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Model calculating annual mean atmospheric dispersion factor for coastal site of nuclear power plant

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Abstract: This paper describes an atmospheric dispersion field experiment performed on the coastal site of nuclear power plant in the east part of China during 1995 to 1996. The three-dimension joint frequency are obtained by hourly observation of wind and temperature on a 100m high tower; the frequency of the "event day of land and sea breezes" are given by observation of surface wind and land and sea breezes; the diffusion parameters are got from measurements of turbulent and wind tunnel simulation test.

A new model calculating the annual mean atmospheric dispersion factor for coastal site of nuclear power plant is developed and established. This model considers not only the effect from mixing release and mixed layer but also the effect from the internal boundary layer and variation of diffusion parameters due to the distance from coast.

The comparison between results obtained by the new model and current model shows that the ratio of annual mean atmospheric dispersion factor gained by the new model and the current one is about 2.0.

Key words: meteorological experiment; NPP siting; model of annual mean atmospheric dispersion factor

Introduction

An atmosphere dispersion field experiment was done on the coastal site of nuclear power plant (NPP) in the east part of China during 1995—1996. The content of this experiment includes: hourly observation of wind and temperature on the tower of 100m; Observation of surface wind and see and land breeze, measurement of turbulent and wind tunnel simulation. The results of the experiment show that the frequencies of see and land breeze and the internal boundary layer are quite high. The current guides(NRC, 1977; IAEA, 1980) relative to calculating atmospheric dispersion for NNP does not consider the effect of the internal boundary layer.

A new model which takes into account comprehensive effect of all following factors on calculation of annual mean atmospheric dispersion factor are developed and established: variation of diffusion parameters between onshore wind and offshore wind and due to the distance from coast, mixing release caused by buildings, mixed layer and internal boundary layer and so on.

1 Brief of the studied region and experiments

1.1 Topography of the study region

The studied region is located on the southern part of the Fujian Province, and is surrounded by the open ocean surface of the Taiwan Straits on the southeast side and plain and hills linking with the Daiyun Mountain. The coastline in the region is aligned along the general SW-NE direction. The Huian NNP site as well as the meteorological tower is located at latitude 24°51′N and longitude 118°46′E, and is facing southwards the Quanzhou Bay. The site and topography of the region is shown in Fig.1, which covers an area of 240 km from east to west and 160 km from north to south. There are the Mulan River on the northern part over land that flows into the Xinghua Bay, the Jinjiang River in the middle that flows into the Quanzhou Bay and the river mouth of the Jiulong River on the southwestern part. The highest terrain in the west and northwest of the domain is about 100m above sea level.

1.2 Experiments and meteorological data

In order to obtain the information on dispersion of the air pollution in this region, the following works were done in the study:

(1) A 100m-high meteorological tower was setup, on which 4 sets of probes were installed respectively at 10, 30, 70 and 100m above ground surface to measure hourly wind speed, wind direction and temperature. Meanwhile, the surface meteorological elements were observed simultaneously.

(2) The low-level rawinsonde observations of atmospheric boundary layer were conducted at Xiayang(#23), Chengbian (#21) and Dongyuan(#22) with the period of from 5 July to 15 August, 1995 and only at Xiayuan in the winter with the period of from 4 to 20 January, 1996.

(3) The short-term measurement of turbulent characteristics was carried out at the level of 27m equipped with a set of sonic anemometer-thermometer and at 102m with three-axis anemometers during the summer experiment. Only the measurement at 27m was performed in the winter.

(4) The measurements of heat budget components on land surface, as well as the temperature of land surface and underground, were also conducted simultaneously with the turbulence measurement.

(5) The temperature of sea surface and land surface were derived from the remote sensing information of the NOVA-12 and NOVA-14 satellites.

In this study, we also collected hourly wind data of 12 meteorological stations for the representative month in each season. The information on routine upper-air rawinsonde observations and weather pattern were acquired from daily synoptic map. Moreover, additional measurements of surface wind were conducted at Xiangzhi(# 31) and Dongyuan(# 22) during the summer experiment. The location and code of each station are shown in Fig.1.

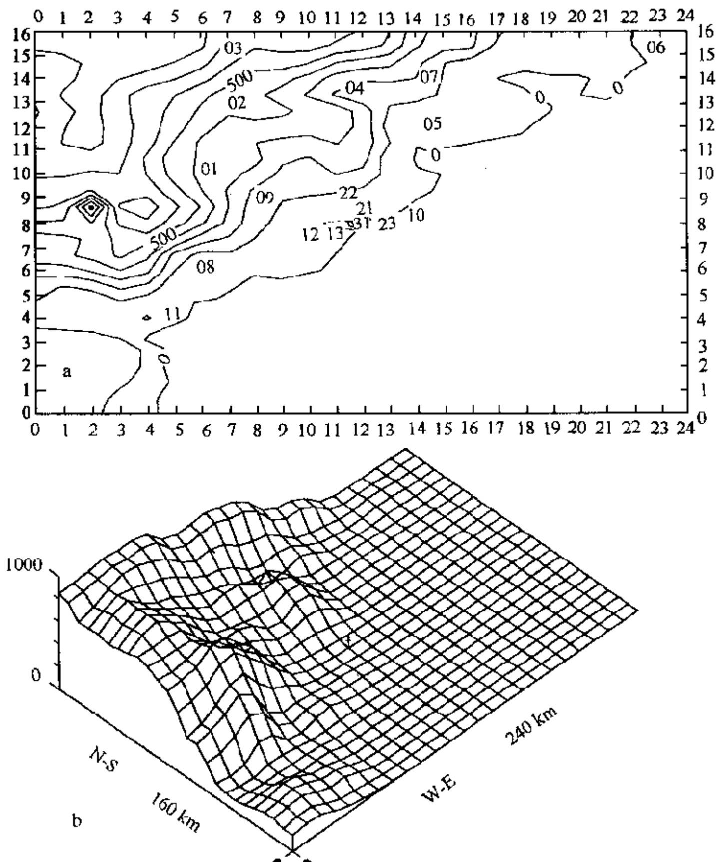

Fig. 1 Topography of the studied region and locations of the observational stations for meso-scale wind field study at Huian NNP site
(a) horizontal domain of the studied region. Topographic contours are heights above sea level in 100m interval;
(b) three dimensional relief map of the studied region

Except the turbulence data, which is mainly used to estimate diffusion parameters, the data mentioned above are used in the analyses of wind field or as the input of numerical simulation such as objective diagnostic model and dynamic model.

