KfK 3751
Juni 1984

# The Meteorological System and the Basic Parameters Required for Predicting the Transfer of Radionuclides Released into the Atmosphere

A. Shamsaldin
Hauptabteilung Sicherheit

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE
Hauptabteilung Sicherheit

KfK 3751

# The Meteorological System and the Basic Parameters Required for Predicting the Transfer of Radionuclides Released into the Atmosphere

A. Shamsaldin

Kernforschungszentrum Karlsruhe GmbH, Karlsruhe

Kernforschungszentrum Karlsruhe GmbH
ISSN 0303-4003

**Abstract**

The meteorological measuring system, operating at the site of the Karlsruhe Nuclear Research Centre, and the present working programme of the Environmental Meteorology Department of the Karlsruhe Nuclear Research Centre are described in this report.

The main aspects of meteorology and radioecology during normal operation and possible accidents arising from nuclear facilities, and natural sources of radioactivity are presented. Besides, different methods of dividing the atmosphere into stability classes and of determining the dispersion parameters are indicated.

Die zur Vorhersage des Transfers der in die Atmosphäre freigesetzten Radionuklide erforderlichen meteorologischen Einrichtungen und grundlegenden Parameter

**Kurzfassung**

Im vorliegenden Bericht werden die auf dem Gelände des Kernforschungszentrums Karlsruhe in Betrieb befindlichen Einrichtungen für meteorologische Messungen und das derzeitige Arbeitsprogramm der Abteilung "Umweltmeteorologie" des Kernforschungszentrums Karlsruhe beschrieben.

Dargestellt werden die wichtigsten meteorologischen und radioökologischen Aspekte bei Normalbetrieb und unter Bedingungen vorstellbarer Unfälle in nuklearen Anlagen sowie natürliche Quellen für Radioaktivität. Darüber hinaus werden unterschiedliche Methoden zur Einteilung der Atmosphäre in Ausbreitungskategorien und zur Bestimmung der Ausbreitungsparameter genannt.

**Table of Contents**

## 1. Introduction

At the Irak Nuclear Research Centre (INRC), routine environmental monitoring, restricted to the area covered by the site proper and its immediate vicinity, is going on. For this purpose, activity concentrations are measured and analysed in various material samples (soil, water, precipitation, biological materials). Accumulated doses are also measured - if any - by TL dosemeters, distributed at different points on the INRC area. But more effective environmental monitoring requires prediction of radiation exposure of the population living in the vicinity. Radiation exposure calculation, besides the accurate knowledge about the source data (e.g., the emission height, the emission rate, the composition of the emission), needs knowledge about the microclimate of the site. And this requires a meteorological measuring system able to provide continuously meteorological data, operating on the location. Sufficient trained staff is also necessary. For this purpose I am in the Environmental Meteorology Department of the Karlsruhe Nuclear Research Centre (HS/M), for a period of 9 months, which permitse me to study the meteorological measuring system and working programme of HS/M, participating in some studies about Doppler-Sodar, and to be provided by helpful advices from the leader and the expert personel of HS/M. In this report the meteorological measuring system of HS/M which furnishes continuously satisfactory data required for their actual routine and research work, is described as a system required for studying the atmospheric diffusion of the pollution and the calculation of the potential dose.

The meteorological data required for such studies and calculations, the parameters characterizing the dispersion of the radioactive materials released into the air, the effect of terrain roughness on these parameters and their determinations are described in a simple way in order to help beginners in these fields of study.

## 2. The Meteorological Measuring System and Programme of HS/M

### 2.1 Description of the Meteorological Information System (MIS)

The MIS of HS/M includes about 50 instruments in total, which are used to measure the following parameters:

- The horizontal wind speed u.
- The horizontal wind direction $\theta$.
- The wind vector ($\vec{v}$) from which vertical and horizontal wind direction $\phi$ and $\theta$, the standard deviation of the vertical wind direction $\sigma_\phi$ and the standard deviation of the horizontal wind direction $\sigma_\theta$ are deduced.
- The air temperature T.
- The dewpoint.
- The solar radiations (long and short waves) and ground radiations.
- The precipitation.
- The atmospheric pressure P.

Most of these instruments are mounted at the 200 m high meteorological tower, at different levels. It stands in south west of KfK. Fig. 1 shows the scheme of the tower and the instrumentation of the meteorological information system at KfK. The other instruments are located on a rectangular meadow of 100 m x 60 m in area. This meadow is surrounded by a pine forest of about 20 m height. The specifications of the meteorological instruments are summarized in Table 1.

The different columns have the following indications

(1) The instrument measuring and the measuring height.
(2) The type and measuring principle.
(3) The accuracy A (in perentage) and the measuring thresholds T.
(4) Non available data (in perentage) in 1983.
(5) The reason for which the instrument is changed.
(6) The normal operating interval of the instrument.
(7) The measuring time intervals.

All the instruments specified in Table 1 are connected to the computer system in HS/M. Figures 2 to 9 show some of these measuring instruments (DI 76, KI 82).

## 2.2 The Hardware of the Meteorological Information System (MIS)

The scheme of the hardware of MIS in HS/M is shown in Fig. 10. This hardware consists of three systems:

### Control System

The control system contains:

- A Camac which includes channels concerning 4 s rythm instruments and channels concerning 1 s rythm (see Table 1). Meterological data are measured every 4 seconds (every 1 s for those measured by the vector vane) and averaged over a 10 min time interval (see 2.5). It means that the data are furnished as 10 min mean-values. Every channel has his own control programme such that in the case of a failure in an instrument only this data is lossed and a message is recorded and also sent to the alarm centre (KI 81, KI 82).

- A radio clock.
- A computer PDP 11/34.
- A system disc.
- A data disc.

The central system includes:

- The central process computer PDP 11/44.
- Data discs with a capacity of 2 months (10 min mean-values). It means that it is possible to keep the data furnished during 2 months on these data discs. Usually all the measured data (as 10 min values) are stored in the computer centre (HDI) of KfK.

- A system disc.
- A magnet-tape system to record the furnished data, which are monthly sent to HDI, to be recorded and stored on tapes to be available upon request.
- A cassette station COLUMBIA C300 and TU58. This system serves to transmit, e.g., Doppler-Sodar data (see TH 83), recorded on cassettes to IBM compatible tapes.
- A terminal system which permits to change some parameters in the control programme.
- A user terminal which prints the 10 min data blocks. A data block includes: wind speed and direction at 40 m, 100 m, 160 m heights, air temperature at 2 m, 100 m, 200 m heights, the temperature gradient $\Delta T°C/100$ m, the dewpoint measured at 2 m height, global solar radiation, solar balance SB (see 2.3), $\sigma_\theta$ and $\sigma_\phi$ at 100 m and the rainfall amount. It can be remarked that 100 m height is the most interesting measurement height because most of the stacks of the nuclear power plants in the Federal Republic of Germany are 100 m high. 40 m height for the wind data is choosen because it is considered to be the lowest level not influenced by the obstacles (e.g., the surrounding trees, the buildings of KfK). The 160 m height is interesting because the effective height of the emission source can be higher than the geometrical stack height, and 200 m height is interesting for the air temperature measuring because it is the highest possible level of measuring. The 200 m tower system furnishes the lapse rate which is the temperature gradient over 100 m height in °C/100 m.

- User terminals distributed in different departments in KfK. One of them (GIGI) is in HS/M, which is connected to the plotter existing nearby. The users terminals actually permit monitoring the meteorological conditions on the site of KfK and the radionuclide concentration distribution in the atmosphere, during a defined time interval, if the emission height and rate are available. The informations can be obtain digital or in coloured figures and/or the hardcopy can be also furnished.

Testing System

The testing system permits to test every instrument connected to the hardware. During the testing time interval, only, the tested instrument is separated from the Camac and the concerning data is loosed.

## 2.3 The Software of MIS

All the computer programmes are written in FORTRAN language. The programmes are able to calculate and furnish the measured data (shown in Table 1) as 10 min mean values. Some programmes are written to calculate and furnish other parameters needed for the diffusion calculations of offgas plume. The following are hardcopies of some furnished informations:

- Table 2 shows the 10 min mean values of the horizontal wind speed (mean, min, max), the calm frequency during this 10 min, the measuring heights and the horizontal wind direction (mean) for the 10 min time interval from 9 h 50 until 10 h 00 at 29 March 1984.

- Fig. 11 shows the wind speed profile and the mean wind directions at different heights for the 10 min from 9 h 50 until 10 h at 29 March 1984. The y-axis represents the measuring heights in m and the x-axis represents the horinzontal wind speed in m/s.

- Fig. 12 shows the standard deviation of the vertical wind direction $\sigma_\phi$ measured by the vector vane from 4 h 00 until 10 h 00 at 29 Mach 1984, at the heights 40 m, 100 m and 160 m. The y-axis is the $\sigma_\phi$ value in degrees and the x-axis is the day time (middle Europe time) in hours.

- Fig. 13 shows the standard deviation of the horizontal wind direction $\sigma_\theta$ ; measured by the vector vane from 4 h 00 until 10 h 00 at 29March 1984. The y-axis is the $\sigma_\theta$ value in degrees and the x-axis the day time in hours.

- Fig. 14 shows the air temperature profile, the temperature gradient in °C/100 m and the dewpoint measured at the heights shown as y-axis in m from 9 h 50 until 10 h 00 at 29 March 1984.

- Fig. 15 shows the solar radiation E and the ground radiation A (long and short waves) from 4 h 00 until 10 h 00 at 31 March 1984. The y-axis represents the radiation in cal/min·cm² and the x-axis represents the day time in hours. The solar balance SB is deduced from the difference between E and A. SB is a parameter which can be used to characterize the stability (see chapter 5).

- Fig. 16 shows the global solar radiation G (short waves) and the ground reflection R for the time interval from 4 h 00 until 10 h 00 at 31 March 1984. The axes have the same meaning as in Fig. 15.

- Fig. 17 shows the wind vector ($\vec{v}$) variation at 40 m, 100 m, 160 m for the 10 min time interval from 9 h 50 until 10 h 00 at 29 March 1984. The y-axis represents the wind velocity in m/s and the x-axis represents the day time in (h).

- Fig. 18 shows the radionuclide concentration distribution around the emission source (presented at the origin point) for an emission height of 100 m and an emission rate of $0.37 \times 10^{11}$ Bq/h. The maximum position showed in a dark square is in the north east of the source, because the wind was blowing from south west. The axes show the directions nourth N, south S, east and west W and are divided in km (0 to 10 km from every direction). The isoconcentration curves of 50 %, 10 %, 1 % and 0.1 % of the maximum value 9.21 Bq·h/m³, as calculated, can be distinguished on the terminal screen in different colours. These informations are obtained using the programme ISOKON which is helpful in the case of an accident to monitor the location of high concentration, and the doses can soon be calculated, using the concentration found by ISOKON.

The calculation to obtain the informations is usually made within a very short time and the results can be furnished on the screen or on hardcopy, digital or as curves and they can be also stored.

## 2.4 Maintenance and Calibration of MIS

The measuring system is supervised by the HS/M staff and the measured data are evaluated continuously. When a doubtful measuring is noticed, the measuring instrument is tested using the testing system (see 2.2). If the problem is caused by the instrument, it is directly changed and replaced by a new one. The failed instrument is tested again in HS/M and if the failure is certain it is sent to the responsible service in KfK. Simple problems in the computer system are resolved directly by HS/M staff. In the case of non directly reparable problems the computer service is called and the repair takes place within few minutes.

The calibration of the measuring instruments is going on after every change or repair of the instrument, therefore the calibration time interval of every instrument is the normal operating time interval of this instrument (see Table 1, column 6). But the barometer is controlled daily, using a Torcilly barometer as a standard.

