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Meteorological Guide for Safety Analysis of Nuclear Power Reactor Facilities

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I. Objectives

This Guide provides meteorological measurement methods, statistical processing methods of measured values, and analytical methods of atmospheric dispersion which are required for estimation of dispersion conditions of radioactive material in the atmosphere in performing dose assessments during normal operation and postulated accidents (major accidents and hypothetical accidents) of nuclear power reactor facilities.

This Guide was established with the purpose of its practical use, based on the current knowledge and experiences, and is to be reviewed when useful information is obtained from future experiences and new knowledge.

Even if methods other than those specified by this Guide are used, it will be accepted when they have adequate rationale.

II. Meteorological Measurement Method

1. Purpose and Classification of Meteorological Measurement

The meteorological measurement is performed in order to obtain meteorological data required for estimation of dispersion conditions of radioactive material in the atmosphere, by classifying the measurements into normal measurement and special measurement.

The normal measurement is to start before installation of a nuclear reactor facility and continues until its decommissioning, in order to obtain the meteorological data directly regarding to dose assessment before installation of the nuclear reactor facility and after its commissioning.

The special measurement is performed for a specific period of time, in order to obtain meteorological characteristics at a site and its surrounding area for conducting the safety analysis prior to installation of a nuclear reactor facility.

2. Measurement Parameters

Measurement parameters for the normal measurement shall be wind direction, wind speed, amount of solar radiation, and radiation balance.

Measurement parameters for the special measurement shall be wind direction, wind speed, wind at an elevated level, and air temperature difference.

3. Measurement Method

The meteorological instruments shall be installed at an measurement field provided at an appropriate location within the premise of a nuclear reactor facility, or at an measurement tower, an measurement column etc. provided at an appropriate location within the premise of the nuclear reactor facility or in the surrounding area.

The type of meteorological instruments, measurement units, minimum orders of measured values, measurement height, etc. shall be as shown in Tables 1 and 2.

Meteorological instruments certified by the Japan Meteorological Agency shall be used.

Percentage of missing data (including atmospheric stability) shall be, in principle, 10 % or less in 12 continuous months.

4. Measurement Period

The normal measurement shall be initiated at least one year prior to the application for approval of establishment of a nuclear reactor facility, and be continued until the nuclear reactor facility is decommissioned.

Wind direction and wind speed for the special measurement shall be continuously measured for at least one year prior to the application for nuclear reactor facility establishment permit, and wind at an elevated level and air temperature difference shall be measured at appropriate time during this period.

Table 1 Normal measurement.

Measurement parameter	Meteorological instrument	Unit of Measurement	Minimum order of measured value	Measurement height etc.
Wind direction	Wind vane or Doppler sodar	16 orientations	1	(1) Wind direction and wind speed of surface wind representative of a site are to be measured, in principle, at a height of approx. 10 m above ground, and a wind vane and an anemometer are to be used as their instruments. (2) For the wind direction and wind speed of wind at an elevated level related to stack discharge, they are to be measured at a height representative of the wind at an elevated level, with a wind vane and an anemometer or Doppler sodar as their instruments. In addition, when a wind-mill type wind vane and anemometer is used as a wind vane and an anemometer, a breeze wind vane and a breeze anemometer are to be used together with it.
Wind speed	Anemometer or Doppler sodar	m/s	1/10	
Amount of solar radiation	Radiometer	kW/m^2	1/100	In principle, at a height of approx. 1.5 m above ground at an measurement field
Radiation balance	Net radiometer	kW/m^2	1/1500	At a height of approx. 1.5 m above ground at an measurement field

Table 2 Special measurement

Measurement item	Meteorological instrument	Unit of Measuremen t	Minimum order of measured value	Measurement height etc.
Wind direction	Wind vane	16 orientations	1	At a height of 10 m or more above ground, immune to effects of structures and trees
Wind speed	Anemometer	m/s	1/10	
Wind at an elevated level	Pilot balloon etc.	-	-	Above a site (approx. 1 km or less)
Air temperature difference	Differential temperature indicator or thermometer	°C	1/10	Above a site (approx. 1 km or less)

III. Statistical Processing Method of Measured Values

1. Hourly Meteorological Data

Hourly meteorological data as specified below shall be used as the basis for statistics.

(1) Wind direction, wind speed, amount of solar radiation, and radiation balance

For the wind direction, wind speed, amount of solar radiation, and radiation balance, average values of their measured values over 10 minutes to the hour shall be deemed as their values at the hour concerned.

(2) Atmospheric stability

The atmospheric stability is classified according to Table 3 based on the wind speed, amount of solar radiation, and radiation balance of "surface wind representative of a site" at the hour of interest, and the stability is treated as the atmospheric stability at the hour concerned.

Table 3 Classification table of atmospheric stability

Wind speed (U) m/s	Amount of solar radiation (T), kW/m^2				Radiation balance (Q), kW/m^2		
	T ≥ 0.60	0.60 > T ≥ 0.30	0.30 > T ≥ 0.15	0.15 > T	Q ≥ -0.020	-0.020 > Q ≥ -0.040	-0.040 > Q
U < 2	A	A - B	B	D	D	G	G
2 ≤ U < 3	A - B	B	C	D	D	E	F
3 ≤ U < 4	B	B - C	C	D	D	D	E
4 ≤ U < 6	C	C - D	D	D	D	D	D
6 ≤ U	C	D	D	D	D	D	D

(3) When any of meteorological elements of wind direction, wind speed and atmospheric stability is not measured, meteorological data at the hour concerned are to be treated as missing data.

The statistics derived from the measurement data excluding missing data are to be treated as to represent the year of interest.

2. Statistical Processing of Meteorological Data

(1) During normal operation

Hourly meteorological data are to be statistically processed on the following items.

(a) Summation of inverses of wind speeds classified according to wind direction and atmospheric stability
(b) Average of inverses of wind speeds classified according to wind direction and atmospheric stability
(c) Average of inverses of wind speeds classified according to wind direction
(d) Frequency of appearance of wind directions
(e) Frequency of appearance of wind directions with a wind speed of 0.5 to 2.0 m/s

In statistically processing the above-mentioned (1), (2) and (3), the measurement data under windy conditions (wind speeds 0.5 m/s or more) shall be used as they are, but those data under calm conditions (wind speeds less than 0.5 m/s) shall be used as wind speed of 0.5 m/s and as wind direction proportionally allocated according to the frequency of appearance of wind directions with wind speeds of 0.5 to 2.0 m/s.

(i) Summation of inverses of wind speeds classified according to wind direction and atmospheric stability ($S_{d,s}$) is to be calculated as follows.

Summation of inverses of wind speeds classified according to wind direction and atmospheric stability under windy conditions (${}_{w}S_{d,s}$) is to be calculated using the formula (III-1);

$$ {}_{w}S_{d,s} = \sum_{i=1}^{N} \frac{{}_{d,s}\delta_i}{U_i} \quad \cdots\cdots\cdots (\text{III}-1) $$

N : Number of times of actual measurements

U_i : Wind speed (m/s) at the time of i

${}_{d,s}\delta_i$: ${}_{d,s}\delta_i$ = 1 when wind direction is d and atmospheric stability is s at the time of i.

${}_{d,s}\delta_i$ = 0 in other cases

Summation of inverses of wind speeds classified according to wind direction and atmospheric stability under calm conditions (${}_{c}S_{d,s}$) is to be calculated using the formula (III-2);

$$ {}_{c}S_{d,s} = \frac{{}_{c}N_{d,s}}{{}_{c}U} \quad \cdots\cdots\cdots (\text{III}-2) $$

${}_{c}N_{d,s}$: Number of times of appearance of atmospheric stability under calm conditions s allocated to wind direction d

$$ {}_{c}N_{d,s} = \frac{N'_d}{\sum_{d=1}^{16} N'_d} \cdot {}_{c}N_s $$

N'_d : Number of times of appearance of wind direction d with wind speeds of 0.5 to

2.0 m/s

$_{c}N_{s}$: Number of times of appearance of atmospheric stability s under calm conditions

$_{c}U$: Wind speed (0.5 m/s) under calm conditions

$$S_{d,s} = {}_{w}S_{d,s} + {}_{c}S_{d,s} \quad \cdots\cdots (III-3)$$

(ii) Average of inverses of wind speeds classified according to wind direction ($\bar{S}_{d,s}$) is to be calculated using the formula (III-4).

$$\bar{S}_{d,s} = \frac{1}{N_{d,s}} \cdot S_{d,s} \quad \cdots\cdots (III-4)$$

$N_{d,s}$: Total number of times of appearance of wind direction d and atmospheric stability s

$$N_{d,s} = {}_{w}N_{d,s} + {}_{c}N_{d,s}$$

$_{w}N_{d,s}$: Number of times of appearance of wind direction d and atmospheric stability s under windy conditions

(iii) Averageof the inverse of the wind speed classified according to wind direction ($\bar{S}_{d}$) is to be calculated using the formula (III-5).

$$\bar{S}_{d} = \frac{1}{\sum_{S=A}^{F} N_{d,s}} \cdot \sum_{S=A}^{F} S_{d,s} \quad \cdots\cdots (III-5)$$

(2) Postulated accident

Meteorological data at every hour on the hour are to be compiled for each hour on wind direction, wind speed, and atmospheric stability.