2 Analysis of land and sea breezes

2.1 Daily changes of wind direction and wind speed at a single station

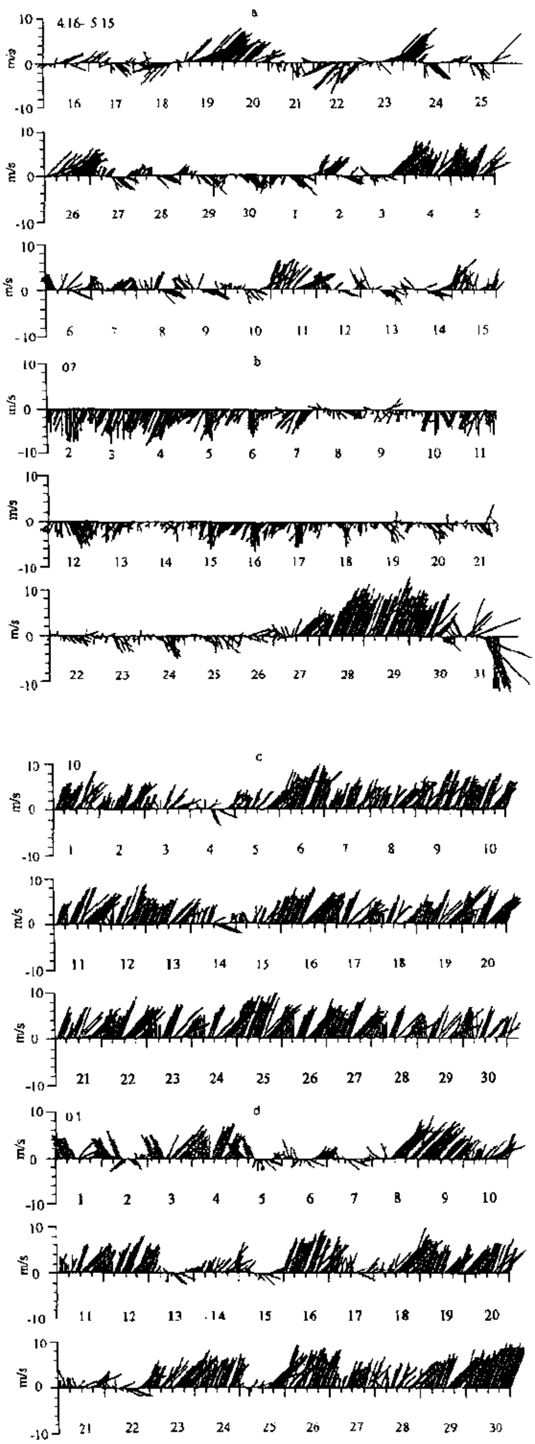

Fig. 2 Time series of the surface wind vectors plotted from data collected at meteorological tower site for (a) 16 April to 15 May, 1995; (b) 2 to 31 July, 1995; (c) 1 to 30 October, 1995; and (d) 1 to 31 January, 1996. The velocity scale are shown on left side of each panel, and date under the panels

Fig. 2 presents the hourly changes of wind vector measured at the meteorological tower on representative months, where the length of the line is used to indicate the wind speed instead of the tail in synoptic analysis. It is clearly shown that the surface wind data obtained from the meteorological tower are able to illustrate the pattern of meso-scale flow. For example, almost all days on October, 1995 belonged to systematic NE wind pattern, and most on the first ten-day of July belonged to SW wind pattern. It also can be seen that the onshore flow regularly occurred from late morning to evening in some periods of clear days with complete light wind or systematic wind direction during the night and the morning. From those results, it is not difficult to conclude that the surface wind records at the meteorological tower station may play the role of a good indicator for the sea breeze event. It should be worth pointing out that besides land and sea breeze the forcing of heat difference between sea and land is very significant even under conditions of strongly synoptic wind dominating. As a result, the deflection of wind direction towards land in the afternoon is commonly observed. The most typical cases be found in Fig.2c for October, 1995.

2.2 Case analysis of land and sea breeze

There is no lack of typical examples of land and sea breeze in this area through observational analysis. One case given below is well identified by using a diagnostic model, and a prognostic model as well.

Fig.3a and 3b are the horizontal and vertical wind fields respectively, which are plotted from the results of a mass-consistent wind field model. At 02:00, the calm occurred at high altitude, the wind speed over surface was relatively low, and the wind direction was unstable. After 09:00 the components of onshore flow presented at coast sites. The wind in the lowest 200m layer formed a distinctive onshore flow over sea at 11:00, which had extended to the coastal zone, but the wind in inland sites was still low. The depth of onshore flow was added up to about 300m with the reverse flow at higher level at 14:00. Sea breeze reached to the strongest over sea and over the coast at 14:00 and 15:00 while at 17:00 for inland sites. According to the meteorological report, there had been local convection current appeared over the sea at 17:00 and the wind turned to southern abruptly, meaning the ease of onshore flow. Although the disturbance of local convection made the sea breeze end early that day, the sea breeze circulation is typical because of weak synoptic flow. During the summer, the main regions influenced by the onshore wind are the Xinghua Bay and the Mulan River on the northeastern corner over land, as well as the Quanzhou Bay and the Jinjiang River valley.