## 2.5 The Working Programme of HS/M

In HS/M, research and routine works are going on. The routine work can be summarized as following:

- Measuring the meteorological data at different levels distributed between 30 m and 200 m (see Table 1). The measured values are evaluated and averaged over 10 min time intervals, such as for the 4 s rythm instruments, 150 measured values are averaged, and for the 1 s rythm instruments, 600 measured values are averaged to obtain every 10 min mean value. These 10 min mean values are available listed in HS/M or stored on tapes at HDI.

- Calculating, annually, the frequencies of: the direction of propagation (wind direction), wind velocity, atmospheric stability classes and rain intensity. These statistics are available upon request (VO 83).

- Determination annually of the diffusion stability classes by the following three methods: $\sigma_\phi$, $\sigma_\theta$ and $\Delta T/\Delta Z$ combined with the horizontal wind speed at 40 m level (see 5.2).

- The radiological impact assessment of radioactive offgas, released with exhaust air, on the environment of KfK within 10 km distance from the emission point. The calculated results are compared to the permissible dose equivalent. This task is solved annually due to the occasional addition of new emitters and the change in the source strenghts, the nuclide mixture and the meteorological conditions. Computer programmes are developed to take all these changes into account without difficulties, e.g., (NA 75, HU 79, BA 84a, BA 84b, PA 82).

Some examples of research works carried out at HS/M:
- Determination of atmospheric stability classes by statistical equivalence method (NE 80).
- Experimental determination of the atmospheric dispersion parameters (the horizontal and vertical standard deviations $\sigma y$ and $\sigma z$) over the site of KfK (TH 76a, TH 76b, TH 81, TH 83).
- Modeling of photochemical and heterogeneous sulfate aerosol formation in plumes (NE 83).
- A dynamic interaction of cooling tower and stack plumes (NE 82).
- Accident and risk analysis (BA 82).
- Experimental investigation in meso-scale transport by tetroon-flight technique (HU 82).
- Doppler-Sodar testing as a meteorological system (TH 83).
- The influence of ground roughness on atmospheric diffusion (NE 77).

# 3. Main Aspects of Meteorology and Radioecology

## 3.1 Meteorology and Environmental Monitoring

During operation of nuclear facilities radioactive materials are released into the atmosphere from the exhaust air stack. The radioactive plume travels away from the source of emission at wind velocity. The pollution concentration decreases continuously in the air in the course of this movement, mainly due to turbulence in the atmosphere, to dry deposition and to precipitation scavenging (rainout and washout). On the other hand these processes cause the transport of pollution to water, soil and vegetation. Radioactive decay of the nuclides is another way of dilution in the air. But during these processes new radioactive isotopes can be built up which can take part in the environmental pollution.

From these pollutants, dispersed in the environs of the nuclear facilities man is exposed both externally (e.g., radioactive plumes) and/or internally (by radionuclides brought into the body with inhaled air, water and food). Therefore environmental monitoring is necessary such as to fulfil the following functions:

- Recording the environmental radioactivity already existing at the site of nuclear facilites (caused by natural sources) by means of background measurement (see 3.4).

- Routine monitoring while the facility operates under normal conditions.

- Monitoring following the release of radioactive meaterials due to an accident (see 3.3).

Controlling the rise of the environmental radioactivity, caused by fallout after nuclear weapons explosion tests, is also necessary to distinguish this activity rise from any impacts due to the operation of nuclear facilites. In addition an effective environmental monitoring must be based on a number of informations (source data, topography, geological conditions, agricultural structure and the knowledge of micrometeorology of the closer vicinity which is of particular importance).

## 3.2 Meteorological Requirement for Radioactive Dose Calculation in the Environment of Nuclear Facilities

From my studies I have deduced that:

Calculating the exposure in the environs during normal operation of a nuclear facility requires the knowledge of the meteorological conditions at the nuclear facility and its environs. Therefore a meteorological measuring system, able to provide continuously the necessary data (discussed in chapter 4 and 5) with computer controlled instrumentation, operating on the locality, is necessary.

Evaluation of measurements, data analysis, preparing statistically correct meteorological data about the site and providing instantaneous data are required to determine the diffusion of the pollutants in the atmosphere. Computer models which determine atmospheric diffusion, dispersion parameters and all the factors necessary for calculating doses (e.g., washout and rainout coefficients, dose equivalent factors in addition to the parameters discussed in 4. and 5.) to man due to the radioactive materials released with the exhaust air, is also desirable. The described treatment of information besides the maintenance of the instrumentation need sufficient staff who is trained in diffusion modeling and environmental impact assessment. Therefore the potential doses can be calculated annually and compared to permissible dose limit.

On the other hand, in the case of the escape of radioactive substances or the release of activity as a concequence of incidents or accidents, the spread of possible environmental contamination should be determined. For this purpose suitable computer models for short term release should be available. Therefore the concentration of the radioactive substance in the atmosphere and on the ground deposition, and the doses caused by the accidental release can be determined.

## 3.3 Natural Sources of Radiation

Until this century natural sources of radiation were the only sources of radioactivity in the atmosphere, and even nowadays, they contribute more than do all other artificial sources. The basic natural sources referred to ICRP (39) are:

- Cosmic radiation from sun and from outer space, which varies with altitude and latitude.
- Cosmic radionuclides (mainly $^{14}C$) produced through interaction of the cosmic rays with atoms in the atmosphere.
- Primordial radionuclides, which have existed in the earth's crust (rocks and soil) throughout its history (e.g., $^{40}K$ and nuclides in the uranium and thorium decay series).

The radioactivity caused by natural sources (called the background radioactivity) is measured as a first step to build a nuclear facility on a site. Preparing the site specification, the pattern of radioactivity in the environment is required to allow a distinction to be made between the operational impact and the activity background in the course of future operation of the nuclear facility. On the other hand, extensive measurements over the last few years sometimes has shown high natural radioactivites in some countries. The natural radioactivity is influenced in many ways by man activity (e.g., the contribution of new building materials enhanced the concentration of Radium and reduced ventilation rates have caused high radon concentrations).

A direct measurement of the natural radioactivity at many points distributed in the area can be made using a sensitive counting tube (e.g., ionisation chamber). Direct radiation doses and dose rates, caused by the natural sources, can be directly; determined using a sensitive dosimeter (e.g., solid-state dosimeters). Examples about background level measurements can be founed in (ME 83).

# 4. Meteorological Parameters Relevant to the Determination of the Dispersion of Radionuclides and the Influence of Topography on these Parameters

## 4.1 The Radionuclide Concentration Distribution

In order to assess the resulting exposure of the population living in the vicinity of the nuclear facility, caused by radioactivity released into the atmosphere, atmospheric diffusion calculation must be performed. A wide spectrum of mathematical air pollution dispersion models is now available, varying from the simple Gaussian model designed for a single source on smooth terrain to models dealing with long-range transport over complex topography, taking into account chemical transformation, radioactive decay, and various scavenging phenomena. In general a double Gaussian function is used as the basis of these calculations. The extension of the plume in the vertical and cross wind directions is described by the dispersion parameters $\sigma_y$ and $\sigma_z$, the standard deviations of the double Gaussian function.

The double Gaussian function describing the concentration distribution C (in $Ci/m^3$), normalized by the source strength Q (in Ci/s), close to the ground level at the field point p(x,y,o) downwind of the source, reads:

$$\frac{C(x,y,o)}{Q} = \frac{1}{\bar{u}\,\pi\,\sigma_y(x)\,\sigma_z(x)} \exp - \left( \frac{y^2}{2\,\sigma_y^2} + \frac{H^2}{2\,\sigma_z^2} \right) \qquad (1)$$

The dilution factor

$$\frac{C(x,y,o)}{Q}$$

(in $s/m^3$) is an important factor in calculating the doses delivered to man. In equation (1):

| | |
|---|---|
| $\bar{u}$ | average wind velocity in m/s (see 4.2) |
| H | effective emission height in m |
| $\sigma_y(x)$, $\sigma_z(x)$ | dispersion parameters in m (see 4.3) |
| x | downwind distance in m |
| y | crosswind distance in m |

Eq. (1) follows from the diffusion equation for steady-stade conditions, constant emission rate and reflection of the pollutant at ground level. The effective emission height is $H = h + \Delta h$, where h is the geometrical stack height and $\Delta h$ is the plume rise; for details see (HA 82). Plume rise is an important factor in determining maximum ground level concentrations from industrial sources, because industrial pollutions are emitted with high temperature ($\frac{\Delta h}{h}$ amounts to a factor up to 10). The maximum ground level concentration is roughly proportional to the inverse square of the effective emission height. But for nuclear plants, the effective emission height can be considered equal to the stack hight (geometrical emission height), because the plume rise is small, compared to the stack height, so that it can be neglected.

## 4.2 Meteorological Input Data Required for Air Pollution Dispersion Calculation

The Gaussian model, see Eq. 1, as all dispersion models, requires only 2 types of meteorological informations in order to determine the transport and dispersion of pollutants: the mean wind informations ($\bar{u}$, $\theta$) to describe the transport and the degree of turbulence to calculate the dispersion (see 4.2.2).

### 4.2.1 The Mean Wind Informations ($\bar{u}$ and $\theta$)

Air pollution dispersion models usualy take the observed wind information at plume level or extrapolate and/or interpolate from data observed at other locations to arrive at the mean wind at the level of interest. The values are then applied directly to the dispersion equation. If $\bar{u}$ at the plume height is not available, it is necessary to have representative measurements at lower levels, free from effects of buildings, trees etc. (see 5.2).

One assumption to account for the increase in wind speed with height is the use of an exponential law:

$$\bar{u} = \frac{1}{2H} \int_{0}^{2H} u_1 \left(\frac{z}{z_1}\right)^m dz$$

From this law the following equation can be derived

$$\bar{u} = \frac{u_1}{1 + m} \left(\frac{2H}{z_1}\right)^m \qquad (2)$$

where

$\bar{u}$ the average wind speed in m/s

$u_1$ the wind speed of the lower level in m/s

m exponent of vertical wind speed profile which has values from 0 to 1, depending upon the surface roughness of the site and the stability class.

Fig. 19 shows the influence of terrain roughness, characterised by open country (smooth terrain), woodland or suburban, and city centre (higher roughness), on the wind speed profile (OK 78).

The values of m, recommended by the Federal Republic of Germany Regulatory Guides, for rough terrain are given in Table 3.

Horizontal wind direction $\theta$ measurement, continuously, is necessary to assess the main atmospheric diffusion sector. The statistical wind direction frequency, which can be represented by the windrose (SL 68), must be available. If the highest frequency of wind direction is in the sector (e.g.) SW the max. concentration will be in the sector NE. Normally, no adjustment is made for changes in wind direction with height. This assumption (using low level $\theta$ for the plume level $\theta$) might be acceptable in simple dispersion problems such as emissions from a single stack in smooth terrain. However, it fails in coastal or complex terrain applications where strong wind shears and flow reversals are observed in the vertical wind profiles. This assumption also can fail in strongly stable conditions in flat terrain.

### 4.2.2 Turbulence Aspects Related to the Dispersion of Pollution

The dispersion of the pollution in the atmosphere is related to the turbulence intensity. For horizontal diffusion (characterized by $\sigma_y$), a relation can be satisfactory which depends only on the time and space scales. For vertical diffusion (characterized by $\sigma_z$), the relation between diffusion and turbulence intensity ($\sigma_z/u$) depends, additionally, on the stability class. The phenomenon underlying this relation is that an upward moving eddy which contributes a certain amount to the observed vertical turbulence produces more diffusion in unstable conditions than in stable conditions. In the unstable case, it rises higher before merging its material with the surrounding air. The dispersion parameters $\sigma_y$ and $\sigma_z$ are discussed in 4.3 and the stability classification in chapter 5.