IV. Basic Dispersion Equation

The concentration in the air of radioactive material during normal operation and postulated accidents shall be calculated using the following dispersion equation assuming that the spatial concentration distribution of the radioactive material is a normal distribution both in the horizontal direction and in the vertical direction when wind direction, wind speed and all the other meteorological conditions are uniformly steady, the radioactive material is being constantly released from a release source, and topography is flat .

In this case, the coordinates of the dispersion equation are rectangular coordinates with the ground surface directly under the release source as its coordinate origin, the downwind direction as its x-axis, the rectangular direction to x-axis as its y-axis, and the vertical direction as its z-axis.

$$\chi(x,y,z)=\frac{Q}{2\pi\cdot\sigma_y\cdot\sigma_z\cdot U}\cdot\exp\left(-\lambda\frac{x}{U}\right)\cdot\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\times\left[\exp\left\{-\frac{(z-H)^2}{2\sigma_z^2}\right\}+\exp\left\{-\frac{(z+H)^2}{2\sigma_z^2}\right\}\right]\cdots\cdots(\text{IV}-1)$$

$\chi(x, y, z)$	: Concentration of radioactive material at a point of (x, y, z) (Bq/m^3)
Q	: Release rate (Bq/s)
U	: Wind speed representative of a height of a release source (m/s)
λ	: Physical decay constant of radioactive material (1/s)
H	: Height of a release source (m)
σ_y	: Parameter for spread of concentration distribution in y direction (m)
σ_z	: Parameter for spread of concentration distribution in z direction (m)

Parameters σ_y and σ_z for spread of the concentration distribution are expressed as a function of a downwind distance and atmospheric stability, and this functional relation is provided in Figure 1 and Figure 2.

V. Analytical method of atmospheric dispersion during normal operation

1. Concentrations in the air on the ground surface to be used for dose calculation

Concentrations in the air on the ground surface to be used for dose calculation during normal operation are to be calculated using the formula (V-1) derived from the formula (IV-1).

When the formula (V-1) cannot be used because of the effect of buildings etc., it should be calculated according to the formula (V-2). However, concentrations in the air on the ground surface are required to be corrected because of the results of a wind tunnel test etc., an appropriate correction shall be made.

$$\chi(x,y,o)=\frac{Q}{\pi\cdot\sigma_y\cdot\sigma_z\cdot U}\cdot\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\cdot\exp\left(-\frac{H^2}{2\sigma_z^2}\right)\cdots\cdots(\text{V}-1)$$

$\chi(x, y,0)$	: Concentration of radioactive material at a point of (x, y, 0) (Bq/m^3)
Q	: Release rate (Bq/s)
U	: Wind speed (m/s)
σ_y	: Parameter for spread of concentration distribution in y direction (m)
σ_z	: Parameter for spread of concentration distribution in z direction (m)
H	: Effective height of a release source (m)

$$\chi(x,y,o)=\frac{Q}{\pi\cdot\Sigma_y\cdot\Sigma_z\cdot U}\cdot\exp\left(-\frac{y^2}{2\Sigma_y{}^2}\right)\cdot\exp\left(-\frac{H^2}{2\Sigma_z{}^2}\right)\cdots\cdots(\text{V}-2)$$

Σ_y : $(\sigma_y{}^2 + cA/\pi)^{1/2}$

Σ_z : $(\sigma_z{}^2 + cA/\pi)^{1/2}$

A : Projected area in the windward direction of buildings etc. (m^2)

c : Shape coefficient

2. Calculation of yearly average concentration

(1) For the calculation of yearly average concentrations of radioactive material, the contribution when wind goes from a release point to an orientation including a point of interest (an orientation of interest) and the contribution when wind goes to the adjacent directions shall be added together.

(2) For the calculation of the yearly average concentration in an orientation of interest, summation of inverses of wind speeds classified according to wind direction and atmospheric stability is to be used in the case of a continuous release.

In the case of an intermittent release, based on the frequency of appearance of wind direction toward an orientation of interest and the adjacent directions (sum of the frequency of appearance of three directions) and on the number of times of yearly release, the total number of times of wind toward the three directions is to be determined with 67 % reliability of its binomial probability distribution, and then, the total number obtained is to be proportionally allotted according to the frequency of appearance of wind direction toward the three directions. And, for wind speed, the average of inverses of wind speeds classified according to wind direction and atmospheric stability is to be used.

However, when the number of times of releases is large, and the release duration is long, the number of times of releases to each orientation shall be considered to be proportional to the frequency of appearance of the wind direction.

(3) For the calculation of the yearly average concentration in an orientation of interest, the concentration is to be averaged assuming that the wind direction fluctuates uniformly within one direction.

VI. Analytical method of atmospheric dispersion during a postulated accident

Concentrations in the air on the ground surface to be used for dose calculation during a postulated accident are calculated by multiplying the downwind concentration per unit release rate (defined as relative concentration) by a release rate of radioactive material during the accident.

1. Relative concentration to be used for dose calculation

(1) The relative concentration is to be determined at a point of interest for each orientation, based on the meteorological data at each hour on the hour and the effective release duration (to be determined with account taken of temporal change in the release rate of radioactive material, hereinafter called as effective release duration).

(2) The relative concentration at a point of interest is the one corresponding to 97 % of the integrated frequency of appearance when relative concentration of each hour on the hour is integrated in ascending order over one year.

(3) The maximum value among the relative concentrations derived in the above (2) is to be used as the relative concentration to be used for the dose calculation.

2. Calculation of relative concentration

The relative concentration (χ/Q) is to be calculated according to the formula (VI-1).

$$\chi/Q=\frac{1}{T}\sum_{i=1}^{T}(\chi/Q)_i\cdot{}_d\delta_i \quad \cdots\cdots (\text{VI}-1)$$

(χ/Q) : Relative concentration during the effective release duration (s/m^3)
T : Effective release duration (h)
$(\chi/Q)_i$: Relative concentration at the time of i (s/m^3)
${}_d\delta_i$: ${}_d\delta_i$ = 1 when wind direction is d of interest at the time of i.
${}_d\delta_i$ = 0 when wind direction is at other directions at the time of i.

In this case, $(\chi/Q)_i$ is to be calculated as specified below depending on the length of the effective release duration, effects of buildings, etc.

However, when $(\chi/Q)_i$ is required to be corrected due to the results of a wind tunnel test etc., an appropriate correction shall be made.

(1) Short-term release

For the case of short-term release, $(\chi/Q)_i$ is to be calculated according to the formula (VI-2), assuming that the wind direction is constant.

$$(\chi/Q)_i=\frac{1}{\pi\cdot\sigma_{y_i}\cdot\sigma_{z_i}\cdot U_i}\cdot\exp\left(-\frac{H^2}{2\sigma_{z_i}{}^2}\right) \quad \cdots\cdots (\text{VI}-2)$$

σ_{yi} : Parameter for spread of concentration distribution in y direction at the time of i (m)

σ_{zi} : Parameter for spread of concentration distribution in z direction at the time of i (m)

U_i : Wind speed at the time of i (m/s)

H : Effective height of a release source (m)

(2) Long-term release

For the case of a long-term release, $(\chi/Q)_i$ is to be calculated according to the formula (VI-3) assuming that total amount of released radioactive material is uniformly distributed only within one orientation.

$$(\chi/Q)_i=\frac{2.032}{\sigma_{zi}\cdot U_i\cdot x}\cdot\exp\left(-\frac{H^2}{2\sigma_{zi}^2}\right) \cdots\cdots\cdots\cdots (\text{VI}-3)$$

$$2.032=\sqrt{\frac{2}{\pi}}\times\frac{16}{2\pi}$$

X: Distance from a release point to a point of interest (m)

(3) Correction for effects of buildings etc.

When the above-mentioned formula is not used due to effects of buildings etc., $(\chi/Q)_i$ is to be calculated according to the following formula.