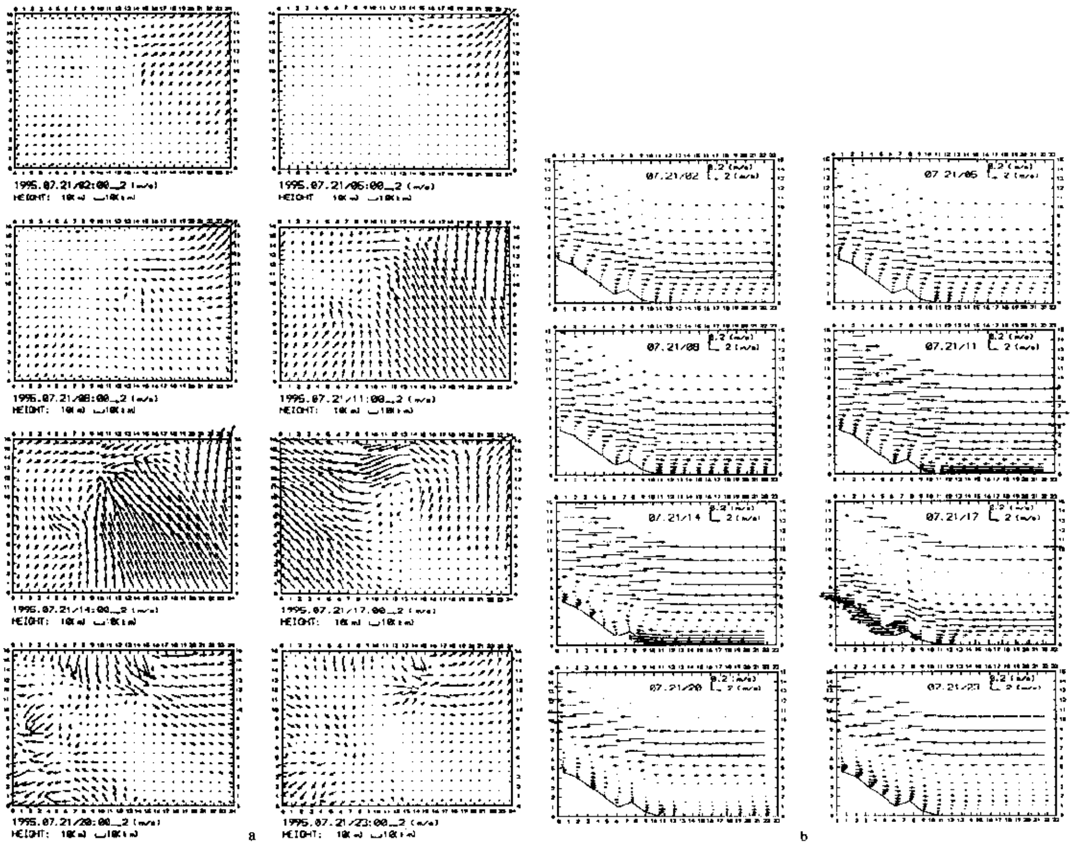

Fig.3 Surface wind field at 3h intervals for sea breeze event of July 21, 1995(the time is Beijing standard time)

During the spring and the winter there also exists obvious land and sea breezes, however, the time duration is short and the intensity is weaker in general.

2.3 Frequencies of land and sea breeze

The results predicted from a prognostic meso-scale model have indicated that thermally driven flows, such as slope wind and valley wind caused by thermal contrast between hilly area at terrain play significant roles in wind field structure in inland sites, and in enhancing sea breeze at coastal zone, especially at river mouth area. Due to overlapping of various flow schemes the pollutants released from the source located at NNP site may show on and off transport around the source or along the river valley following diurnal alternation of the flow. For classifying the wind field to specify the transport characteristics of air pollutants, we have defined the "event day of land and sea breeze" according to following rules:

(1) On the basis of the data obtained from the meteorological tower, SE, ESE, E and ENE flows appear more than 4 hours on the daytime, among which there are at least 3 hours occurring continuously. The change of wind direction between daytime and night reaches to nearly 90°or more, or surface wind speed is less than 2 m/s and wind direction is uncertain at night.

(2) The onshore wind along the coast goes on for at least 3 hours at the daytime.

(3) The marked particle released from the source located on the Huian site transports on and off shore alternately, the transport trajectories of the particle are winding and stagnant and finally pass over the boundary of the region along the same area.

The above rules are made on the basis of transport and diffusion of air pollutant, which do not mean that all the "event days" belong to typical land and sea breeze in meteorology.

The frequencies of the "event day of land and sea breeze" on each representative month are listed at Table 1. The other types of wind field are also given in order to fully understand and compare all kinds of wind fields. As for January, April, July and October, the frequencies are obtained by comprehensively judging in the light of the above requirements, for other months they are obtained by an analysis of the single station's records. The data listed at Table 1 indicate that the types of meso-scale wind field in each season are rather single. Besides systematic wind, the frequencies of occurring land and sea breeze are relatively high. Because land and sea breeze and local air circulation along the coast have been considered a major factor influencing local atmospheric diffusion and pollutant transport, they should be taken into account for estimating the environmental impact of nuclear power plant, especially for nuclear accident condition.

Table 1 The numbers and frequencies of the "event day of land and sea breeze" and other types of wind field (The other types include typhoon occurring during the summer and autumn, and transition of systematic wind; the values in brackets are frequencies in terms of percentage)

Date	Land and sea breeze	Wind by north	Wind by south	Others
1995.4.16 – 30	7(47)	5(33)	3(20)	0(0)
1995.5.1 – 15	7(47)	6(40)	0(0)	2(13)
1995.7	11(36)	0(0)	15(48)	5(16)
1995.8	15(48)	2(7)	10(32)	4(13)
1995.10	2(7)	29(93)	0(0)	0(0)
1995.11	4(13)	26(87)	0(0)	0(0)
1996.1	9(29)	22(71)	0(0)	0(0)
1996.4.1 – 15	2(13)	13(87)	0(0)	0(0)