### 4.3 Dispersion Parameters

The dispersion parameters $\sigma_y$ and $\sigma_z$ describe the horizontal and vertical distribution respectively, of the concentration perpendicular to the transport direction. The parameters $\sigma_y$ and $\sigma_z$ depend on the meteorological and topographical conditions prevailing at the respective sites. Experiments carried out at Alabama/U.S.A. showed that the values of $\sigma_y$ and $\sigma_z$ over complex terrain are factors 2 to 10 greater than that predicted by Pasquill curves (discussed later). Therefore experimental determinations of $\sigma_y$ and $\sigma_z$ are required at the site (see 4.4). However, the dispersion parameters $\sigma_y$ and $\sigma_z$ can be determined using the following curves and equations:

- Pasquill-Gifford curves (Fig. 20) which are determined over uniform terrain and small roughness lenght (PA 83).

- Brookhaven National Laboratory (BNL) Method, using the following equations

$$\sigma_y = a\, x^b \qquad (3)$$

and

$$\sigma_z = c\, x^d \qquad (4)$$

(x downwind distance in m).

a, b, c, d are constants given in Table 4. These constants depend on stability classes, and they are given for the more frequent classes in the location of BNL. The equations (3) and (4) are based on hourly average measurements out to 10 km, elevated source and a roughness length of about 1 m.

- Briggs equations shown in Table 5 which are widely used, because they are simple and independent of release height and ground roughness. x is the downwind distance in m.

- Power functions suggested by Pasquill which are:

$$\sigma_y = p_y\, x^{q_y} \qquad (5)$$

and

$$\sigma_z = p_z\, x^{q_z} \qquad (6)$$

x has the same meaning as before; the constants $p_y$, $p_z$, $q_y$, $q_z$ depend on emission height and stability category. Power functions are recomended in the Federal Republic of Germany Regulatory Guide using the constant values shown in Table 6 (GM 79).

But in any case the atmospheric stability classes must be determined first.

These methods can provide only a rough estimation of $\sigma_y$ and $\sigma_z$. Best estimation can be made using equations relating $\sigma_y$ and $\sigma_z$ to $\sigma_\theta$ and $\sigma_\phi$, respectively. For this purpose, research is still going on to find the satisfactory formulas and therefore the availability of $\sigma_\theta$ and $\sigma_\phi$ will be necessary (PA 83).

## 4.4 Experimental Determination of the Dispersion Parameters

Most of the experimental determinations of the dispersion parameters fall into one out of three main groups in which different techniques are adopted for describing and measuring the dispersion effect.

These are:

(1) Optical methods, using a suitable form of smoke. By taking distant photographs of smoke clouds it is usually possible subsequently to draw some outline around the image of the cloud and to specify a shape and size from which the dispersion parameters ($\sigma_y$ and $\sigma_z$) are determined. This method is simple but there are, however, several difficulties in the analysis and interpretation.

(2) The measurement of trajectories of individual marked particles. Neutral markers may be arranged for short-range observations, as soap bubbles and other flight objects. But by far the most widely used marker is the balloon. Tetroon (tetrahedral shaped balloon) flights can provide many informations on atmospheric dispersion in the range up to 100 km. The horizontal dispersion parameter $\sigma_y$ can be determined from radar tracked tetroon flights (HU 82). The exploitation of the method requires the contribution of computed air trajectories. By all trajectory methods only the horizontal dispersion parameter $\sigma_y$ can be determined and moreover they require a large number of repititions to provide a statistically satisfactory result, so that apart from the operational effort a large computing effort is also involved.

(3) Measurement of the concentration of easily detectable tracer elements (e.g., tritiated water, halogenated hydrocarbons) introduced into the air. Vertical and horizontal wind dispersion parameters $\sigma_z$ and $\sigma_y$ can be determined up to 10 km downwind. This method is the most direct one in respect to the assessment of the hazards arising from the release of toxic materials. Such experiments carried out at KfK are presented in (TH 76, TH 81, TH 83). More details about the experimental determination of the dispersion parameters can be found in (PA 83).

## 4.5 The Roughness Lenght $z_o$

The roughness lenght can be defined as the height at which the neutral wind speed profile extrapolates to zero wind speed (Fig. 21). This figure shows the wind profile under unstable, neutral, and stable conditions, where wind profiles are plotted with a natural logarithmic scale. Typical values of $z_o$ are listed in Table 7 (OK 78). In the case of non availability of wind speed profile, $z_o$ can be approximately determined using the equation:

$$z_o = 0{,}5 \; h \; (A^*/A') \qquad (7)$$

where h is the roughness element height (e.g., building height).

$z_o$ and h in m
$A^*$ assumed lot areas (in m²)
$A'$ assumed silhouette (in m²)

The $z_o$ is related to h and is a function of the shape and density distribution of the roughness elements. All these parameters are considered in Eq. (7). Table 8 shows the estimated values of the roughness lenght $z_o$ based on idealized building configurations. If the described parameters (wind speed profile, or $A^*$ and $A'$) are not available, $z_o$ can be roughly estimated as $z_o \simeq h/10$ (LU 64).

# 5. Atmospheric Stability Classification

## 5.1 Types of Stability Classification

Several types of stability classification are available. Table 9 summarizes five types which are:

- Pasquill letter classes (A through F) in column 2 describing the different stability classes described under column (1). A scheme of determination of Pasquill classes is based on five categories of surface wind speed (< 2, 2-3, 3-4, 4-6 and > 6 m/s), three categories of day time insolation (strong, moderate, slight) and two categories of night time clouds (> 4/8 sky covered by cloud and $\leq$ 3/4 sky is covered by cloud). It is presented in Table 10. Some users have used the class G (extremely stable) which they assert applies during light wind, stable conditions.

- Turner classes (1, 2, 3, 4, 6 and 7) listed under column (3) which is also based on synoptic data.

- Brookhaven National Laboratory (BNL) classes (A, $B_1$, $B_2$, C and D) listed under column (4), which is based on the horizontal wind direction $\theta$ fluctuation.

- Cramer classes (25°, 20°, 15°, 10°, 5°, 2.5°) based on the standard deviation of horizontal wind direction $\sigma_\theta$, listed under column (5). The roughness type is taken into account only for the neutral condition (HA 82).,

- Klug-Manier classes (V, IV, $III_2$, $III_1$, II, I) (MA 75) listed in column (6). These classes are based on meteorological service observation.

The Pasquill letter classes (but not the Pasquill scheme) are the most widely used ones.

## 5.2 Methods of Stability Class Determination

Different methods, based on different meteorological parameters, can be used to determine the stability classes. The methods are:

(1) Synoptic data method. Synoptic observations of night time sky cloud cover combined with day time insolation and the surface wind speed $\bar{u}$ can be used to determine the stability classes as shown in Table 10. The cloud cover, approximately, determined by synoptic observations combined with the surface wind speed can also be used as shown in Table 11. The surface wind speed is measured at the lowest level not influenced by obstacles. For plain terrain it is usually measured at 10 m height, from ground surface, but for a location like KfK site, surrounded by trees of about 20 m height, the measured $\bar{u}$ at 40 m is taken.

(2) $\sigma_\phi$ method. The standard deviation of the vertical wind direction $\sigma_\phi$ is the best turbulence indicator. Therefore this is a direct method of the stabiity class determination. $\sigma_\phi$ can be directly measured by a vector vane (Fig. 4) which is sensitive against falling droplets. It fails when rain drops or snow or dust etc., accumulate on it.

(3) $\sigma_\theta$ method. The standard deviation of the horizontal wind direction $\sigma_\theta$ is also a direct method to determine the stability class. This parameter can be measured directly by a wind vane (e.g., Fig. 3) or by a vector vane.

(4) $\Delta T$ method. The vertical temperature gradient per 100 m height $\Delta T$°C/100 m (lapse rate) combined with the surface wind speed $\bar{u}$ can be used, if the vertical temperature profile is available.

(5) SB/$\bar{u}$ method. The solar balance SB combined with the surface wind speed can be used, if the SB is available. SB can be deduced from the difference between the sun radiation (long and short waves) and the ground reflection measured by a radiation measuring instrument (e.g., the instrument shown in Fig. 6).

(6) The wind profile exponent (m) can also be used, if the wind speed profile is available. The value of m bein derived from the following formula:

$$\frac{\bar{u}(z)}{\bar{u}(z_1)} = \frac{(z-d)^m}{z1-d}$$

where

$\bar{u}(z)$ horizontal wind speed at z height,

$\bar{u}(z_1)$ horizontal wind speed at $z_1$ height,

d zero point displacement, which is the height determined by the extrapolation of the wind profile to zero wind speed.

There are other parameters (Richardson number Ri (LU 64), Bulck Richardson Number B and Monin-Obukhov length L (HA 77)) to determine the stability classes, which are considered as direct measures of the stability, because they account for the effect of both mechanical mixing and buoyancy forces, but they need other diffusion models, which are more sophisticated than the Gaussian model.

The assignment of the parameters to the stability classes, used in the different methods, depends on the site conditions. E.g., for the site of KfK the limits of every parameter corresponding to the different stability classes are given in (NE 80).

## 5.3 Final Remarks

The method to determine the stability classes used at any site, depends on available data. If all or most of the meteorological parameters described in 5.2, are available, the most representative parameter must be determined first. However, determination of the stability classes by other available data is desirable. For example, the U.S. Nuclear Regulatory Commission (NRC) recommends the method (4) in 5.2 and the Tennessee Valley Authority (TVA) uses this method. But in the KfK the parameter $\sigma_\phi$ is considered as the basic parameter to determine the stability classes, and if this parameter is not available (failure of vector vane), the method (4) is used. If this method also fails, the method (3) is used (VO 83). Therefore statistically determined distribution of the stability classes (in addition to the distribution of wind speed and wind direction) at the location should be available (see 4.2). This is called the three parametric diffusion statistics. If precipitation is taken into account, the distribution of the three parameters must be extended to include the precipitation distribution. This is called the four parametric diffusion statistics.

**References**

(BA 84a) M. Bär, S. Honců, W. Hübschmann
EFFDOS - Ein Fortran 77 Programm zur Berechnung der effektiven Äquivalentdosis, KfK 3631, Jan. 1984

(BA 84b) M. Bär, S. Honců, W. Hübschmann
Die im Jahr 1984 zu erwartenden effektiven Äquivalentdosen in der Umgebung des Kernforschungszentrums Karlsruhe durch die Emission radioaktiver Stoffe in die Atmosphäre, KfK 3664, Jan. 1984

(BA 82) A. Bayer, K. Burkart, J. Ehrhardt, W. Hübschmann, M. Schückler, S. Vogt
The German risk study: Accident consequence model and result of the study, Nuclear Technology Vol. 59 (20-50) Oct. 1982

(DI 76) H. Dilger
Das meteorologische Meßsystem des Kernforschungszentrums Karlsruhe, KfK 2347, Aug. 1976

(GM 79) Gemeinsames Ministerialblatt, Bonn, den 15. Aug. 1979, Nr. 21

(HA 77) S.R. Hanna, G.A. Briggs, J. Deardorff, B.A. Egon, F.A. Gifford and F. Pasquill
AMS Workshop on Stability Classification and Sigma Curves; Summary of Recommendations, Bulletin American Meteorological Society, Vol. 58, No 12, Dec. 1977

(HA 82) S.R. Hanna, G.A. Briggs, R.P. Hosker
Handbook on Atmospheric Diffusion, 1982, Technical Information Center, U.S. Department of Energy

(HU 79) W.G. Hübschmann
ISOLA-III - A Stop Torwards Realistic Environmental Dose Assessment, European Nuclear Conference, May 1979, Hamburg, West Germany. American Nuclear Society, Transactions 31, 1979, p. 445

(HU 82) W.G. Hübschmann, P. Thomas, S. Vogt
Tetroon Flights as a Tool in Atmospheric Meso-sclae Transport Investigation, Proceedings of 13th International Technical Meeting on Air Pollution Modeling and its Application, Sep. 1982, Ile des Embiez, France, p. 457-474

(IRCP39) Annals of the ICRP, Statement from the 1983 Washington Meeting of the ICRP Principles for Limiting Exposure of the Public to Natural Sources of Radiation, Vol. 14, No 1, 1984

(KI 81) H. Kiefer, W. Koelzer, L.A. König, (ed.), Jahresbericht 1981 der Hauptabteilung Sicherheit, KfK 3272, March 1982

(KI 82) H. Kiefer, W. Koelzer, L.A. König, (ed.), Jahresbericht 1982 der Hauptabteilung Sicherheit, KfK 3535, April 1983

(LU 64) J.L. Lumley and A. Panofsky, The Structure of Atmospheric Turbulence, 1964, Interscience Publ.