(a) Short-term release

$$(\chi/Q)_i=\frac{1}{\pi\cdot\Sigma_{yi}\cdot\Sigma_{zi}\cdot U_i}\cdot\exp\left\{-\frac{H^2}{2\Sigma_{zi}^2}\right\} \cdots\cdots\cdots\cdots (\text{VI}-4)$$

Σ_{yi} : $(\sigma_{yi}^2 + cA/\pi)^{1/2}$

Σ_{zi} : $(\sigma_{zi}^2 + cA/\pi)^{1/2}$

A : Projected area in the counterwind direction of buildings etc. (m^2)

C : Shape coefficient

(b) Long-term release

$$(\chi/Q)_i=\frac{2.032}{\Sigma_{zi}\cdot U_i\cdot x}\cdot\exp\left\{-\frac{H^2}{2\Sigma_{zi}^2}\right\} \cdots\cdots\cdots\cdots (\text{VI}-5)$$

VII. Effective height of a release source

Effective height of a release source is determined taking into account the ground height of a stack, the plume rise, and effects due to buildings and topography, etc.

In this case, the plume rise is to be determined according to the following formula (VII-1).

$$\Delta H = 3\frac{W}{U} \cdot D \quad \cdots\cdots (\text{VII}-1)$$

ΔH	: Plume rise (m)
W	: Blow velocity (m/s)
D	: Diameter of stack outlet (m)
U	: Wind speed (m/s)

VIII. Wind tunnel test

When the topography of a site is complex, or effects of buildings etc. are expected to be significant, a wind tunnel test is to be performed using a model simulating relevant geometric conditions in order to consider adequacies of the effective height of a release source etc..

Note:

This Guide is described focusing on the calculations of the concentration in the air on the ground surface when gaseous radioactive material is dispersed within several kilometers from a release source. For the matters not clearly specified in the Guide, they shall be treated, for the time being, based on the purpose of the Guide as follows:

1. The γ ray dose from the radioactive cloud shall be determined by calculating spatial concentration distribution of radioactive material and applying the result to a γ ray dose calculation model, without using the concentration in the air on the ground surface.

   For the γ ray dose during a postulated accident, it is to be determined in the same manner as the Guide by using D/Q obtained by combining the spatial concentration distribution and a γ ray dose calculation model (defined as relative dose), instead of relative concentration (χ/Q).

2. During a postulated accident by which radioactive material is released to the atmosphere with high-temperature and high-pressure coolant, the concentration in the air on the ground surface is to be determined by using an appropriate method taking into consideration steam cloud formation and its uprise, movement, dispersion, etc.

3. When radioactive material dispersion over wide areas as in the case of a collective dose calculation, the concentration in the air on the ground surface is to be determined assuming appropriate wind speed, spreading width, atmospheric stability, etc.

Figure 1 Parameter for spread in y direction (σ_y)

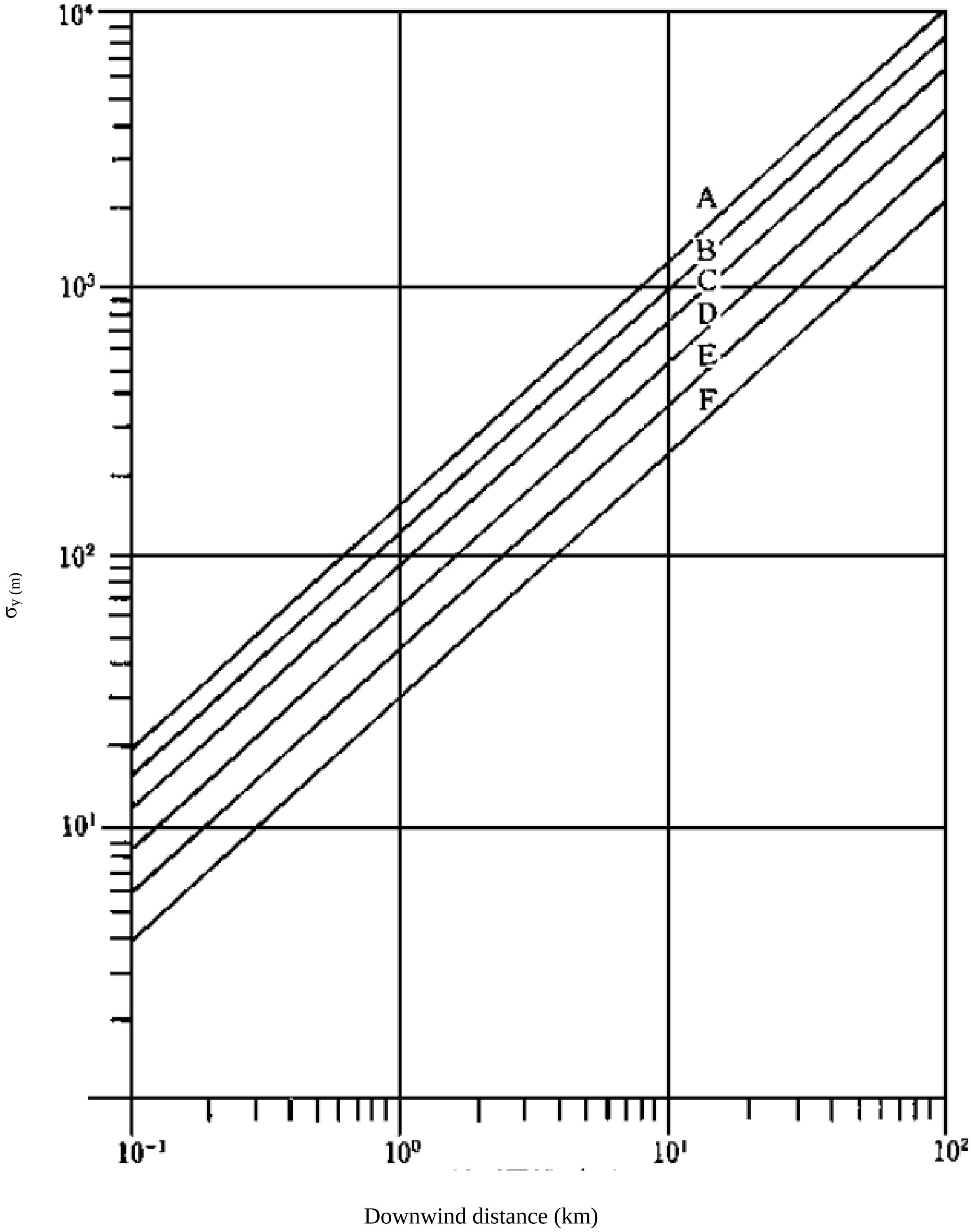
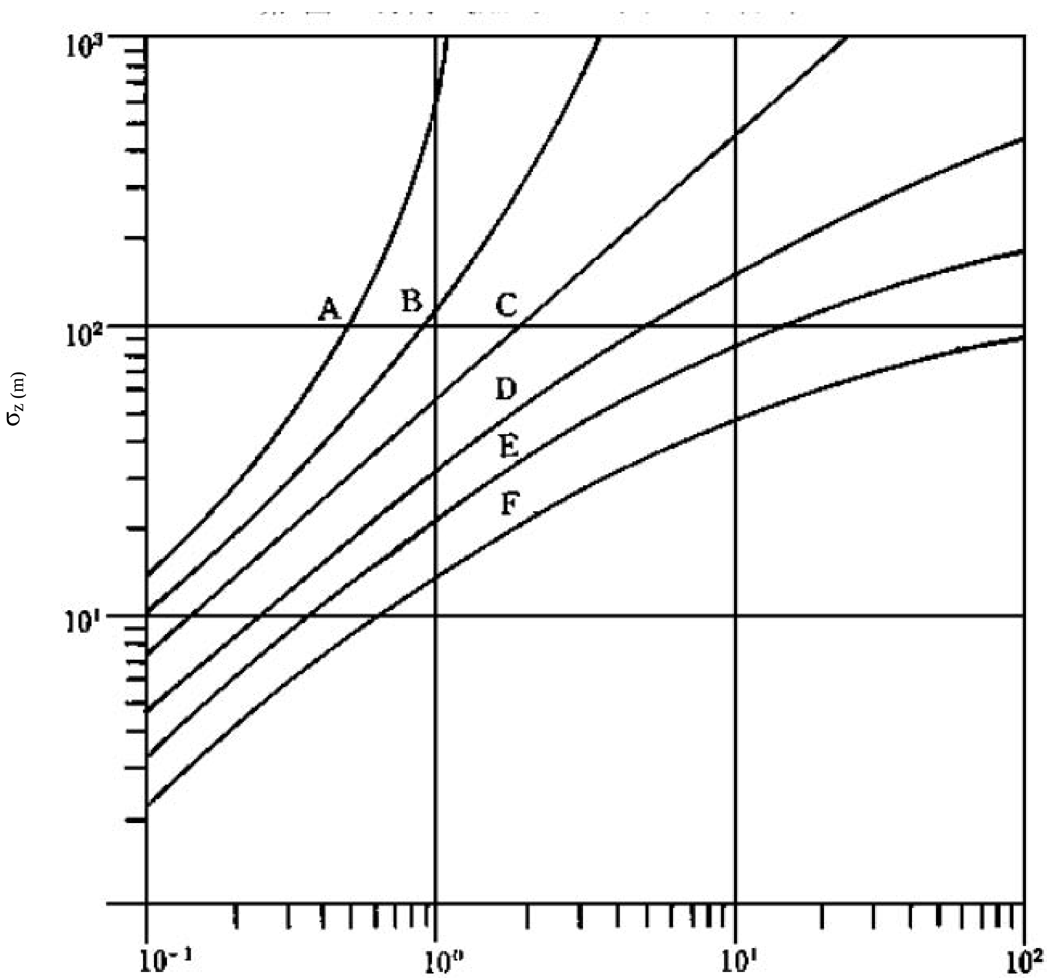