3 The new model of the annual mean atmospheric dispersion factor for coastal site of NPP

3.1 Current equations of estimating the annual mean atmospheric dispersion factor under mixing release

In the cases where the release point is higher than height but less than the twice height of adjacent solid structures, a mixing released mode should be assumed, in which the plume is considered as an elevated release during part of time [(1-Et)%] and as a ground level release during the remainder of the time (Et%). In this case the annual mean atmospheric dispersion factor in i wind direction $(\chi/Q)_i$ could be calculated as follows:

$$(\chi/Q)_i = \sum_{j=1}^{6}[\zeta_{i,j,1}(\chi/Q)_{i,g} + \zeta_{i,j,2}(\chi/Q)_{i,h} + (1 - \zeta_{i,j,1} - \zeta_{i,j,2})Et_{i,j}(\chi/Q)_{i,g} + (1 - \zeta_{i,j,1} - \zeta_{i,j,2})(1 - Et_{i,j})(\chi/Q)_{i,h}], \quad (1)$$

where, $(\chi/Q)_{i,h}$ and $(\chi/Q)_{i,g}$ is annual mean atmospheric dispersion factor respectively for elevated release and ground-level release. They could be estimated by following equation,

$$(\chi/Q)_{i,h} = \begin{cases} \dfrac{2.032}{\chi}\sum_{j=1}^{6} f_{D,j}f_{F,j}f_{W,j}\dfrac{1}{\sigma_{zj}}\exp\left(-\dfrac{H_{e,j}^2}{2\sigma_{z,j}^2}\right)\left(\dfrac{cf_{ij}}{0.5} + \sum_{k=1}^{6}\dfrac{{}_{w}f_{i,j,k}}{\bar{u}_{j,k}}\right) & x \le x_L \\ \dfrac{8}{\pi\chi}\sum_{j=1}^{6} f_{D,j}f_{F,j}f_{W,j}\dfrac{1}{L_j}\left(\dfrac{cf_{ij}}{0.5} + \sum_{k=1}^{6}\dfrac{{}_{w}f_{i,j,k}}{\bar{u}_{j,k}}\right) & x \ge 2x_L, \end{cases} \quad (2)$$

where $x_L < x < 2x_L$, the value of $(\chi/Q)_{i,h}$ could be obtained by liner interpolation of values given by $x = x_L$ and $x = 2x_L$.

$$(\chi/Q)_{i,g} = \begin{cases} \dfrac{2.032}{\chi}\sum_{j=1}^{6} f_{D,j}f_{F,j}f_{W,j}\dfrac{1}{\Sigma_{zj}}\left(\dfrac{cf_{ij}}{0.5} + \sum_{k=1}^{5}\dfrac{{}_{w}f_{i,j,k}}{\bar{u}_{j,k}}\right) & x \le x_L \\ \dfrac{8}{\pi\chi}\sum_{j=1}^{6} f_{D,j}f_{F,j}f_{W,j}\dfrac{1}{L_j}\left(\dfrac{cf_{ij}}{0.5} + \sum_{k=1}^{5}\dfrac{{}_{w}f_{i,j,k}}{\bar{u}_{j,k}}\right) & x \ge 2x_L, \end{cases} \quad (3)$$

where, $f_{D,j}f_{F,j}f_{W,j}$ are the modified factors respectively for dry deposition, wet deposition and radioactive decay; ${}_{w}f_{i,j,k}$ is the joint frequency for i wind direction, j is the stability and k is the set of wind speed; ${}_{c}f_{i,j}$ is the frequency for i wind direction, j is the stability and calm; $\sum_{z,j}^{2} = \sigma_z^2 + \sigma_{z0}^2$, here σ_{Z0} is an initial diffusion parameter caused by building, $\zeta_{i,j,1}$ and $\zeta_{i,j,2}$ are defined as follows,

$$\zeta_{i,j,1} = n_{i,j,1}/n_{i,j} \quad \zeta_{i,j,2} = n_{i,j,2}/n_{i,j}, \quad (4)$$

where, $n_{i,j}$ is the number of hours for i wind direction, j is the stability in 1 year; $n_{i,j,1}$ and $n_{i,j,2}$ are numbers of hours for i wind direction, j stability and with $W_0/u_{i,j,n} < 1.0$ or $W_0/u_{i,j,n} > 5.0$ respectively in 1 year; W_0 is exit velocity of effluents from stack.

The value of $Et_{i,j}$ is given by following equations [USNRC, 1977]:

$$Et_{i,j} = 2.58 - 1.58\left[\frac{1}{n}\sum_{n}(W_0/u_{i,j,n})\right] \qquad \text{if } 1 \le (W_0/u_{i,j,n}) \le 1.5,$$

$$Et_{i,j} = 0.3 - 0.06[\frac{1}{n}\sum_{n}(W_0/u_{i,j,n})] \qquad \text{if } 1.5 \leqslant (W_0/u_{i,j,n}) \leqslant 5.0. \tag{5}$$

3.2 New model to calculate the annual atmospheric dispersion factor for coast site of NPP.

3.2.1 For offshore wind

3.2.1.1 The diffusion mode for offshore wind

In this case only the effect of mixing release and mixed layer but no internal boundary layer should be taken into account. It is assumed that: for the A, B, C, D stability, when $x \leqslant 1.5x_{Lj}$, the plume will be free diffused; when $x > 1.5x_{Lj}$, the plume will be evenly mixed under the mixed layer. Here $x_{L,j}$ expresses the downwind distance at which the upper edge of plume arrives the height of the mixed layer in the j stability. The value of diffusion parameters is dependent on the condition of terrain and named offshore diffusion parameter σ_{off}, meantime the initial diffusion parameter σ_{z0} and σ_{Y0} caused by disturbance of buildings should be considered.