(MA 75) G.Manier
Vergleich zwischen Ausbreitungsklassen und Temperaturgradienten, Meteorologische Rundschau 28, March 1975

(ME 83) A.H. Mendonca, A.W. Nobrega, R.U. Mulder, M.E. Vianna, C.E. Almeida, M. Winter
Preoperational Environmental Monitoring of the Angra Reactor Site, ISSN-0101-6148, CNEN 1001, KfK 3448, March 1983

(NA 75) D. Nagel, D. Papadopoulos
WOLGA 1 - Ein Fortran IV-Program zur Berechnung der Dosisleistung durch Gammastrahlung aus der radioaktiven Abluft eines oder mehrerer Daueremittenten, KfK 2189, Okt. 1975

(NE 77) K. Nester, W. Hübschmann, P. Thomas
Influence of Ground Roughness on Atmospheric Diffusion Proceedings of the 4th International Clean Air Congress, Dec. 1977, Tokyo, Japan, p. 153-156

(NE 80) K. Nester
Statistisch äquivalente Verfahren zur Bestimmung von Ausbreitungskategorien, Seminar on radioactive releases and their dispersion in the atmosphere following a hypothetical reactor accident, Vol. 1, April 1980, Risø, Denmark, p. 203-221

(NE 82) K. Nester, H. Verenkotte
Dynamic Interaction of Cooling Tower and Stack Plumes, Proceedings of the 13th International Technical Meeting on Air Pollution and its Application, Sep. 1982, Ile des Embiez, France, p. 245-257

(NE 83) K. Nester, H. Verenkotte, R. Dlugi, H. Bunz, S. Jordan
Moedeling of Photochemical and heterogeneous Sulfate Aerosol Formation in Plumes, Jahrestagung der Gesellschaft für Aerosolforschung, Sept. 1982, München, West Germany

(OK 78) T.R. Oke
Boundary layer climates, London, 1978, Methuen & Co. Ltd.

(PA 82) D. Papadopoulos, M. Bär, S. Honců
Kollektiv-Äquivalentdosen in der Umgebung des Kernforschungszentrums Karlsruhe, KfK 3574, Aug. 1983

(PA 83) F. Pasquill and F.B. Smith
Atmospheric Diffusion 3rd Edition 1983, Study of the Dispersion of Windborne Material from Industrial and Other Sources, Horwood

(SL 68) D.H. Slade
Meteorology and Atomic Energy 1968, TID-24190

(TH 76a) P. Thomas, W. Hübschmann, L.A. König, H. Schüttelkopf, S. Vogt, M. Winter
Experimental Determination of the Atmospheric Dispersion Parameters over Rough Terrain, Part 1, KfK 2285, July 1976

(TH 76b) P. Thomas, K. Nester
Experimental Determination of the Atmospheric Dispersion Parameters over Rough Terrain, Part 2, KfK 2286, June 1976

(TH 81) P. Thomas, K. Nester
Experimental Determination of the Atmospheric Dispersion Parameters at the Karlsruhe Nuclear Research Center for 60 m and 100 m Emission Heights, Part 2, Evaluation of Measurement, KfK 3091, July 1981

(TH 83) P. Thomas, W. Hübschmann, H. Schüttelkopf, S. Vogt
Experimental Determination of the Atmospheric Dispersion Parameters at the Karlsruhe Nuclear Research Center for 160 m and 195 m Emission Heights, Part 1, Measured Data, KfK 3456, März 1983

(TH 83) P. Thomas, R. von Holleuffer-Kypke, W.G. Hübschmann
Doppler Acoustic Sounding Performance Test, 2nd International Symposium on Acoustic Remote Sensing of the Atmosphere and Oceans, Sep. 1983, Rome, Italy

(VO 83) S. Vogt
Three- and Four-Parameter Diffusion Statistics as a Basis for Calculating the Long-term Pollution Load, KfK 3477, June 1983

**Acknowledgements**

This study has been carried out by the cooperation of Hauptabteilung Sicherheit, Karlsruhe Nuclear Research Centre and the Irak Nuclear Research Centre (INRC).

Dr. W.G. Hübschmann, the leader of the Environmental Meteorology Department (HS/M) has accepted my training in his department. I wish to express my sincere appreciation for his help in according these studies and for reviewing the text of this report.

I would like to express my particular thanks to Dr. P. Thomas for accepting my participitation in some studies about Doppler-Sodar performance test, his help and his encouragement.

I wish to thank Dipl.-Met. K. Nester for the helpful discussions and providing some references.

The encouragement, support and help of Dipl.-Met. S. Vogt during these studies are gratefully acknowledged.

Special thanks are due to Dipl.-Met. R. von Holleuffer-Kypke for his support, helpful advices and contributing to the substance of chapter 2 in this report.

The consistent support and encouragement, helpful advices, providing informations of Dr. M. Bär are highly appreciated.

I express my sincere thanks for Dipl.-Phys. P. Wittek and Dipl.-Met. Verenkotte for the helpful discussions and advices.

The useful technical support of Mrs. S. Honců, Miss S. Dienst, Mr. T. Koerlin and Mr. Hagen is gratefully acknowledged.

I would like to express my gratitude to Mrs. E. Gruber for her secretarial support during my training in HS/M.

And I am very grateful to Dr. L.A. König, Dr. D. Papadopoulos and all the personnel of the Radioecological Department (HS/R) for their helpful advices and in providing required references about the environmental monitoring.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Instrument measuring; Measuring height | Type and measuring principle | Accuracy (A) and measuring threshold (T) | % Non available data in 1983 | The reason for instrument change | Normal operating interval | Scanning interval |
| Horizontal wind speed at 2,20,30,40, 50,60,80,100,130, 160, 200 m | Cup anemometer, photoelectric impulse producing 180 impulses per rotation | A (m/sec):<br>$u < 1.5$: ±0.16<br>$u = 1.5$: ±0.21<br>$u = 10$: ±0.14<br>$u = 20$: ±0.24<br>$u = 30$: ±0.28<br>T: 0.1 m/sec | 4.87 | Ball bearing | $1\frac{1}{2}$ y | 4 s |
| Horizontal wind direction at: 40,60,80,100,160, 200 m | Wind vane, voltage by potentiometer | A: ±3°<br>T: 1° | 1.89 | Hail or lightning | 3 y | 4 s |
| Windvector, horizontal and vertical wind direction their standard deviations at: 40,100,160 m | Vector vane, $\theta,\phi$ voltage by potentiometer; $\|\vec{v}\|$ photoelectric impulse; $\sigma_\theta,\sigma_\phi$ electronic calculations for $\nu \geq 1/180$ Hz | A: $\theta$= 3°<br>$\phi$= 2°<br>$\|\vec{v}\|$= +1 %<br>-10 %<br>$\sigma_\theta,\sigma_\phi$=±2 %<br>T: $\theta$=1°, $\phi$=0.1°<br>$\|\vec{v}\|$=0.1 m/s<br>$\sigma_\theta,\sigma_\phi$=0.1° | $\|\vec{v}\|$:38.48<br>$\theta$:5.33<br>$\phi$:19.95<br>$\sigma_\theta$:12.36<br>$\sigma_\phi$:10.35 | Propeller breaking; Potentiometer or photocell defect, tail breaking | $\frac{1}{4}$ y | 1 s |
| Temperature at: 2,30,60,100,130,160, 200 m | Resistance thermometer, double Pt-100 wheatstone bridge with normal resistance | A: ±0.03 K<br>T: 0.01 K | 4.19 | Ventilation system defect, pollution of the radiation protection tubes | 1 y | 4 s |
| Dew point at: 2,30,100,200 m | LiCl-system, measuring vapour pressures of saturated aqueous salt solution with Pt-100 | A: ±0.4 K<br>T: ±0.1 K | 23.24 | Pollution of LiCl | 1 month | 4 s |
| Radiation at 1.5 m | Solar radiation $0.3 < \lambda < 3.0$ µm and radiation balance $0.3 < \lambda < 100$ µm measuring the temperatur difference between the black plates and the body | A: ±5 %<br>T: 0.07 mW/cm² | 34.32 | Dome defect | $\frac{1}{2}$ y | 4 s |
| Precipitation at 1.1 m | Precipitation collector surface 200 cm², voltage producing by potentiometer | A: ±1 %<br>T: ±0.02 mm | 2.75 | Tube closing by pollution or particles; potentiometer defect | Weekly in summer | 10 min |
| Pressure at the station height | Aneriod barometer, voltage producing by electrical way transducer | A: ±0.5 mbar<br>T: ±0.1 mbar | 6.75 | | | 10 min |

Table 1: Specifications of the meteorological measuring system

| WIND SPEED (m/s) | | | | | WIND DIRECTION (degree) |
|---|---|---|---|---|---|
| Mean | Minimum | Maximum | Calm | Height | Mean |
| 1.6 | 0.7 | 3.7 | 0 | 2 | |
| 4.9 | 1.8 | 9.6 | 0 | 20 | |
| 6.3 | 2.9 | 10.8 | 0 | 30 | |
| 7.2 | 3.8 | 11.4 | 0 | 40 | 239 |
| 7.7 | 3.7 | 11.7 | 0 | 50 | |
| 8.1 | 4.4 | 11.6 | 0 | 60 | 238 |
| 9.1 | 4.8 | 12.7 | 0 | 80 | 238 |
| 10.0 | 5.5 | 13.9 | 0 | 100 | 236 |
| 10.7 | 6.5 | 13.5 | 0 | 130 | |
| 11.8 | 8.5 | 14.8 | 0 | 160 | 237 |
| 12.4 | 9.0 | 15.2 | 0 | 200 | 240 |

Table 2: The wind speed and the horizontal wind direction measured at different heights during the 10 min from 9 h 50 till 10 h at 29 March 1984

| Diffusion Category | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| m | 0.09 | 0.20 | 0.22 | 0.28 | 0.37 | 0.42 |

Table 3: Exponent m of the vertical wind speed profile

| Pasquill Type | Type | Parameter | | | |
|---|---|---|---|---|---|
| | | a | b | c | d |
| C | $B_2$ | 0.40 | 0.91 | 0.41 | 0.91 |
| B | $B_1$ | 0.36 | 0.86 | 0.33 | 0.86 |
| D | C | 0.32 | 0.78 | 0.22 | 0.78 |
| F | D | 0.31 | 0.71 | 0.06 | 0.71 |