Figure 2 Parameter for spread in z direction (σ_z)



Downwind distance (km)

Commentary

I. Philosophy in developing the Guide

Since safety analyses of a nuclear reactor facility evaluate the doses from radioactive material discharged from the facility, it is important to estimate the dispersion conditions of radioactive material in the air in the vicinity of the nuclear reactor facility.

Since there are too many related factors and the areas to be covered are also too large to understand the atmospheric dispersion conditions in the vicinity of the nuclear reactor facility, it is difficult to establish an analytical method with theoretical justification and adequate accuracy. Therefore, the Guide was developed to promote practical use considering the existing knowledge and experiences.

Safety analyses of a nuclear reactor are performed generally for normal operation and postulated accidents, it was decided to determine meteorological conditions by taking into account the characteristics of those events.

Since safety analyses for normal operation is usually to assess long-term doses such as one-year doses in the vicinity of the nuclear reactor facility, it was decided to conduct a realistic analysis for this case based on yearly meteorological data, taking into account the effect of buildings, topography etc. on the atmospheric dispersion conditions, release modes, etc.

Since safety analyses for a postulated accident is to assess doses during the postulated accident, it is required to use extreme meteorological conditions that are red to be rarely encountered in view of its frequency of appearance as opposed to the rage meteorological conditions, considering that the postulated accident could happen at arbitrary time and its effective release duration is short. For this reason, considerations are given in the Guide so that the concentration of radioactive material would correspond to one during extreme meteorological conditions by analyzing the relative concentration during the postulated accident according to the probability of appearance based on meteorological measurement data and choosing its extremely low frequency of appearance.

II. Meteorological measurement method

1. Measurement parameter

(1) Normal measurement

Since measured values of wind direction, wind speed, and atmospheric stability (wind speed, amount of solar radiation, and amount of radiation balances near the ground surface) are required to use an atmospheric dispersion formula, each of these elements is determined to be measured.

In addition, since wind-mill type wind vane and anemometer do not necessarily provide correct values for weak wind, in order to make a correction for this, it is determined to use instruments which can also measure directions and speeds of slight wind.

As normal measurement is required to understand doses in the peripheral environment after commissioning as well as to assess doses prior to the installation of a nuclear reactor facility, it was determined that normal measurement is to start before installation of the nuclear reactor facility and to continue until the decommissioning.

(2) Special measurement

In order to understand the meteorological characteristics at site and its vicinity, it was decided to measure as necessary, ground surface wind at spots other than those for normal measurement, and to measure wind at an elevated level and air temperature differences at appropriate time for grasping the meteorological conditions above a stack.

And, in addition to the above-mentioned measurements, it is desirable to carry out measurements of relative humidity, snow precipitation, sea surface temperatures, etc. in addition to measurements of amount of rainfall and atmospheric temperatures specified under the "Rule for the Installation, Operation, etc of Commercial Nuclear Power Reactors ".

2. Measurement method

The meteorological measurement method is provided in the Guide II.3, and the points to be noted on the method are discussed in the following:

(1) The notification of meteorological measurement facilities shall be made according to the Meteorological Service Standards.

(2) The "Guide on Surface Meteorological Measurement” issued by the Japan Meteorological Agency shall be referred in performing the measurement.

(3) The meteorological instruments subject to certification of the Japan Meteorological Agency shall be periodically calibrated (13, 14) to confirm that their accuracies are within those required for their measurement purposes.

In addition, for a Doppler sodar, the models technically evaluated by the Japan Meteorological Agency shall be used, and when using them, the frequency of appearance of the specific meteorological conditions (strong wind, heavy rain, etc.) etc. interfering with measurements shall be confirmed.

(4) As for an measurement field, it shall be provided in a flat area within the premises of a reactor facility, planted with grass etc. and without structures, trees, etc. in its vicinity.

(5) In installing an measurement tower, an measurement column, etc., the required number of appropriate locations to observe the surface wind representative of a site and the wind at an elevated level relevant to a stack release and other wind necessary for information shall be selected. In this case, the stack position, structures, topography, settlements in the vicinity of the site, etc. shall be taken into consideration.

(6) For normal measurement, the positions of a measurement field, a measurement tower, a measurement column, etc. shall be selected, in principle, so that it would not be required to relocate them after plant commissioning. When their relocation is required, the measure shall be taken to maintain the continuity of records.

In addition to continuously recording the measurements of the meteorological measurement on recording paper, they shall be recorded on a magnetic tape etc. so as to improve reliability of the recording and to permit their computer processing. It is desirable to record the measurements at a place such as a main control room to allow continuous measurements monitoring after commissioning of the nuclear reactor facility.

Since these measured values are statistically processed so as to compensate also missing data, the percentage of missing data in 12 continuous months was determined to be 10 % or less, in principle, in order to make the percentage as low as possible. In addition, since it is not desirable that missing data exist at a particular period of time, efforts shall be made to make this percentage of missing data 30% or less in 30 continuous days. In order to achieve this, the methods for inspections and maintenance of meteorological instruments shall be established, and their inspections and maintenance shall be periodically performed. And, it is desirable to maintain backup instruments, as required.

In addition, examples of meteorological instruments are provided in Table 1 for information.

Table 1 Examples of meteorological instruments

Measurement type	Measurement parameter	Meteorological instruments
Normal measurement	Wind direction and wind speed	(1)Wind-mill type wind vane and anemometer (propeller-type power-generation type) (2) Cup anemometer (three-cup type) and fletching-type wind vane (3) Ultrasonic wind vane and anemometer (4) Doppler sodar
	Amount of solar radiation	(1) Electric-type radiometer
	Amount of radiation balances	(1) Windscreen-type net radiometer
Special measurement	Wind direction and wind speed	(1)Wind-mill type wind vane and anemometer (propeller-type power-generation type) (2) Ultrasonic wind vane and anemometer
	Wind at an elevated level	(1) Pilot balloon etc.
	Temperature difference	(1) Platinum resistance differential temperature indicator (2) Thermistor differential temperature indicator (3) Thermocouple differential temperature indicator (4) Captive balloon, low-altitude sonde

III. Statistical processing method of measured values

1. Normal measurement

(1) Hourly meteorological data

(a) Wind direction, wind speed, amount of solar radiation, and amount of radiation balances

In the Guide, treating the average values over 10 minutes to the hour as the measured values at the hour concerned for wind speed and wind direction is in accordance with the "Guide on Surface Meteorological Measurement" issued by the Japan Meteorological Agency, and other measured values are treated in the same way.

(b) Atmospheric stability

Table 3 in the Guide shows the classification established in Japan so that the classification table of Pasquill-Meade (1) can be applied objectively using meteorological instruments (2, 13).

In performing a dispersion calculation, intermediate stability; A - B, B - C, and C - D of this Table shall be deemed and processed as B, C, D, respectively, and "G" of the column: less than 2 m/s at night shall be deemed and processed as F.

(2) Statistical arrangement of meteorological data

Hourly meteorological data shall be arranged according to the arrangement items of Table 2.

For what requires yearly statistics, all the missing data shall be processed as described hereinafter in consideration of its convenient use, and after converting it to the equivalent for a period of one year, the result shall be entered in the table.