3.2.1.2 The equations of the annual mean atmospheric dispersion factor for offshore wind

The equations to calculate the atmospheric dispersion factor for offshore is as same as the Equation (1) but $(\chi/Q)_{i,h}$ and $(\chi/Q)_{i,g}$ in Equation (1) are given by

$$(\chi/Q)_{i,j,h} = \begin{cases} \dfrac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \dfrac{1}{\sigma_{Z,j,off}} \exp(-\dfrac{H_e^2}{2\sigma^2_{Z,j,off}})(\dfrac{{}_cf_{i,j}}{0.5} + \sum_{k=1}^{5}\dfrac{{}_wf_{i,j,k}}{\bar{u}_{j,k}}) \\ \quad \text{when } j = 5,6 \text{ or } j = 1,2,3,4 \text{ and } x < 1.5x_{L,j} \\ \dfrac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \dfrac{\sqrt{2\pi}}{L_j}(\dfrac{{}_cf_{i,j}}{0.5} + \sum_{k=1}^{5}\dfrac{{}_wf_{i,j,k}}{\bar{u}_{j,k}}) \\ \quad \text{when } j = 1,2,3,4 \text{ and } x \geqslant 1.5x_{L,j}; \end{cases} \tag{6}$$

$$(\chi/Q)_{i,j,g} = \begin{cases} \dfrac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \dfrac{1}{\Sigma_{Z,j,off}}(\dfrac{{}_cf_{i,j}}{0.5} + \sum_{k=1}^{5}\dfrac{{}_wf_{i,j,k}}{\bar{u}_{j,k}}) \\ \quad \text{when } j = 5,6 \text{ or } j = 1,2,3,4 \text{ and } x < x_{L,j} \\ \dfrac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \dfrac{\sqrt{2\pi}}{L_j}(\dfrac{{}_cf_{i,j}}{0.5} + \sum_{k=1}^{5}\dfrac{{}_wf_{i,j,k}}{\bar{u}_{j,k}}) \\ \quad \text{when } j = 1,2,3,4 \text{ and } x \geqslant 1.5x_{L,j}, \end{cases} \tag{7}$$

where $j = 1, 2, 3, 4, 5$ and 6 means A, B, C, D, E and F stability respectively; $\Sigma_{Z,j,off}$ is a total diffusion parameter corresponding to j stability and offshore wind and given by following equation,

$$\Sigma_{Z,off} = (\sigma^2_{Z,off} + \sigma^2_{Z,0})^{1/2}. \tag{8}$$

3.2.2 For onshore wind

In this case all following effects must be considered: mixed layer, mixing release, internal boundary layer, the variation of diffusion parameters from the oceanic diffusion parameter σ_{oc} which is not subjected to the disturbance of terrain to the terrestrial diffusion parameter σ_{te} and the additional diffusion parameter caused by the disturbance from buildings.

3.2.2.1 The diffusion mode for elevated release

For E or F stability the variation of diffusion parameters from σ_{oc} to σ_{tef} is the only factor to be considered. Fig.4 shows the scheme of transport and diffusion of radioactive plume for A, B, C, D stability. When downwind distance $x \leqslant x_c$, the plume transfers and diffuses with diffusion parameter σ_{oc}. Here x_c is the downwind distance at which the axis of plume crosses the internal boundary layer. When $x > x_c$, there are two possibilities: (1) If the internal boundary layer happens (its frequency is assumed as F_m for m-th mouth, $m = 1, 2, \cdots\cdots, 12$, the fumigation phenomenon is assumed to occur and will cause the vertical evenly mixing of plume under the internal boundary layer; (2) If the internal boundary layer doesn't happen [its frequency is $(1\text{-}F_m)$] the transport and diffusion of plume with oceanic diffusion parameter σ_{oc} will be continued until $x = x_{i,j}$. The $x_{i,j}$ expresses such a downwind distance on both sides of which, i.e., for the regions of $0 < x < x_{i,j}$ and $x > x_{i,j}$, the different diffusion parameter σ_{oc} and σ_{off} become characteristic respectively. In view of the sudden variation of diffusion parameter at $x_{i,j}$, in calculating, the diffusion parameter suitable for the region $x > x_{i,j}$ could be estimated by using a "false source" model (Fig. 4, x_0). This new diffusion parameter is here named the terrestrial diffusion parameter σ_{te}. In the region between $x_{L,j}$ and $1.5x_{L,j}$, the plume will continue to transfer and diffuse with terrestrial diffusion parameter σ_{te}. When $x \geqslant 1.5x_{L,j}$ the plume will be evenly mixed vertically under mixed layer.

3.2.2.2 The diffusion mode for ground-level release

For the ground-level release the offshore diffusion parameter which reflects the effect of terrain should be adopted but the additional diffusion parameter from disturbance of buildings must be considered.

For E or F stability the situation is as same as elevated release.

The scheme of transport and diffusion of radioactive plume for A, B, C and D stability condition are shown in Fig. 5a

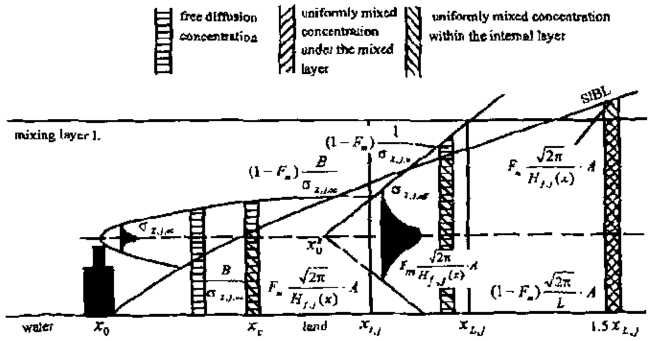

Fig.4 The scheme of transport and diffusion of the radioactive released from the elevater point source on the site of coastal NPP for stability category A, B, C, D and for onshore wind

$$A = \frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \left(\frac{f_{i,j}}{0.5} + \frac{u f_{i,j,k}}{\bar{u}_{j,k}} \right), \quad B = A \cdot \exp\left(\frac{-H_e^2}{2\sigma_{z,j,sh}^2} \right)$$

and Fig. 5b.