Table 4: Brookhaven National Laboratory Parameter Values in the Formulas $\sigma_y = a\,x^b$ and $\sigma_z = c \cdot x^d$

| Pasquill Type | $\sigma_y$, m | $\sigma_z$, m |
|---|---|---|
| | Open-Country Conditions | |
| A | $0.22x(1 + 0.0001x)^{-\frac{1}{2}}$ | $0.20x$ |
| B | $0.16x(1 + 0.0001x)^{-\frac{1}{2}}$ | $0.12x$ |
| C | $0.11x(1 + 0.0001x)^{-\frac{1}{2}}$ | $0.08x(1 + 0.0002x)^{-\frac{1}{2}}$ |
| D | $0.08x(1 + 0.0001x)^{-\frac{1}{2}}$ | $0.06x(1 + 0.0015x)^{-\frac{1}{2}}$ |
| E | $0.06x(1 + 0.0001x)^{-\frac{1}{2}}$ | $0.03x(1 + 0.0003x)^{-1}$ |
| F | $0.04x(1 + 0.0001x)^{-\frac{1}{2}}$ | $0.016x(1 + 0.0003x)^{-1}$ |
| | Urban Conditions | |
| A-B | $0.32x(1 + 0.0004x)^{-\frac{1}{2}}$ | $0.24x(1 + 0.001x)^{-\frac{1}{2}}$ |
| C | $0.22x(1 + 0.0004x)^{-\frac{1}{2}}$ | $0.20x$ |
| D | $0.16x(1 + 0.0004x)^{-\frac{1}{2}}$ | $0.14x(1 + 0.0003x)^{-\frac{1}{2}}$ |
| E-F | $0.11x(1 + 0.0004x)^{-\frac{1}{2}}$ | $0.08x(1 + 0.00015x)^{-\frac{1}{2}}$ |

Table 5: Formulas recommended by Briggs for $\sigma_y(x)$ and $\sigma_z(x)$ ($10^2 < x < 10^4$ m)

| EMISSION HEIGHT | DIFFUSION CATEGORY | DETERMINED COEFFICIENT | | | |
|---|---|---|---|---|---|
| | | $p_y$ | $q_y$ | $p_z$ | $q_z$ |
| 50 m | A | 0.869 | 0.810 | 0.222 | 0.968 |
| | B | 0.869 | 0.810 | 0.222 | 0.968 |
| | C | 0.718 | 0.784 | 0.215 | 0.944 |
| | D | 0.625 | 0.767 | 0.205 | 0.936 |
| | E | 1.691 | 0.621 | 0.162 | 0.809 |
| | F | 5.382 | 0.578 | 0.396 | 0.618 |
| 100 m | A | 0.229 | 1.003 | 0.097 | 1.158 |
| | B | 0.227 | 0.970 | 0.155 | 1.024 |
| | C | 0.224 | 0.938 | 0.247 | 0.890 |
| | D | 0.222 | 0.905 | 0.398 | 0.755 |
| | E | 1.691 | 0.621 | 0.162 | 0.809 |
| | F | 5.382 | 0.578 | 0.396 | 0.618 |

Table 6: Determined coefficients $p_y$, $q_y$, $p_z$, $q_z$ in function of stability classes and emission height,
for emission height > 75 m the coefficients corresponding to 100 m are taken and for < 75 m those of 50 m can be taken

| Surface | Remarks | $z_o$ Roughness length (m) | d Zero plane displacement (m) |
|---|---|---|---|
| Water | Still - open sea | $(0.1\text{-}10.0)\times10^{-5}$ | - |
| Ice | Smooth | $0.1\times10^{-4}$ | - |
| Snow | | $(0.5\text{-}10.0)\times10^{-4}$ | - |
| Sand, desert | | 0.0003 | - |
| Soils | | 0.001-0.01 | - |
| Grass | 0.02-0.1 m | 0.003-0.01 | $\leq$ 0.07 |
| | 0.25-1.0 m | 0.04-0.10 | $\leq$ 0.66 |
| Agricultural crops | | 0.04-0.20 | $\leq$ 3.0 |
| Orchards | | 0.5-1.0 | $\leq$ 4.0 |
| Forests | Deciduous | 1.0-6.0 | $\leq$ 20.0 |
| | Coniferous | 1.0-6.0 | $\leq$ 30.0 |

Table 7: Typical values of the roughness length $z_o$ in function of other aerodynamic properties

| Building type | Assumed building height h (m) | Assumed lot areas A' ($m^2$) | Assumed silhouette A* ($m^2$) | Roughness length $z_o$ (m) |
|---|---|---|---|---|
| Low | 4 | 2,000 | 50 | 0.05 |
| Medium | 20 | 8,000 | 560 | 0.70 |
| High | 100 | 20,000 | 4,000 | 10.00 |

$z_o = 0.5\ h\ (A^*/A')$

Table 8: Estimated values of the roughness length ($z_o$) based on idealized building configurations

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Stability Discription | Pasquill | Turner | BNL | Cramer $\sigma_\theta$(10 m) | Klug |
| Extremly unstable | A | 1 | A | 25° | V |
| Moderately unstable | B | 2 | $B_1$ | 20° | IV |
| Slightly unstable | C | 3 | $B_2$ | 15° | $III_2$ |
| Neutral | D | 4 | C | 10° | $III_1$ |
| Slightly stable | E | 6 | | 5° | II |
| Moderately stable | F | 7 | D | 2.5° | I |

Table 9: Relations among stability classification types

| Surface wind speed, m/sec | Daytime insolation | | | Nightime conditions‡ | |
|---|---|---|---|---|---|
| | Strong | Moderate | Slight | Thin overcast or $\geq\frac{4}{8}$ low cloud | $\leq\frac{3}{8}$ cloudiness |
| <2 | A | A-B | B | * | * |
| 2-3 | A-B | B | C | E | F |
| 3-4 | B | B-C | D | D | E |
| 4-6 | C | C-D | D | D | D |
| >6 | C | D | D | D | D |

Table 10: Meteorological Conditions Defining Pasquill Turbulence Types

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

*Some users have used the class G (extremely stable) which they assert applies during light wind, stable conditions.
+Applicable to heavy overcast day or night.
‡The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon that is covered by clouds.

| WIND SPEED $\bar{u}$ (10 m) height | NIGHT $\frac{0}{8}-\frac{6}{8}$ | NIGHT $\frac{7}{8}-\frac{8}{8}$ | DAYS $\frac{0}{8}-\frac{2}{8}$ | DAYS $\frac{3}{8}-\frac{5}{8}$ | DAYS $\frac{6}{8}-\frac{8}{8}$ |
|---|---|---|---|---|---|
| $\leq$ 2 (knot*) | I | II | IV | IV | IV |
| 3,4 | I | II | IV | IV | $III_2$ |
| 5,6 | II | $III_1$ | IV | IV | $III_2$ |
| 7,8 | $III_1$ | $III_1$ | IV | $III_2$ | $III_2$ |
| $\geq$ 9 | $III_1$ | $III_1$ | $III_2$ | $III_1$ | $III_1$ |

*1 knot = 0.514 m/s

Table 11: Klug - Manier turbulence types

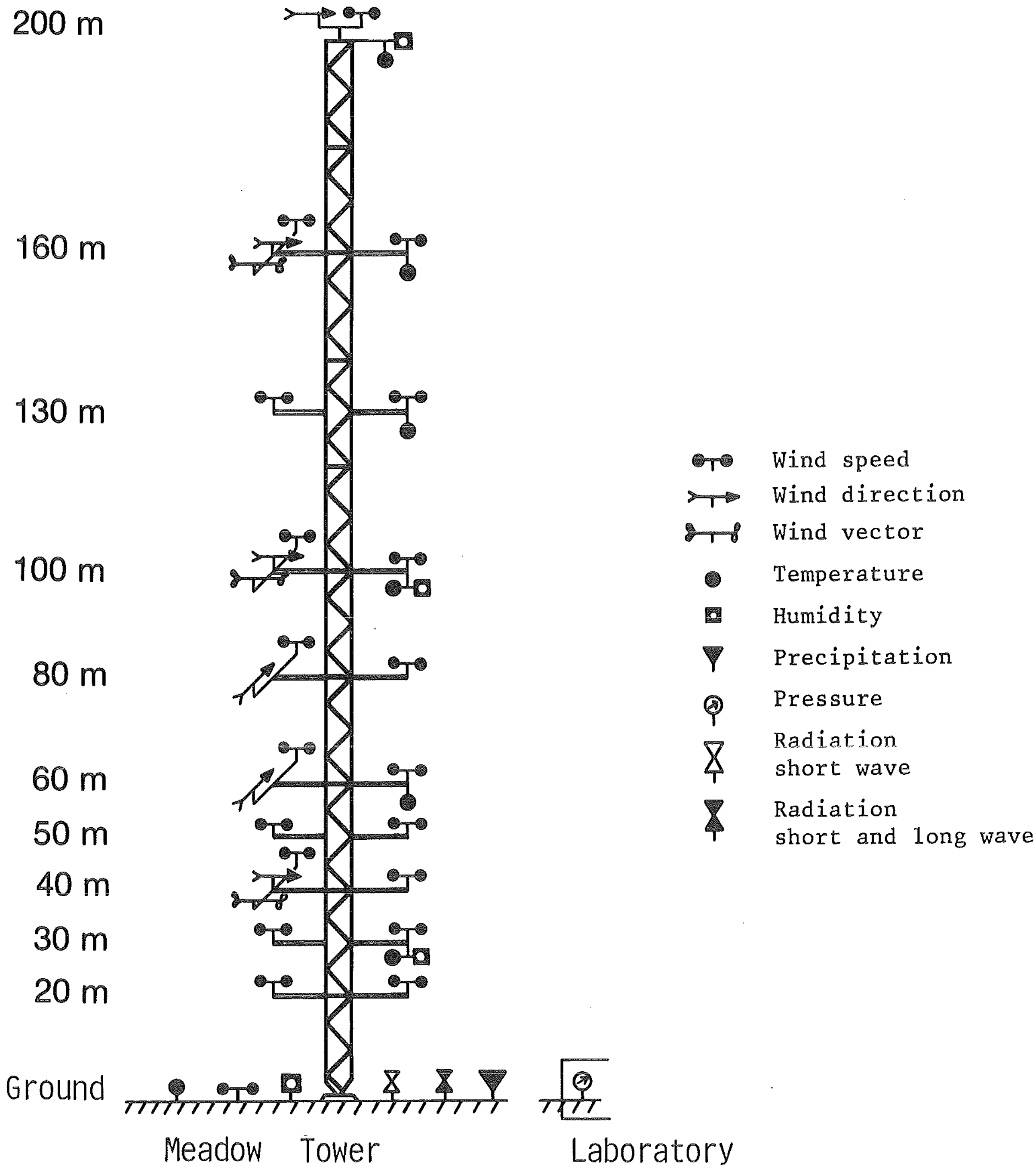


Fig. 1: The Instrumentation of the Meteorological Information System (MIS)