(3) Summation and average of inverses of wind speeds classified according to wind direction and atmospheric stability

The summation ($S_{d,s}$) and average ($\overline{S}_{d,s}$) of inverses of wind speeds classified according to wind direction and atmospheric stability to be used for the calculation of the yearly average concentration are to be determined by the following procedure using the atmospheric stability to be determined from the amount of solar radiation, the night radiation balances, and wind speed (10 m in height, in principle) and the wind direction and wind speed to be measured at a height representative of a release height.

(a) When there is any missing data of atmospheric stability, wind direction, or wind speed, the hour concerned will be treated as missing-data hour.

(b) When there are missing data in measurement data, the summation ($S_{d,s}$) of inverses of wind speeds classified according to wind direction and atmospheric stability is to be multiplied by Nt/N to convert it to the value for one year.

Nt: Total number of times of measurements for one year (8,760)

N: Number of times of actual measurements excluding missing-data times for 1 year

2. Special measurement

The measured values of special measurement are to be statistically processed so as to identify the following matters:

(1) Conditions of surface wind and wind at an elevated level in the vicinity of a site

(2) Vertical distribution of air temperatures above the site

Table 2 Parameters to be statistically processed

Item	Symbol	Unit	Minimum order	Remarks
(1) Summation of inverses of wind speeds classified according to wind direction and atmospheric stability	$S_{d,s}$	s/m	0.01	
(2) Average of inverses of wind speeds classified according to wind direction and atmospheric stability	$\bar{S}_{d,s}$	s/m	0.01	
(3) Average of inverses of wind speeds classified according to wind direction	$\bar{S}_{d}$	s/m	0.01	
(4) Frequency of appearance of wind direction		%	0.1	Calm wind also to be included.
(5) Frequency of appearance of atmospheric stability		%	0.1	
(6) Number of times of appearance according to wind direction and atmospheric stability	$N_{d,s}$	No. of times	1	
(7) Number of times of appearance of atmospheric stability during calm weather	$_{c}N_{s}$	No. of times	1	Frequency (%) is also to be written together.
(8) Number of times of appearance of wind with a speed of 0.5 to 2.0 m/s	N'_{d}	No. of times	1	
(9) Number of times of monthly missing data		No. of times	1	Frequency (%) is also to be written together.

IV. Basic Dispersion Equation

The atmospheric dispersion equations provided in the Guide should be originally used when radioactive material is constantly discharged from a release source, and topography is flat. Therefore, when topography is complex and the effects of buildings etc. on dispersion from a release source are expected to be significant, it is not necessarily adequate to apply this formula just as it is.

In such a case, it is required that the values derived from the above-mentioned dispersion equation are corrected and evaluated using the results of a wind tunnel test etc.

1. Basic dispersion equation

It is considered that gaseous or particulate materials discharged to the atmosphere move with wind. Since the atmosphere is generally in turbulent flow conditions, the discharged materials are comparatively quickly dispersed and diluted while moving. When the above-mentioned materials are being continuously discharged from one point in the uniform atmosphere without being affected by the ground surface, the downwind concentration is to be calculated using the following formula:

$$\chi(x, y, z) = \frac{Q}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot U} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot \exp\left(-\frac{z^2}{2\sigma_z^2}\right)$$

X : Concentration at a point of (x, y, z) (Bq/m^3)
Q : Release rate (Bq/s)
U : Wind speed (m/s)
σ_y : Parameter for spread of concentration distribution in y direction (m)
σ_z : Parameter for spread of concentration distribution in z direction (m)

Where, the coordinates are rectangular coordinates with a release source as its coordinate origin and the downwind direction as its x-axis.

Next, consider the case where material is being continuously discharged from a height of H above the ground. Taking x-axis and y-axis on the flat ground surface, z-axis in the vertical direction and x-axis in the downwind direction, the coordinate origin is taken directly under a release point. Assuming that the discharged material "reflects off" completely on the ground surface, the concentration at a point of (x, y, z) is expressed by the following formula:

$$\chi(x, y, z) = \frac{Q}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot U} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left\{-\frac{(z-H)^2}{2\sigma_z^2}\right\} + \exp\left\{-\frac{(z+H)^2}{2\sigma_z^2}\right\}\right]$$

Here, it is assumed that wind speed U is constant, and σ_y and σ_z are functions of only the downwind distance x and atmospheric stability. Realistically, there is no guarantee that such assumptions are valid, and the above-mentioned conditions, such as the flat ground surface and the complete reflection of the discharged material, cannot be always met. As for the concentration on the ground surface, since σ_y and σ_z in the formula are given so that the calculated value would agree with the experimental value, the result obtained by this method is reasonable. This is the reason this model is widely used. Values for σ_y and σ_z are generally used which were determined by the researchers of the United Kingdom Meteorological Bureau (3) based on the data of the field experiments mainly conducted in the U.S.

In addition, several other dispersion equations (4) have been proposed, but they are not adopted here on account of practical applicability.

2. Parameters σ_y and σ_z for spread of concentration distribution

Parameters σ_y and σ_z for spread of the concentration distribution of the dispersion equation (IV-1) provided in the Guide are the standard deviations of the concentration distribution in the horizontal direction and the vertical direction, respectively, when the vertical direction can be regarded as infinite with no existence of the ground surface.

Figures 1 and 2 in the Guide were developed almost faithfully according to the figure with so-called vertical 1/10 concentration width h and the description on the angle θ encompassing a horizontal 1/10 concentration width by Pasquill-Meade. There are the following relations among these by definition:

$$h = 2.15\sigma_z$$

$$\frac{1}{2}\theta = \frac{180}{\pi} \cdot \frac{2.15\sigma_y}{x}$$

Where, the unit of h, σ_z, σ_y, and the downwind distance x is m, and the unit of θ is deg.

In the original paper (1), θ is assumed to be θ (0.1 km)/ θ (100 km) = 2, where θ is linearly interpolated on a semilogarithmic scale with taking a downwind distance as logarithm.

$\sigma_y = 0.67775\ \theta_{0.1} * (5 - \log x) * x$ (The unit of x is km)

Here, $\theta_{0.1}$ (deg) is a value of θ at a distance of 0.1 km and given in the following table.

Atmospheric stability	A	B	C	D	E	F
$\theta_{0.1}$	50	40	30	20	15	10

"h" can be approximated on logarithmic scales, using, for example, a quadratic equation or a tertiary equation.

$$\sigma_z = \sigma_1 X^{a_1 + a_2 \log x + a_3 (\log x)2}$$ (The unit of X is km)

Where, σ_1, a_1, a_2, and a_3 are constants and given in Table 3 and Table 4.

In addition, from a practical point of view, σ_2 exceeding 1,000 m in the above formula is treated as 1,000 m..

Table 3 σ_1, a_1, a_2, and a_3 (downwind distance is 0.2 km or more.)

Atmospheric Stability	σ_1	a_1	a_2	a_3
A	768. 1	3. 9077	3.898	1. 7330
B	122.0	1.4132	0.49523	0. 12772
C	58. 1	0. 8916	-0.001649	0.0
D	31.7	0.7626	-0.095108	0.0
E	22.2	0.7117	-0.12697	0.0
F	13.8	0. 6582	-0.1227	0.0

Table 4 σ_1 and a_1 (downwind distance is less than 0.2 km.)

Atmospheric stability	σ_1	a_1
A	165	1.07
B	83.7	0.894
C	58.0	0.891
D	33.0	0.854
E	24.4	0.854
F	15.5	0.822

However, a_2 and a_3 are to be treated as 0.

V. Analytical methods of atmospheric dispersion during normal operation

1. Calculation of spatial concentration distribution

The plume discharged from a stack is generally deemed as a release from an elevated location, and the calculation of the spatial concentration distribution can be performed using the formula (IV-1) in the Guide.

On the other hand, when the difference between a release source height taking into account a plume rise and heights of buildings etc. is small, the phenomenon that the plume is engulfed in the downwind direction of the buildings (building wake effects) is well known. In this case, the Guide requires that the spatial concentration distribution is to be calculated using the formula (V-2). In this formula, the release source is assumed to have its spread. That is, it is assumed that the plume dispersion caused by building wake effects has occurred before it spreads due to normal atmospheric dispersion. This dispersion parameter is a function of the projected areas of buildings etc., and the concentration distribution in the areas is assumed to be normal distributions. Now, setting the parameters for the initial dispersion due to building wake effects as

σ_{y0} and σ_{z0}, and the parameters for the spread due to normal atmospheric dispersion in the downwind direction as σ_y and σ_z, overall dispersion parameter will be given by the following formulas;

$$\Sigma_y^2 = \sigma_{y0}^2 + \sigma_y^2$$
$$\Sigma_z^2 = \sigma_{z0}^2 + \sigma_z^2 .$$

Here, taking that $\sigma_{y0}^2 = \sigma_{z0}^2 = \dfrac{cA}{\pi}$,

A : Projected areas in the windward direction of buildings etc. (m^2)
C : Shape coefficient

Formula (V-2) of the Guide is obtained.