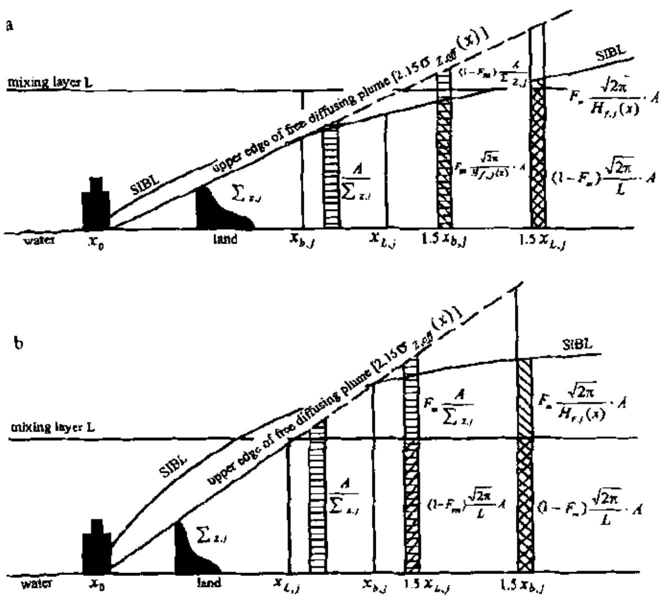

Fig.5 The scheme of transport and diffusion of the radioactive plume released from the gound-level source on the site of coastal NPP for stability category A, B, C, D and for on shore wind

(a. when $x_{L,j} > x_{b,j}$), $\sum_{z,j} = (\sigma_{z,eff}^2 + \sigma_{z0}^2)^{1/2}$; b. when $x_{b,j} > x_{L,j}$)

In Fig.5a it is assumed that the down wind distance $x_{b,j}$, at which the upper edge of plume for ground-level release crosses the internal bound layer, is less than $x_{L,j}$ i.e., $x_{L,j} > x_{b,j}$, and that in the region of $0 < x < 1.5x_{b,j}$ the plume released from ground-level source freely transfers and diffuses with the diffusion parameter $\sum_{zj}$. In the region of $1.5x_{b,j} \leqslant x < 1.5x_{L,j}$ the plume will be evenly mixed under the internal boundary layer during part of time (F_m) or continue to transfer and diffuse with $\sum_{z,j}$ during the remainder of the time ($1\text{-}F_m$). When $x \geqslant 1.5x_{L,j}$ the latter part of plume is assumed to be evenly distributed vertically under the mixed layer.

The analysis of transport and diffusion process shown in Fig.5b is the same as above. The difference is only $x_{b,j} > x_{L,j}$.

3.2.2.3 The equations of the annual mean atmospheric dispersion factor for onshore wind

The equation to estimate the annual mean atmospheric dispersion factor for onshore wind is still given by Equation (1). Meantime the $(\chi/Q)_{i,k}$ and $(\chi/Q)_{i,g}$ in Equation(1) will be estimated by

$$
(\chi/Q)_{i,j,h} = \begin{cases}
\frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \frac{1}{\sigma_{Z,j,sh}} \exp\left(\frac{-H_e^2}{2\sigma_{Z,j,sh}^2}\right)\left(\frac{{}_c f_{i,j}}{0.5} + \sum_{k=1}^{5} \frac{{}_w f_{i,j,k}}{\bar{u}_{j,k}}\right) \\
\quad \text{when } j = 5,6 \text{ or } j = 1,2,3,4, \text{and } x < x_c; \\
\frac{1}{12}\left\{\frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \left(\frac{{}_c f_{i,j}}{0.5} + \sum_{k=1}^{5} \frac{{}_w f_{i,j,k}}{\bar{u}_{jk}}\right) \cdot \right. \\
\left. \sum_{m=1}^{12}\left[(1 - F_m)\frac{1}{\sigma_{Z,j,sh}} \cdot \exp\left(\frac{-H^2}{2\sigma_{Z,j,sh}^2}\right) + F_m \frac{\sqrt{2\pi}}{H_{f,j}(x)}\right]\right\} \\
\quad \text{when } j = 1,2,3,4 \text{ and } 1.5x_{L,j} > x \geq x_c; \\
\frac{1}{12}\left\{\frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \left(\frac{{}_c f_{i,j}}{0.5} + \sum_{k=1}^{6} \frac{{}_w f_{i,j,k}}{\bar{u}_{j,k}}\right) \cdot \right. \\
\left. \sum_{m=1}^{12}\left[(1 - F_m)\frac{\sqrt{2\pi}}{L_j} + F_m \frac{\sqrt{2\pi}}{H_{f,j}(x)}\right]\right\} \\
\quad \text{when } j = 1,2,3,4 \text{ and } x \geq 1.5x_{L,j}.
\end{cases} \tag{9}
$$

$$
(\chi/Q)_{i,j,g} = \begin{cases}
\frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \frac{1}{\Sigma_{Z,j,off}}\left(\frac{{}_c f_{i,j}}{0.5} + \sum_{k=1}^{5} \frac{{}_w f_{i,j,k}}{\bar{u}_{j,k}}\right) \\
\quad \text{when } j = 5,6 \text{ or } j = 1,2,3,4, \text{and } x < \min(1.5x_{b,j}, 1.5x_{L,j}); \\
\frac{1}{12}\left\{\frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \left(\frac{{}_c f_{i,j}}{0.5} + \sum_{k=1}^{5} \frac{{}_w f_{i,j,k}}{\bar{u}_{j,k}}\right) \cdot \sum_{m=1}^{12}\left[(1 - F_m)\frac{1}{\Sigma_{Z,j,off}} + F_m \frac{1}{H_{f,j}(x)}\right]\right\} \\
\quad \text{when } j = 1,2,3,4 \text{ and } 1.5x_{L,j} > x \geq 1.5x_{b,j}; \\
\frac{1}{12}\left\{\frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \left(\frac{{}_c f_{i,j}}{0.5} + \sum_{k=1}^{5} \frac{{}_w f_{i,j,k}}{\bar{u}_{j,k}}\right) \cdot \sum_{m=1}^{12}\left[(1 - F_m)\frac{\sqrt{2\pi}}{L_j} + F_m \frac{\sqrt{2\pi}}{\Sigma_{Z,j,off}}\right]\right\} \\
\quad \text{when } j = 1,2,3,4 \text{ and } 1.5x_{b,j} > x \geq 1.5x_{L,j}; \\
\frac{1}{12}\left\{\frac{2.032}{x} f_{D,j} f_{F,j} f_{W,j} \left(\frac{{}_c f_{i,j}}{0.5} + \sum_{k=1}^{5} \frac{{}_w f_{i,j,k}}{\bar{u}_{j,k}}\right) \cdot \sum_{m=1}^{12}\left[(1 - F_m)\frac{\sqrt{2\pi}}{L_j} + F_m \frac{\sqrt{2\pi}}{H_{f,j}(x)}\right]\right\} \\
\quad \text{when } j = 1,2,3,4 \text{ and } x \geq \max(1.5x_{b,j}, 1.5x_{L,j}),
\end{cases} \tag{10}
$$

where $\sigma_{Z,j,sh}$ is the diffusion parameter corresponding to j stability and onshore wind and given by

$$
\sigma_{Z,j,sh} = \begin{cases} \sigma_{Z,j,oc} & x < x_{i,j} \\ \sigma_{Z,j,le} & x \geq x_{i,j} \end{cases}. \tag{11}
$$