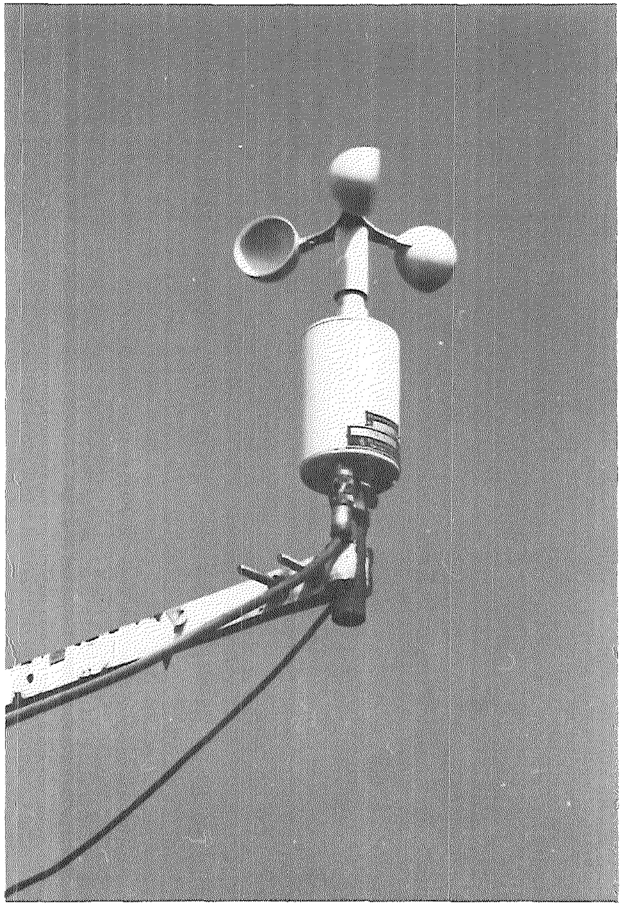

Fig. 2: Cup anemometer

Fig. 3: Wind vane

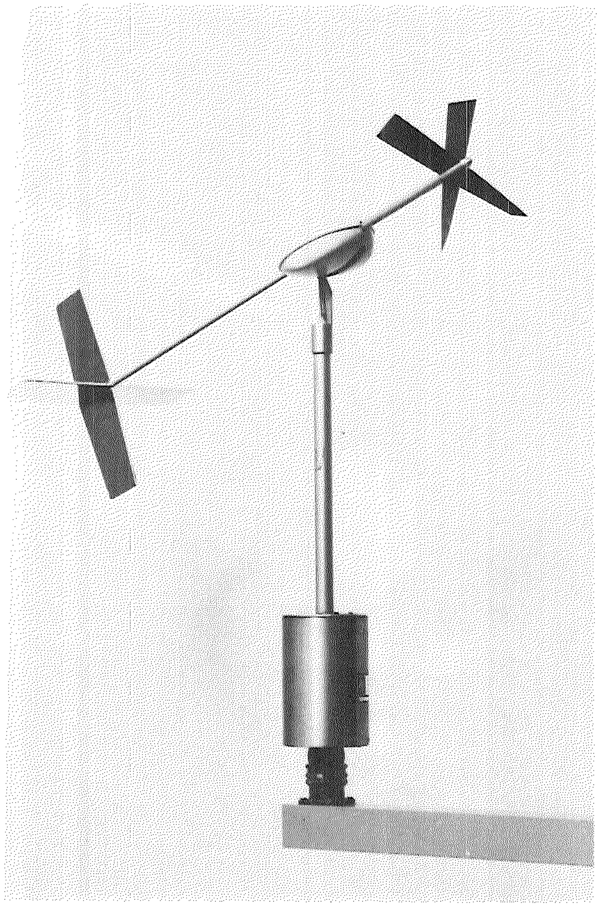

Fig. 4: Vector vane

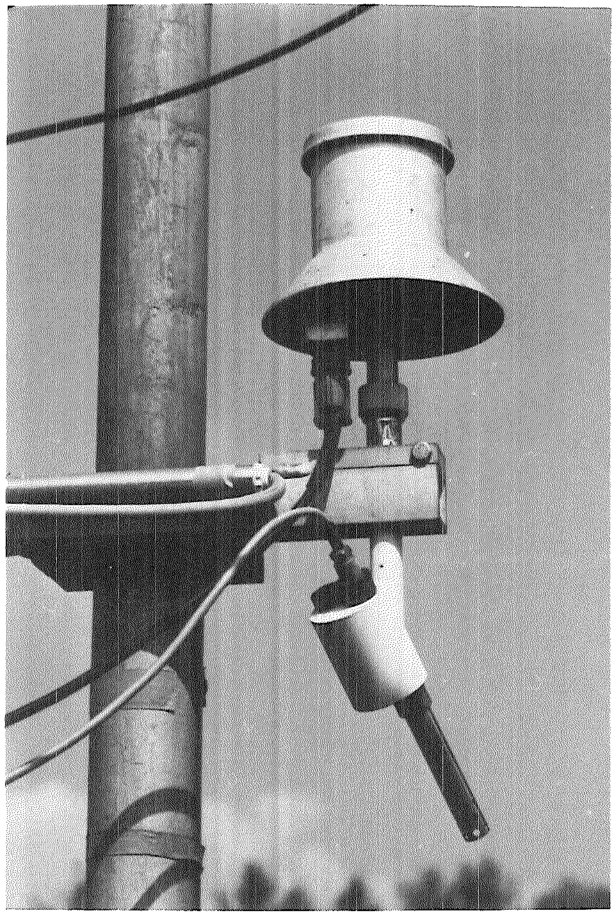

Fig. 5: Ventilated thermometer

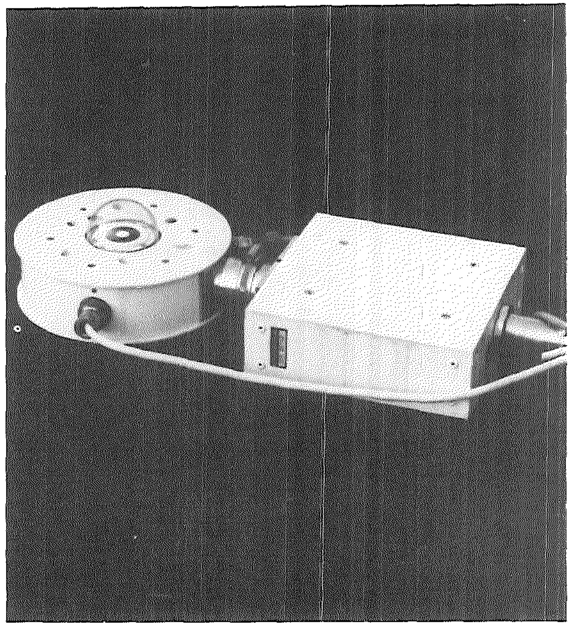

Fig. 6: Radiation measuring instrument

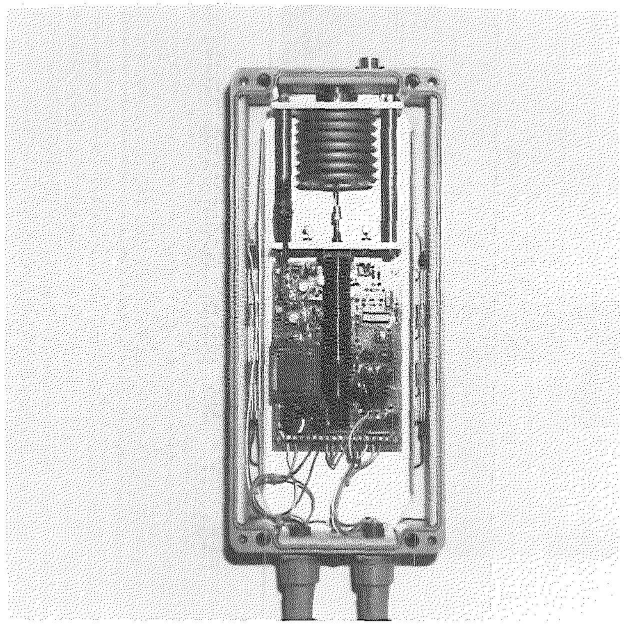

Fig. 7: Barometer

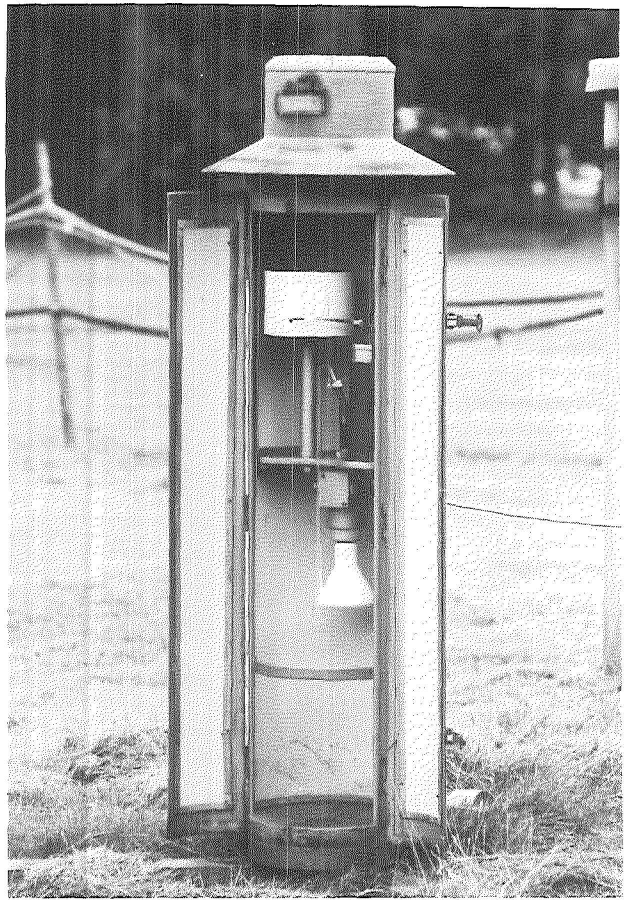

Fig. 8: Rainfall measuring instrument

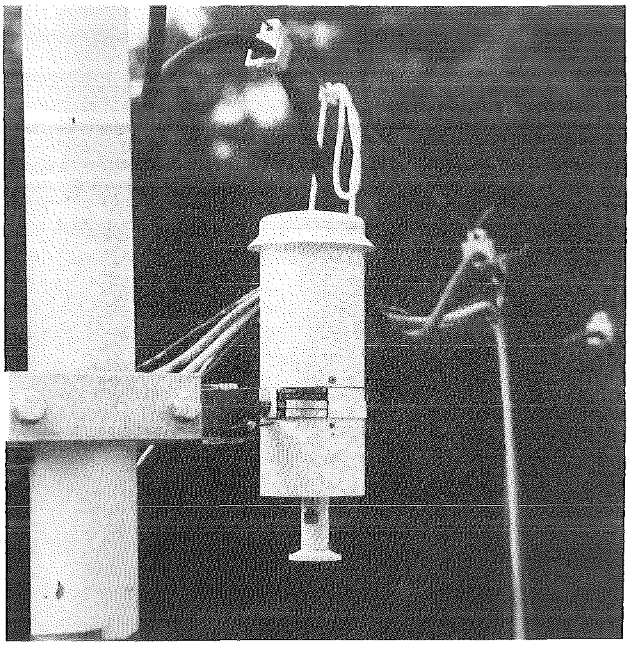

Fig. 9: Dew point measuring instrument

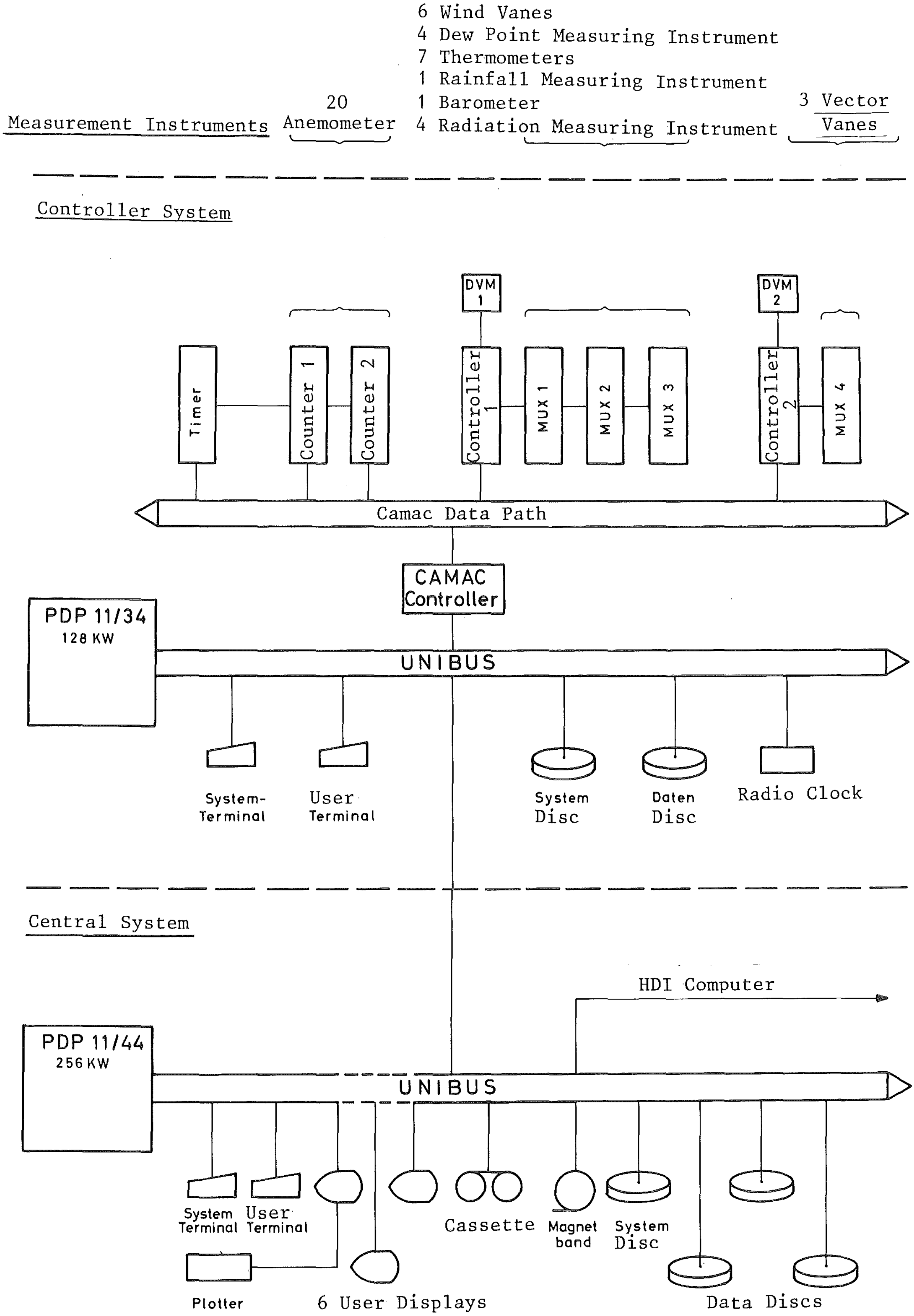


Fig. 10: Scheme of PD (Processing Data) Meteorological Information System in HS/M