For the shape coefficient c and an effective height of a release source H in the formula (V-2), 1/2 and 0 shall be used, respectively, unless special bases for them are provided, in principle. In addition, Gifford recommends $1/2 < c < 2$ (10).

2. Calculation of yearly average concentration

(1) Basic calculation of yearly average concentration

Assuming that radioactive material is constantly discharged and topography is flat, the concentration distribution on the ground surface is expressed by the following formula when the decay effect of the radioactive material during movement toward a point of interest is ignored;

$$\chi(x, y, o) = \frac{Q}{\pi \cdot \sigma_y \cdot \sigma_z \cdot U} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot \exp\left(-\frac{H^2}{2\sigma_z^2}\right) \cdots\cdots\cdots\cdots (1)$$

$\chi(x, y, o)$: Concentration of radioactive material at a point of (x, y, o)
Q : Release rate (Bq/s)
U : Wind speed (m/s)
H : Effective height of a release source (m)
σ_y : Parameter for spread of concentration distribution in y direction (m)
σ_z : Parameter for spread of concentration distribution in z direction (m)

In actually calculating the yearly average concentration, contributions from an orientation of interest and the adjacent orientations shall be taken into consideration. Specific calculation is to be performed, in principle, based on the following method (a) which is more likely to represent actual conditions. In addition, in some cases, it is acceptable to perform the calculation based on the following method (b) in the light of the characteristics of frequency of appearance of wind direction and wind speed, etc.

Method (a)

In this method, contributions of a direction of interest and the adjacent directions are averaged out on each contribution within the direction of interest using the meteorological data of each orientation.

The calculation of the yearly average concentration by this method will be carried out using an electronic computer, and the basic formula for that calculation is expressed as follows;

$$\chi = \sum_{S=A}^{F} \left[\frac{Q}{\pi \cdot \sigma_{ys} \cdot \sigma_{zs} \cdot U_{s_1}} \cdot \exp\left(-\frac{H_1^2}{2\sigma_{zs}^2}\right) \cdot F_{s_1} + \frac{Q}{\pi \cdot \sigma_{ys} \cdot \sigma_{zs} \cdot U_{s_2}} \times \exp\left(-\frac{H_2^2}{2\sigma_{zs}^2}\right) \cdot F_{s_2} + \frac{Q}{\pi \cdot \sigma_{ys} \cdot \sigma_{zs} \cdot U_{s_3}} \cdot \exp\left(-\frac{H_3^2}{2\sigma_{zs}^2}\right) \cdot F_{s_3} \right] \cdots\cdots (2)$$

σ_{ys}, σ_{zs} : σ_y, σ_z when atmospheric stability is s

U_{s1} : Wind speed of a direction of interest when atmospheric stability is s (m/s)

U_{s2}, U_{s3} : Wind speed of the adjacent directions when atmospheric stability is s (m/s)

H_1 : Effective height of a release source to a direction of interest (m)

H_2, H_3 : Effective height of a release source to the adjacent directions (m)

F_{s1} : Average coefficient for the concentration in a direction of interest when atmospheric stability is s

F_{s2}, F_{s3} : Average coefficient for the concentration in the adjacent directions when atmospheric stability is s

However, average coefficients F_{s1}, F_{s2}, and F_{s3} are expressed by the following formulas:

$$Fs_1 = \frac{\int_0^{y_1} \exp(-\frac{y^2}{2\sigma_{ys}^2})dy}{y_1} \cdots\cdots(3)$$

$$Fs_2 = Fs_3 = \frac{\int_0^{y_2} \exp(-\frac{y^2}{2\sigma_{ys}^2})dy - \int_0^{y_1} \exp(-\frac{y^2}{2\sigma_{ys}^2})dy}{y_2 - y_1} \cdots\cdots(4)$$

$$y_1 = \frac{2\pi x}{16} \times \frac{1}{2} = \pi x/16$$

$$y_2 = \frac{2\pi x}{16} \times \frac{3}{2} = 3\pi x/16$$

x: Distance from a release point to a point of interest (m)

Method (b)

This method averages out the concentration, assuming that, at a certain wind direction, total amount of the discharged radioactive material is uniformly distributed in that orientation (it can be said that this method holds parts outside of an orientation of interest over an orientation of interest). In this case, the yearly average concentration at a point of interest is expressed by the following formula;

$$\chi = \sum_{S=A}^{F} \sqrt{\frac{2}{\pi}} \cdot \frac{Q}{\sigma_{zs} \cdot Us_1 (2\pi x/16)} \cdot \exp(-\frac{H_1^2}{2\sigma^2_{zs}}) \cdots\cdots(5)$$

(2) Intermittent release

When the number of times of releases is extremely small (20 times or less per year) and the amount released is significant compared with total yearly amount released, the release mode is defined as an intermittent release, and is to be treated separately from a continuous release.

Since contributions of the adjacent orientations are decided to be taken into consideration also for an intermittent release, the Guide applies the binomial probability distribution to the frequency of appearance of wind direction in the three orientations. For the distribution of the number of times of releases to an orientation of interest and adjacent orientations, it was determined to distribute it proportionally to the frequency of appearance of wind direction in each orientation.

In addition, in setting the reliability of the binomial probability, 2/3 (0.67) was adopted here as a somewhat conservative value.

Therefore, when the yearly number of times of an intermittent release is assumed n_y times, the probability that the number of times of the effect to an orientation of interest is m times can be obtained from the calculation of the binomial probability using the following formula;

$$F(m) = {}_{n_y}C_m \cdot P^m \cdot (1-P)^{n_y - m} \quad \cdots\cdots (6)$$

F(m) : Probability that the number of times of the effect to an orientation of interest is m times

${}_{n_y}C_m$: Combination of m times out of n_y

P : Frequency of appearance of wind direction to an orientation of interest

Finding an expectation value that wind direction at the time of an intermittent release coincides with an orientation of interest and taking this value as the number of times of the effects to that orientation, r which satisfies the following formula will be the number of times of the effect to that direction.

$$\sum_{m=0}^{r} F(m) > 0.67 \quad \cdots\cdots (7)$$

In addition, the number of effected times when given frequency of appearance of wind direction and the number of times of releases are given is shown in Table 5.

(3) Yearly average concentration for a continuous release and an intermittent release

When the average concentration in the ground surface air within one orientation with a unit release rate (1 Bq/s) and a unit wind speed (1 m/s) is expressed $\overline{\chi_s}$, the yearly average concentrations for a continuous release and an intermittent release with the atmospheric stability s are expressed in the following formulas, respectively.

$$\chi_{cont,s} = Q_{cont} \cdot \overline{\chi_s} \cdot \frac{1}{Nt} \cdot S_{d,s} \quad \cdots\cdots (8)$$

$$\chi_{in,s} = Q_{in} \cdot \overline{\chi_s} \cdot \frac{n_c}{n_y} \cdot \frac{1}{f_{dt}} \cdot \frac{N_{d,s}}{Nt} \cdot S_{d,s} \quad \cdots\cdots (9)$$

$\chi_{cont,s}$, $\chi_{in,s}$: Yearly average concentrations for a continuous release and an intermittent release with the atmospheric stability s, respectively (Bq/m^3)

Q_{cont}, Q_{in} : Release rates assuming that the total amounts of a continuous release and an intermittent release are uniformly discharged over one year, respectively (Bq/s)

Nt : Total number of measurements (8,760)

$N_{d,s}$: Frequency of appearance of an orientation d and the atmospheric stability s

n_y, n_e : Number of times and the effected times of intermittent releases, respectively (times to 3 orientations)

f_{dt} : Summation of frequency of appearance of wind direction to an orientation of interest and adjacent orientations

Since the following formula (10) is obtained in the course of the calculation of $S_{d,s}$ and $\bar{S}_{d,s}$ provided in the Guide III. 2, it would be simple to calculate the concentrations in the ground surface air for an intermittent release based on the formula.

$$\chi_{in,s} = \chi_{cont,s} \cdot \frac{Q_{in}}{Q_{cont}} \cdot \frac{N'_e}{n_y} \cdot \frac{1}{f_d} \quad \cdots\cdots (10)$$

N'_e: Number of times of the effect to either an orientation of interest or adjacent orientations

f_d: Frequency of appearance of wind direction to show the number of times of the effect N'_e

VI. Analytical methods of the atmospheric dispersion during a postulated accident

1. Relative concentration

When the amount of radioactive material released and release conditions (release duration, effective height of a release source, etc.) for a postulated accident are determined, the concentration of radioactive material in a downwind point of interest will be governed by the meteorological conditions during the release.