4 Measuring of relative parameters

4.1 Three-dimension joint frequency ${}_w f_{i,j,k}$ and ${}_c f_{i,j}$ at different height

Three-dimension joint frequency ${}_w f_{i,j,k}$ and ${}_c f_{i,j}$ were obtained in the light of hourly observation of wind direction, wind speed and temperature at 4 heights of 100m meteorological tower during the period of from 15 April, 1995 to 15 April, 1996.

4.2 Diffusion parameter(Thomas, 1985; Hu, 1998)

Based on 356 sets of observing data of turbulence characteristics at 27m and 102m of the tower in the summer (from 4 July, 1995 to 19 July, 1995) and 183 sets of data at 27m of the tower in the winter (from 3 June, 1996 to 11 June, 1996), the diffusion parameters are estimated by using Draxler's method. Meantime, 26 sets of wind tunnel simulation tests were conducted for the D stability in order to modify the effect from buildings on the diffusion parameter. The results are shown as follows.

4.2.1 Offshore diffusion parameter off σ_{off}

In calculation the following wind directions are assumed to be onshore wind direction: ENE, E, ESE, SE, SSE, S, SSW and SW, i.e., $i = 4,5,6,7,8,9,10,11$. Other wind directions are assumed to be offshore direction. Table 2 shows the values of offshore diffusion parameter σ_{off} for the coastal site where a NPP will be built. Fig.6 shows the comparison between the values of σ_{off} mentioned above (solid line) and Brookhaven diffusion parameter(dashed line).

4.2.2 Onshore wind diffusion parameter

4.2.2.1 Oceanic diffusion parameter σ_{oc}

In some coast region the diffusion parameter is not subjected to the disturbance of terrain and mainly reflects the characteristic of oceanic turbulence. These diffusion parameter are named oceanic diffusion parameter σ_{oc} and are given in Table 3, where the downwind distance x_i less than which the oceanic diffusion parameter σ_{oc} is suitable is also given.

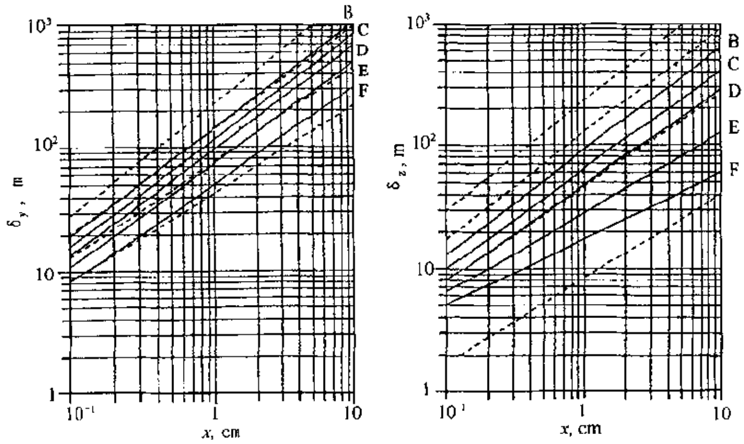

Fig. 6 Comparison of the offshore diffusion parameter σ_{off} (solid line) and Brookhaven diffusion parameter (dashed line)

Table 2 Offshore diffusion parameter $\sigma_{y,off} = P_{y,off}x^{q_{y,off}}$, $\sigma_{z,off} = P_{z,off}x^{q_{z,off}}$

Stability	$P_{y,off}$	$Q_{y,off}$	$P_{z,off}$	$Q_{z,off}$
B(A)	0.351	0.87	0.260	0.85
C	0.305	0.86	0.240	0.81
D	0.271	0.85	0.220	0.78
E	0.239	0.83	0.320	0.65
F	0.215	0.79	0.420	0.54

Table 3 Oceanic diffusion parameter $\sigma_{y,oc} = P_{y,oc}x^{q_{y,oc}}$, $\sigma_{z,oc} = P_{z,oc}x^{q_{z,oc}}$

Stability	$P_{y,oc}$	$Q_{y,oc}$	$P_{z,oc}$	$Q_{z,oc}$	X_i, m
B(A)	0.158	0.94	0.129	0.91	< 200
C	0.140	0.91	0.105	0.87	< 500
D	0.120	0.87	0.090	0.82	< 1000
E	0.088	0.84	0.115	0.66	< 5000
F	0.076	0.79	0.115	0.56	< 5000

4.2.2.2 Terrestrial diffusion parameter σ_{te}

Where $x > x_i$ the oceanic diffusion parameter will be changed to terrestrial diffusion parameter, which could be estimated by following equations based on the "false source" model (Fig. 4):

$$\sigma_{y,te} = P_{y,te}x^{q_{y,te}} = P_{y,off}[(x - x_i) + x_{oy}]^{q_{y,off}}, \tag{12}$$

$$\sigma_{z,te} = P_{z,te}x^{q_{z,te}} = P_{z,off}[(x - x_i) + x_{oz}]^{q_{z,off}}, \tag{13}$$

where,

$$x_{oy} = \left(\frac{P_{y,oc}}{P_{y,off}}x_i^{q_{y,oc}}\right)^{1/q_{y,off}}, \tag{14}$$

$$x_{oz} = \left(\frac{P_{z,oc}}{P_{z,off}}x_i^{q_{z,oc}}\right)^{1/q_{z,off}}. \tag{15}$$