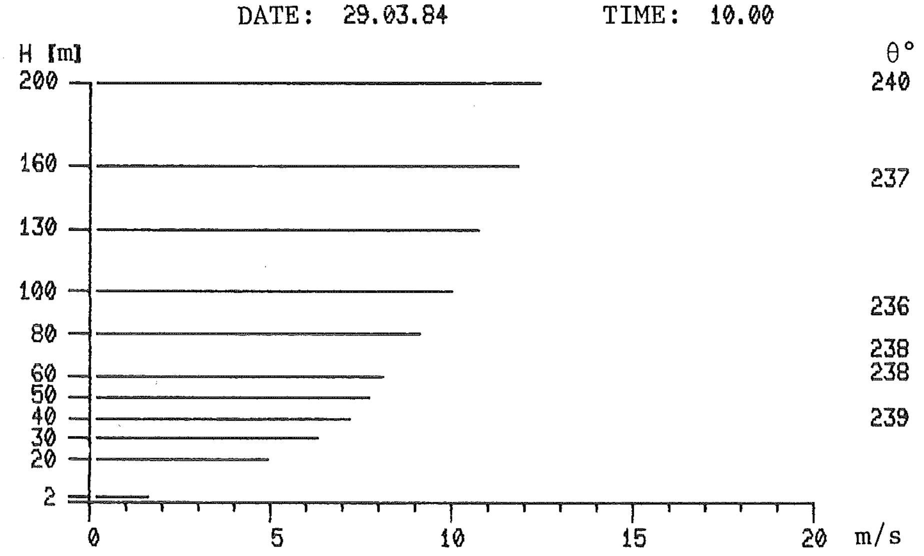


Fig. 11: Wind speed profile and the mean wind direction

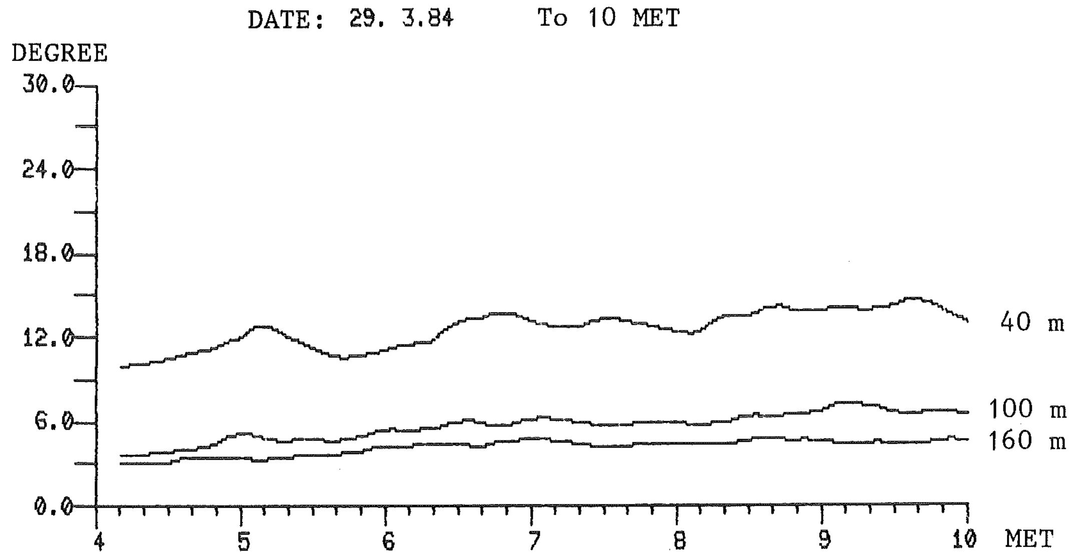


Fig. 12: The $\sigma_\phi$ variation from 4 h until 10 h at 29 March 1984

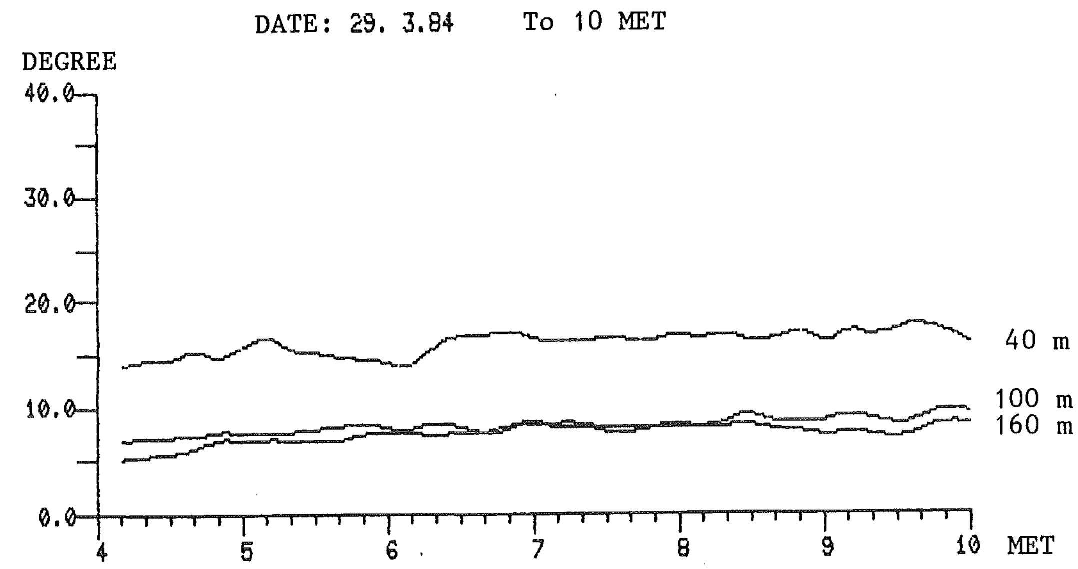


Fig. 13: The $\sigma_\theta$ variation from 4 h until 10 h at 29 March 1984

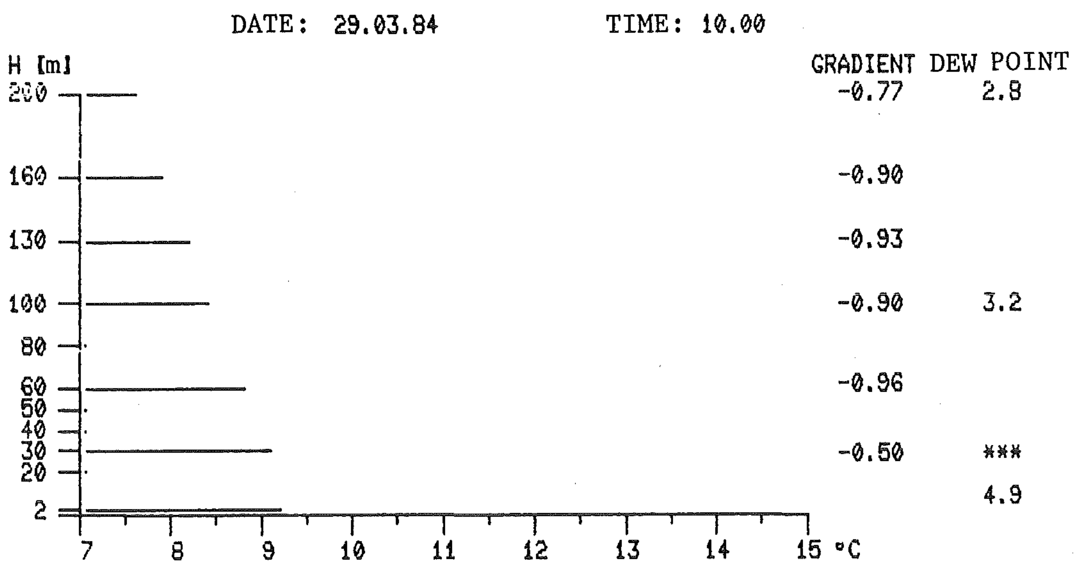


Fig. 14: The air temperature profile with the temperature gradient in °C/100 m and the dew point at different heights for the 10 min from 9 h 50 until 10 h at 29 March 1984
***nonavailable data