However, since the meteorological conditions to be encountered when a postulated accident occurs cannot be known beforehand, the meteorological conditions in this case must be analyzed using a probabilistic methodology. For this reason, in the Guide, it was determined to analyze based on χ/Q to be derived from a basic dispersion equation.

$$\chi/Q(x, y, z) = \frac{1}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot U} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \times \left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\}$$

χ/Q(x, y, z) : Relative concentration at a point of (x, y, z)

σ_y : Parameter for spread of concentration distribution in y direction (m)

σ_z : Parameter for spread of concentration distribution in z direction (m)

U : Wind speed (m/s)

H : Effective height of a release source (m)

χ/Q is the downwind concentration at the hour concerned per unit release rate calculated using hourly wind direction, wind speed, and atmospheric stability, and, so to speak, indicates a degree of dilution by dispersion in the atmosphere.

In the Guide, in order to derive the concentration under the meteorological conditions to be rarely encountered during a postulated accident, it was determined to adopt an appearance probability of 97 % in the light of the past experiences for the relative concentration for this analysis.

The concentration to be used for the dose calculation during a postulated accident can be obtained by multiplying the relative concentration in the ground surface air by a release rate of radioactive material during a period of the accident.

2. Calculation of relative concentration

(1) Since the maximum value of χ/Q may appear at a distance beyond a point of interest depending on an effective height of a release source and a type of atmospheric stability, by calculating a χ/Q at each appropriate distance and finding the χ/Q corresponding to a yearly integrated frequency of appearance of 97 % for each distance, the maximum value among the χ/Q values found shall be taken as the χ/Q value in the orientation concerned.

However, it is also acceptable that, assuming the maximum hourly value of χ/Q at a distance beyond a point of interest as the χ/Q at the point of interest at an hour concerned, the χ/Q corresponding to 97 % of yearly integrated frequency of appearance is taken as the χ/Q value in that orientation.

(2) When the maximum value of χ/Q appears at a point of interest, a specific calculation of χ/Q shall be performed according to the effective release duration using the following procedure.

[Example 1]: A case when the effective release duration is 1 hour

When the effective release duration is 1 hour, χ/Q shall be calculated for each orientation.

As the meteorological elements of wind direction, wind speed, and atmospheric stability are obtained hourly as meteorological data, the number of the meteorological data for one year would be 8,760 without missing data. χ/Q of 1 hour in a certain orientation will be obtained by substituting the hourly meteorological data for one year into the formulas (VI-1) and (VI-2) in the Guide, but some of χ/Qs obtained are those of 0 with wind direction in other orientations.

Arranging these χ/Qs in ascending order and finding the χ/Q corresponding to 97 % of yearly integrated frequency of appearance, it is to be taken as that in the orientation concerned. When there are missing data, taking the number of hours obtained by deducting the number of hours with missing data from the total measurement hours as the total number, the χ/Q corresponding to 97 % of yearly integrated frequency of appearance is to be obtained. Applying the same procedure to all orientations, obtaining the χ/Q value for each orientation, and choosing the maximum from them (the number of obtained χ/Q values is 8 when 8 orientations are covered), the maximum χ/Q value chosen is to be used for the dose calculation.

[Example 2]: A case when the effective release duration exceeds 1 hour

When the effective release duration exceeds 1 hour, since the average χ/Q is to be calculated for that duration, the way to obtain the χ/Q is somewhat different from that for [Example 1].

For example, for the effective release duration of 8 hours, the procedure is as follows.

For χ/Q of 8 hours of a certain orientation, χ/Q of the 8 hours concerned is to be calculated at an arbitrary hour first, by substituting the hourly meteorological data for 8 hours from the hour into the formulas (VI-1) and (VI-2) in the Guide, and then substituting the hourly meteorological data of 8 hours from the hour put off by 1 hour from the arbitrary hour into the same formulas to obtain the χ/Q for 8 hours at the hour concerned.

The same procedure is to be repeated for one year. The χ/Qs obtained in this way also include the χ/Qs which is 0 when all wind directions are in other orientations over 8 hours concerned. Arranging these χ/Qs in ascending order and finding χ/Q corresponding to 97 % of yearly integrated frequency of appearance, the χ/Q is to be taken as that in the orientation concerned.

Applying the same procedure to all orientations, obtaining the χ/Q value for each orientation, and choosing the maximum from the χ/Q values obtained for each orientation, the maximum χ/Q value chosen is to be used for the dose calculation.

When some hours with missing data are included in the 8 hours concerned, the χ/Q must be processed appropriately taking into account distribution conditions of the missing data.

(3) The effective release duration (T) must be appropriately determined taking into account a release mode because the release rate varies depending on the type of postulated accidents. Therefore, it may be one method to use the value obtained by dividing the total amount of radioactive material released during a period of the accident by the maximum amount released per hour.

When the effective release duration exceeds 8 hours, the relative concentration is to be calculated considering the release as a long-term release.

VII. Calculation for calm weather conditions

Dispersion during calm weather conditions should not be treated in the same way as that during windy conditions, but, since no appropriate practical dispersion equation is available now, it was determined to apply the dispersion equation for windy conditions assuming wind speed to be 0.5 m/s for convenience from the following reason.

Since highly-sensitive breeze anemometers often indicate a wind speed of 0.5 m/s or more even during calm weather conditions and extremely-high actual measurements of gamma ray exposure from radioactive plume during calm weather conditions have not been also obtained (12), it is considered that atmospheric dispersion dilution occurs even during calm weather conditions.

In the Guide, it was determined to apply the dispersion equations for windy conditions assuming a wind speed of 0.5 m/s during calm weather conditions in consideration of such facts. For wind directions during calm weather conditions, a wind direction distribution according to breeze anemometers during normal operation is approximately consistent with a wind direction distribution with a wind speed of 0.5 to 2.0 m/s. Therefore, it was decided to distribute the wind direction proportionally to the frequency of appearance of wind direction with a wind speed of 0.5 to 2.0 m/s.

And, in the case of a postulated accident, it was determined that wind directions during calm weather conditions is those before calm weather conditions appear in consideration of sustainability of wind directions, etc.

VIII. Effective height of a release source

(1) The concentration in the ground surface air in downwind orientations are governed according to meteorological conditions, such as wind speed and atmospheric stability, and release conditions, such as an effective height of a release source of radioactive material. As an effective height of a release source, a height which is summation of a plume rise and a stack ground height is normally used, but when topography in the surrounding area of a nuclear reactor facility is complex and the effective height is affected by buildings etc., "an apparent height of a release source" adjusted taking into account their effects on dispersion may be used for the concentration analysis.

Thus, since "an apparent height of a release source" is used as an effective height of a release source in consideration of a plume rise, effects of buildings, topography, etc., "an apparent height of a release source" is used in the Guide as an effective height of a release source.

(2) A plume rise ΔH to be used in calculating an effective height of a release source is an

increase in a release height due to dynamic and thermal effects of the exhaust air, and various calculation formulas have been proposed for the calculation of this ΔH (5, 6. 7). Since the temperature difference between the exhaust air and environmental air is small in the case of a nuclear power reactor facility, it is considered that blow-up of a plume is mostly due to a dynamic effect.

Conventionally, in assessing a plume rise in Japan, there have been many cases that the Holland formula (5) has been used as a reference. However, Briggs (9) studied many subsequent experimental data and has proposed calculation formulas for a plume rise corresponding to several meteorological conditions. In yearly dose assessment, it is appropriate to use a yearly averaged value also for a stack height. Therefore, it was determined to use the formula (VII-1) in the Guide to be applied to a neutral state for calculating a plume rise. Since the wind speed U in this formula is used in the inverse form, it is considered appropriate to use an average of inverse of wind speeds classified according to wind directions （$\bar{S}_d$） for the calculation.

In addition, when a plume rise is taken into consideration during a postulated accident, it is required to use an appropriate method.

IX. Wind tunnel test

The objectives of wind tunnel tests to be used for an atmospheric dispersion analysis are to clarify how the main shaft of the plume from a stack is affected by buildings, topography, etc., whether horizontal and vertical dispersion has specific properties and how an effective height of a stack changes, and their methods include the experiments using small-scale models for investigating the effects of buildings near a stack and topography, etc. and the experiments using large-scale models for investigating the effects of a site boundary and its vicinity and areas beyond it (4, 11).

