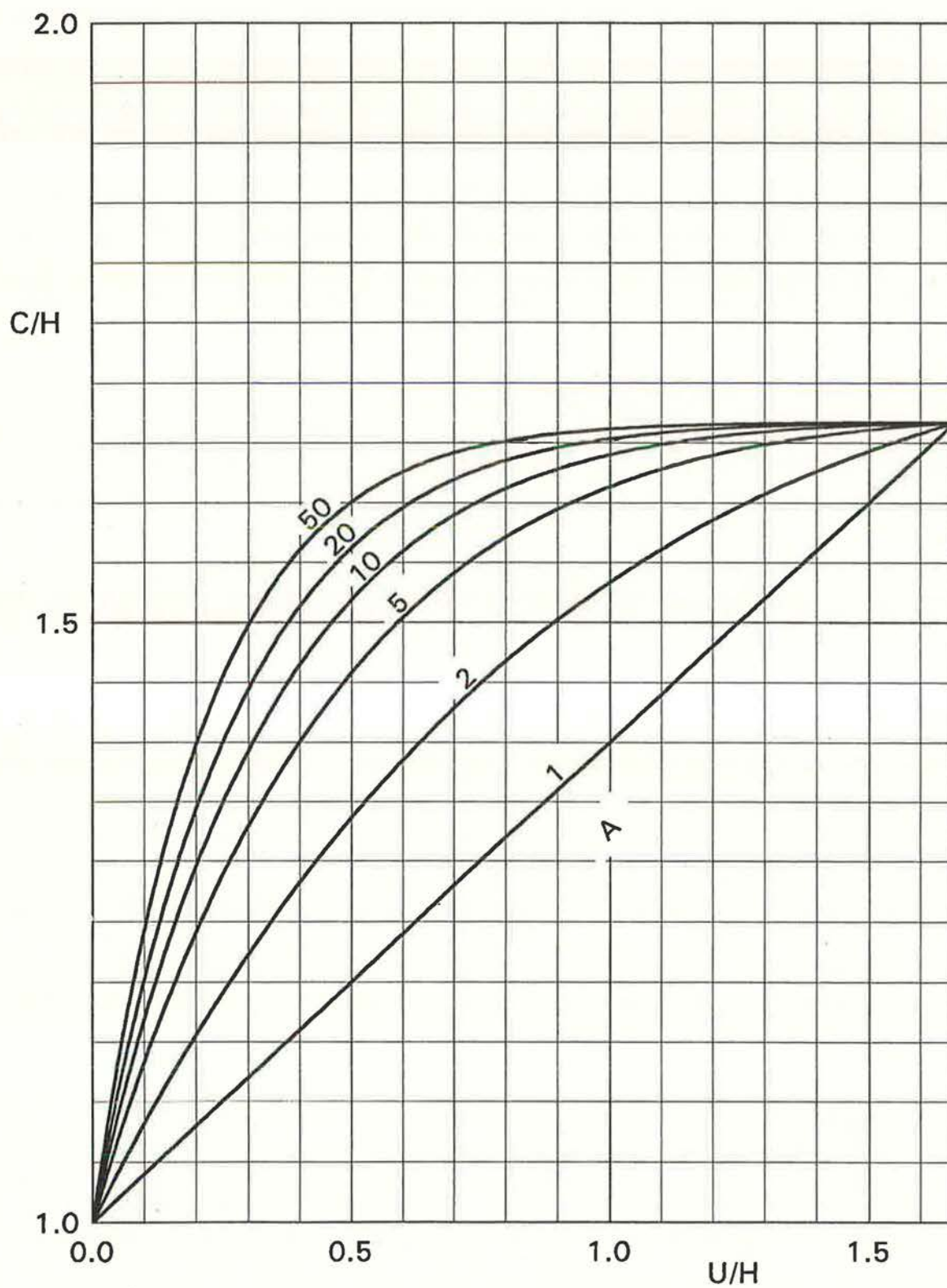


Figure 8 Discharge Stack Height Correction for $H_m/T_m = 0.6$ (Eqn. 18)

Appendix E

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IPR4/15 Processes for the Halogenation of Organic Chemicals

IPR4/16 Processes for the Manufacture of Chemical Fertilizers or their Conversion into Granules

IPR4/17 Bulk storage installations

(IPR4/10-17 due for publication July 1993)

Guidance Notes for processes contained in the remaining sectors will be published progressively before they become subject to integrated pollution control. More details from Room 238 Lambeth Bridge House, Albert Embankment, London SE1 7SB Tel 238 4636

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