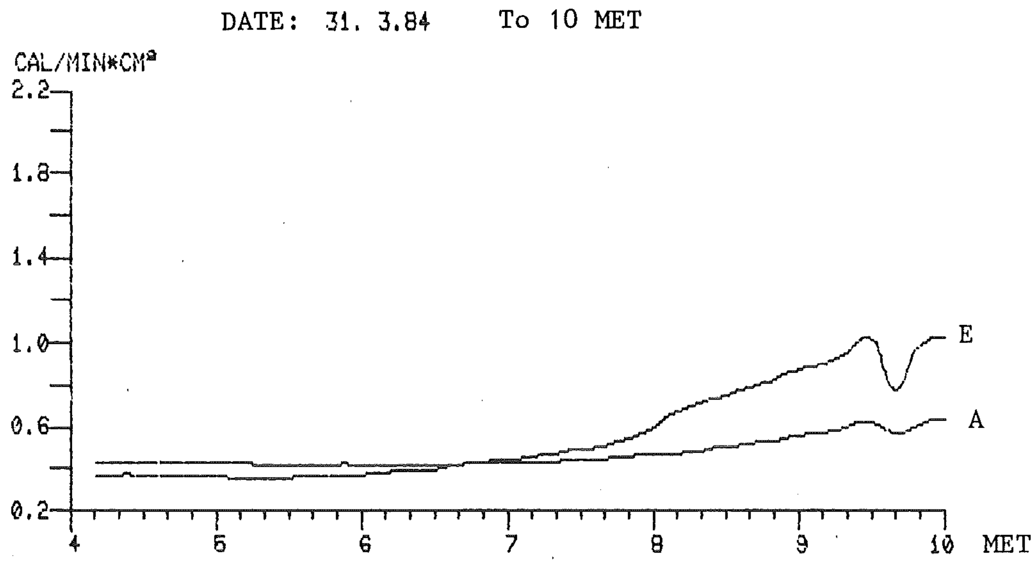


Fig. 15: The solar radiation E and ground radiation A (short and long waves) from 4 h 00 until 10 h 00 at 31 March 1984

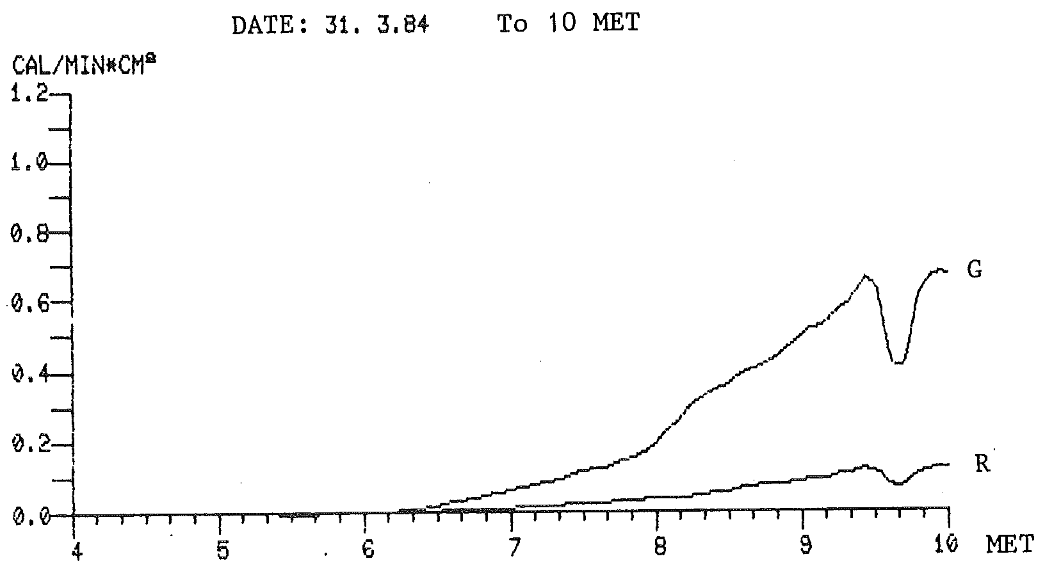


Fig. 16: The golbal solar radiation G (short waves only) and the ground reflection R from 4 h until 10 h at 31 March 1984

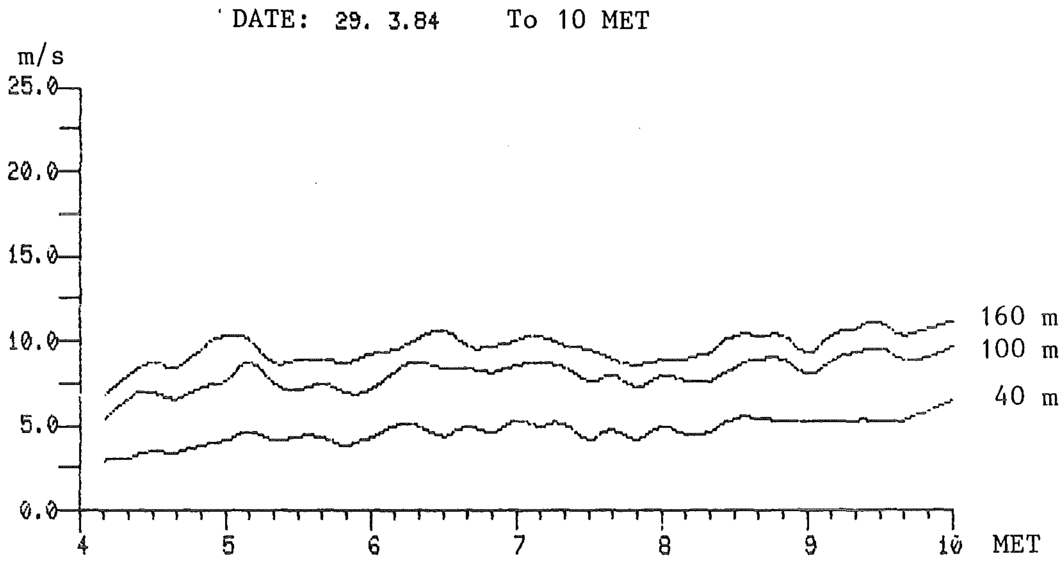


Fig. 17: The wind vector $|\vec{v}|$ variation at 40 m, 100 m and 160 m from 4 h until 10 h at 29 March 1984

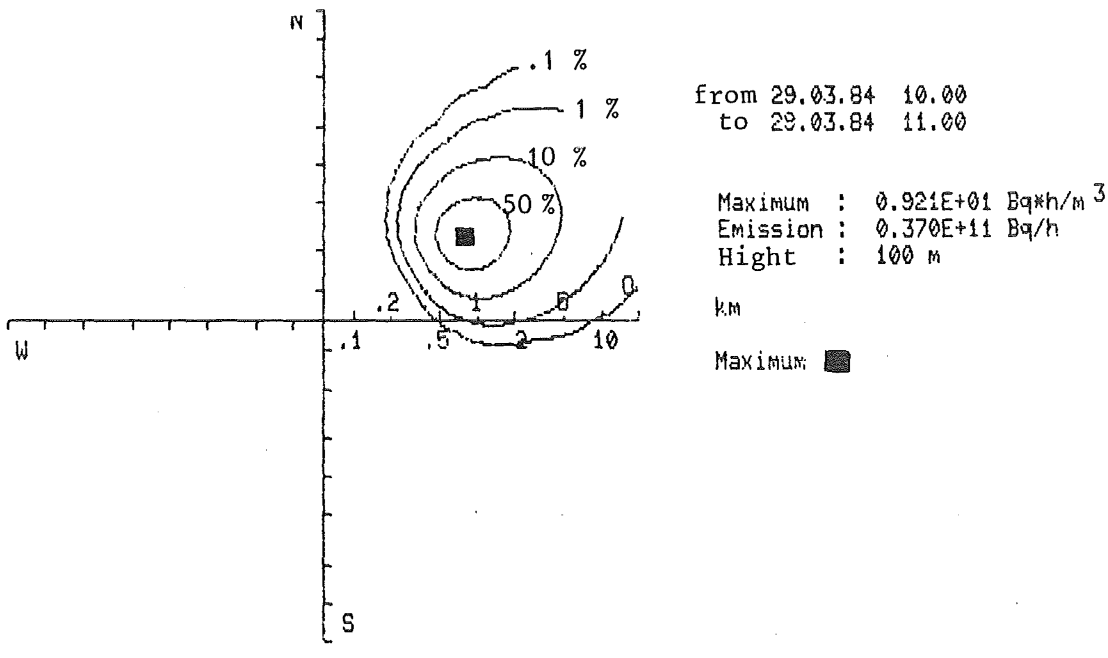


Fig. 18: The radionuclide concentration distribution around the emission center (o) within 10 km distance

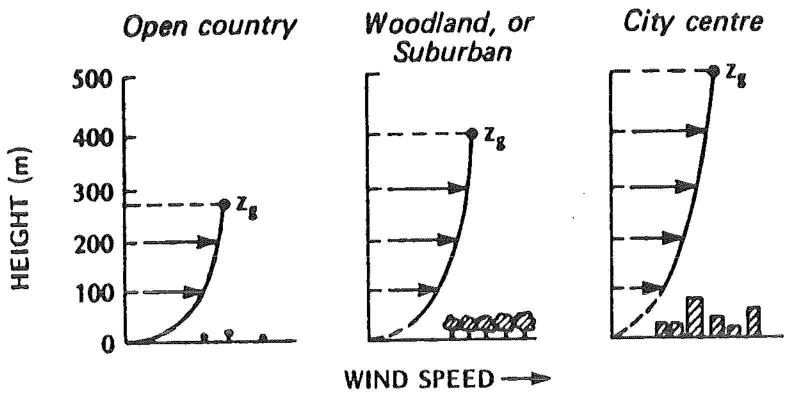


Fig. 19: The influence of terrain roughness on the wind speed profile

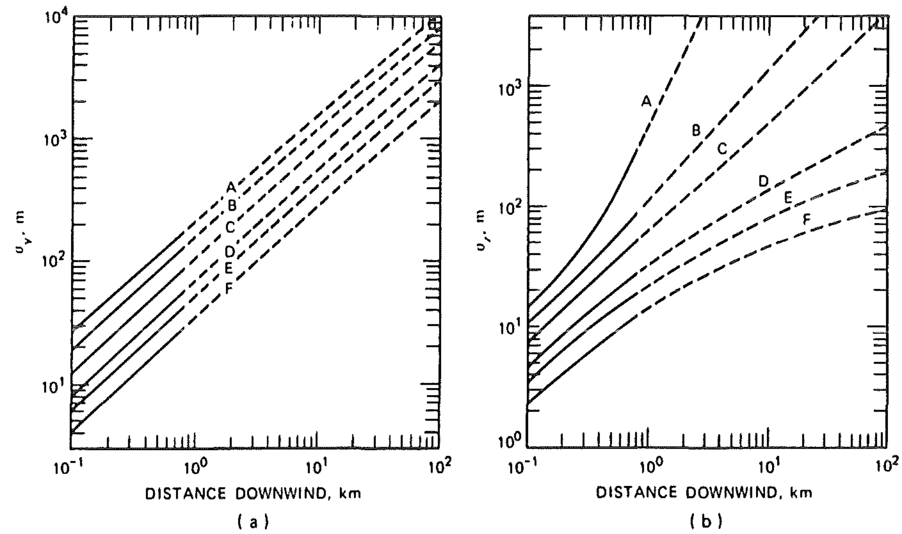


Fig. 20: Pasquill-Gifford curves of $\sigma_y$ and $\sigma_z$

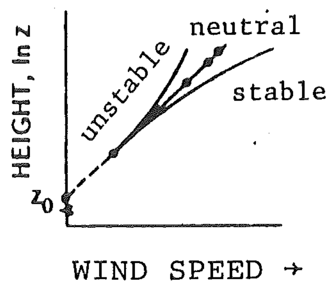


Fig. 21: The wind speed profile effected by the stability classes plotted with a natural logarithm height scale