Here, a wind tunnel test to estimate the concentration in the ground surface air when site topography is complex and the effects of buildings etc. on a release source is expected to be significant is discussed in the following.

Elements to be incorporated into an experimental model include buildings, a stack, a site, and the surrounding topography, etc.

Specific experiments are to be performed by measuring the concentration distributions in the ground surface air in an orientation of interest with a topography model for a height of a release source and with a flat topography model for several kinds of a release height, and both data are compared.

Obtaining an effective height of a release source based on this result, for example, assuming that a stack exists in flat topography, and using this height of a release source in the dispersion formula, it is possible to calculate the concentration affected by the topography etc.

X. Considerations to other meteorological conditions

A material concentration distribution in the atmosphere is estimated by the dispersion formulas established based on many experiments, and the meteorological elements used as parameters for these dispersion formulas are wind direction, wind speed, and atmospheric stability.

The Guide requires that using the meteorological data obtained by observing these meteorological elements for at least one year at a site in the dispersion formulas, the radioactive material concentration in the ground air should be analyzed, but other meteorological conditions were determined to be treated as follows.

1. Yearly variations of meteorological phenomena

The meteorological phenomena repeat themselves almost on a one-year cycle, but yearly variations also exist.

For this reason, yearly variations of the relative concentration to be used for the dose calculation during a postulated accident were investigated over a comparatively long period of time, and it was found out that a ratio of the variation of the relative concentration of each year to the average relative concentration was 30 % or less.

This fact shows that the analytical results based on the meteorological data for one year vary with yearly variations of meteorological phenomena, but it is not so significant. Therefore, it was decided to analyze the relative concentration using the meteorological data for one year, first.

In that case, it is desirable to investigate whether that year is especially unusual one or not using the meteorological data of a nearby government weather station.

When the meteorological data for 2 years or more exist, it is desirable to make effective use of those data.

2. Upper inversion layer

When a stable air layer exists above a stack and the lower layer is in unstable condition, it is said that an upper inversion layer exists there. As the dispersion to the upper layer may be prevented in this case, the concentration near the ground surface could increase.

The Guide requires that the concentration in the ground surface air should be calculated based on dispersion formulas, but it is necessary to study how to treat the upper inversion layer which is a special meteorological condition to those dispersion conditions.

Generation of the upper inversion layer is judged by vertical temperature measurement. As a result of investigating the frequency of appearance of air temperature difference according to altitudes, frequency of appearance of temperature reverse according to altitudes, duration of temperature reverse, etc., it was estimated that generation of the upper inversion layer right above a stack where released radioactive material is confined is a comparatively rare phenomenon.

On the other hand, the calculated value of the concentration in the ground surface air obtained on a very conservative condition (assuming a cover right above a stack) during an appearance of upper inversion layer was not extremely large compared with the value obtained using the dispersion formula in the Guide.

Thus, since it is considered that generation of the upper inversion layer as mentioned above is a comparatively rare phenomenon and that such a high concentration would not be produced even with the upper inversion layer, it was determined not to especially take into account the upper inversion layer for the calculation.

However, in order to confirm that an appearance of the upper inversion layer is rare, it is desirable to understand the frequency of appearance of the air temperature difference according to altitudes, frequency of appearance of temperature reverse according to altitudes, duration of temperature reverse, etc. by observing the air temperature difference for a particular period of time.

Table 5 Number of times of wind direction toward an orientation of interest during an intermittent release (67% reliability)

Frequency of wind direction (%) / Number of times of releases	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	*	*	*	*	*	*	*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
10	*	*	*	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3
15	*	*	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4
20	*	1	1	1	1	2	2	2	2	2	3	3	3	3	4	4	4	4	4	5	5	5	5	6	6
25	*	1	1	1	2	2	2	2	3	3	3	4	4	4	4	5	5	5	6	6	6	6	7	7	7
30	*	1	1	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	8
35	*	1	1	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7	8	8	8	9	9	9	10
40	1	1	2	2	2	3	3	4	4	5	5	6	6	6	7	7	8	8	9	9	9	10	10	11	11
45	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	12
50	1	1	2	2	3	4	4	5	5	6	6	7	7	8	9	9	10	10	11	11	12	12	13	13	14

Frequency of wind direction (%) / Number of times of releases	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
10	3	3	3	3	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	6	6
15	5	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7	7	8	8	8	8	8	4
20	6	6	6	7	7	7	7	7	8	8	8	8	9	9	9	9	9	10	10	10	10	11	11	11	11
25	7	8	8	8	8	9	9	9	10	10	10	11	11	11	11	12	12	12	12	13	13	13	13	13	14
30	9	9	9	10	10	10	11	11	11	12	12	12	13	13	13	13	14	14	14	15	15	15	16	16	16
35	10	11	11	11	12	12	12	13	13	13	14	14	15	15	15	16	16	16	17	17	17	18	18	18	19
40	12	12	12	13	13	14	14	14	15	15	16	16	17	17	17	18	18	19	19	19	20	20	21	21	21
45	13	13	14	14	15	15	16	16	17	17	18	18	19	19	19	20	20	21	21	22	22	23	23	24	24
50	14	15	15	16	16	17	17	18	18	19	19	20	20	21	21	22	23	23	24	24	25	25	26	26	27

[Note] ∗ is to be treated as 1.

XI. Revision history

(1) The meteorological analysis to be used for the safety evaluation of a nuclear power reactor facility had been carried out based on the "Meteorological Guide for a Reactor Safety Analysis", Decision by the Atomic Energy Commission, November 11, 1965. After that, as the studies and researches on the meteorological analysis had progressed, and the experiences on construction and operation of nuclear reactor facilities had been accumulated, the Meteorological Guide was reviewed and this Guide was established from a new viewpoint (Decision by the Atomic Energy Commission, June 14, 1977).

(2) The Nuclear Safety Commission was established in October 1978, and this Committee decided to use continuously the Guide determined in (1) (Decision by the Nuclear Safety Commission, November 8, 1978).

(3) As the implementation rules on the Meteorological Service Law were partially revised and put into effect in January 1981, and the measurement unit of the amount of solar radiation etc. was changed, the related parts of the Guide were revised (determined by the same Commission on January 28, 1982).

(4) The unit of the concentration of radioactive material, etc. which is a relevant part of the Guide was revised in connection with introduction of the International System of Units (Decision by the same Commission, March 27, 1989).

(5) Accepting a use of the Doppler sodar to observe wind direction and wind speed as remote sensing technologies had been progressed, and deciding to delete air temperature difference measured as a reference for dispersion parameter estimation from normal measurement parameters based on accumulated measurement data on air temperature difference, the relevant parts of the Guide were changed (Decision by the same Commission, April 21, 1994).

(6) Terminology change was made in connection with introduction of the 1990 Recommendations of the International Commission on Radiological Protection into the Guide (Decision by the same Commission, March 29, 2001).

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(4) Edition of the Third Subcommittee of Japan Society of Air Pollution; Air Pollution Meteorological Handbook (Chapter 3: Atmospheric Dispersion) Corona-Sya (1965)

(5) U.S. Weather Bureau; A Meteorological Survey of the Oak Ridge area; Final Report Covering the Period 1948 - 1952, USAEC Report ORO-99, pp 554 - 559 (1953)

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(11) Naganori Yokoyama, Koji Kitabayashi, and Yoshinori Adachi; Introduction to Environmental Assessment Methodology (Chapter 5; Methodology of the Environmental Concentration Simulation) Ohm-Sha (1975)

(12) Naoji Ito; Exposure from ^{41}Ar clouds during calm weather, JAERI 5014 (1965), pp 138 - 140

(13) Nuclear Safety Research Association; Measurement Procedure on the Amount of Radiation Balance for Classifying Atmospheric Stability (March 1981)

(14) Nuclear Safety Research Association; Measurement Procedure Using a Doppler Sodar (March 1993)

(For information)

Final Decision Statement by the Nuclear Safety Commission, January 28, 1982

Meteorological Guide for Safety Analysis of Nuclear Power Reactor Facilities

This Commission establishes the "Meteorological Guide for Safety Analysis of Nuclear Power Reactor Facilities" as shown in the attached document, as a result of reviewing the contents of the report on the Guide mentioned in the title, which was submitted from the Special Committee on Safety Standards of Reactors on January 20, 1982.

Previously, this Commission had used the "Meteorological Guide for Safety Analysis of Nuclear Power Reactor Facilities" established by the Atomic Energy Commission on June 14, 1977 in performing the safety review of a nuclear power reactor facility, but instead of this, will use the attached "Meteorological Guide for Safety Analysis of Nuclear Power Reactor Facilities" from now on.