4.3 Height of the internal boundary layer

Based on the analysis of data from the low-level radiosonde observing of atmospheric boundary layer, a realistic formula to estimate the height of the internal boundary layer which suitable for this site of NPP is proposed as follows:

$$H_{f,j}^2 = 25x[1 - \exp(-x^{1/2}/50)]. \tag{16}$$

5 Result and preliminary analysis

Table 4 and 5 show the values of the annual mean atmospheric dispersion factor for offshore and onshore wind respectively for Huian site of NPP on the basis of the new-model mentioned above. It could be seen from Table 4 and 5 that the maximum of the annual mean atmospheric dispersion factor is 5.69E-6 s/m^3 and occurs at downwind distance 500m in the NE wind direction. The value of 2.11E-6 s/m^3 which occurs at downwind distance 500m in the SSW wind direction is chosen as a final annual mean atmospheric dispersion factor to evaluate the dose in the environment impact report for siting of Huian NPP because there is no resident in those region that is located downwind for offshore wind. The comparison between Table 4 and 5 also shows that the maximum of the annual mean atmospheric dispersion factor for offshore wind is about 2.7 times of that for onshore wind. It could be mainly attributed to the fact that the values of annual wind frequencies of NE (29.4%, 27.5%) at 70m and 10m height are about 4.8 and 4.1 times of annual wind frequencies of SSW (6.10%, 6.75%) respectively. But for onshore wind the plume released from ground-level is evenly mixed under the internal bound layer at downwind distance 500m for by A, B stability because $x_{b,j} = 260$ m for A, B stability. It partly compensates the effect caused the above difference of annual wind frequency.

Table 4 Annual mean atmospheric dispersion factor for offshore wind on the Huian site of NPP

Wind direction	Downwind distance, m											
	500	1500	2500	4000	7500	15000	25000	35000	45000	55000	65000	75000
N	7.94E-07	2.25E-07	1.15E-07	6.07E-08	2.48E-08	1.16E-08	6.37E-09	4.29E-09	3.21E-09	2.55E-09	2.10E-09	1.79E-09
NNE	3.83E-06	7.77E-07	3.52E-07	1.67E-07	6.02E-08	2.97E-08	1.72E-08	1.20E-08	9.23E-09	7.47E-09	6.27E-09	5.40E-09
NE	5.69E-06	1.01E-06	4.35E-07	1.98E-07	6.91E-08	3.32E-08	1.94E-08	1.37E-08	1.05E-08	8.53E-09	7.17E-09	6.18E-09
WSW	3.28E-07	1.36E-07	7.48E-08	4.15E-08	1.85E-08	9.57E-09	5.35E-09	3.63E-09	2.71E-09	2.15E-09	1.78E-09	1.51E-09
W	2.30E-07	1.02E-07	5.67E-08	3.34E-08	1.57E-08	8.07E-09	4.50E-09	3.04E-09	2.27E-09	1.79E-09	1.48E-09	1.25E-09
WNW	2.01E-07	8.60E-08	4.84E-08	2.73E-08	1.19E-08	5.66E-09	3.08E-09	2.06E-09	1.54E-09	1.21E-09	1.00E-09	8.48E-10
NW	4.17E-07	1.27E-07	6.43E-08	3.47E-08	1.50E-08	7.30E-09	4.06E-09	2.76E-09	1.08E-09	1.65E-09	1.37E-09	1.17E-09
NNW	5.81E-07	1.58E-07	7.77E-08	4.12E-08	1.61E-08	7.48E-09	4.10E-09	2.77E-09	2.08E-09	1.65E-09	1.37E-09	1.17E-09

Table 5 Annnual mean atmospheric dispersion factor for onshore wind on the Huian site of NPP

Wind direction	Downwind distance, m											
	500	1500	2500	4000	7500	15000	25000	35000	45000	55000	65000	75000
ENE	1.01E-06	2.78E-07	1.38E-08	6.8E-08	3.07E-08	1.05E-08	6.26E-09	3.90E-09	3.36E-09	2.65E-09	2.1E-09	1.85E-09
E	4.46E-07	1.61E-07	8.34E-08	4.21E-08	1.86E-08	6.57E-09	3.98E-09	2.57E-09	2.10E-09	1.67E-09	1.38E-09	1.17E-09
ESE	7.86E-07	2.27E-07	1.12E-07	5.75E 08	2.75E-08	1.05E-08	5.96E-09	3.83E-09	3.01E-09	2.36E-09	1.94E-09	1.63E-09
SE	8.59E-07	2.88E-07	1.44E-07	7.30E-08	3.62E-08	1.43E-08	8.20E-09	5.35E-09	4.21E-09	3.33E-09	2.74E-09	2.33E-09
SSE	6.38E-07	2.21E-07	1.11E-07	5.70E-08	2.78E-08	1.11E-08	6.28E-09	4.11E-09	3.17E-09	2.50E-09	2.06E-09	1.75E-09
S	1.09E-06	3.13E-07	1.54E-07	7.70E-08	3.75E-08	1.43E-08	8.22E-09	5.26E-09	4.21E-09	3.31E-09	2.71E-09	2.29E-09
SSW	2.11E-06	4.80E-07	2.34E-07	1.17E-07	5.90E-08	2.26E-08	1.29E-08	7.88E-09	6.41E-09	4.94E-09	3.99E-09	3.33E-09
SW	1.90E-06	4.31E-07	2.10E-07	1.08E-07	5.64E-08	2.09E-08	1.20E-08	7.24E-09	6.21E-09	4.81E-09	3.90E-09	3.27E-09

Table 6 Annual mean atmospheric dispersion factor on the Huian site of NPP (The effect of internal bound layer is not considered)

Wind direction	Downwind distance, m											
	500	1500	2500	4000	7500	15000	25000	35000	45000	55000	65000	75000
N	7.99E-07	2.25E-07	1.15E-07	6.10E-08	2.48E-08	9.37E-09	6.37E-09	4.29E-09	3.21E-09	2.55E-09	2.10E-09	1.79E-09
NNE	3.86E-06	7.78E-07	3.53E-07	1.68E-07	6.05E-08	1.28E-08	1.72E-08	1.20E-09	9.23E-09	7.47E-09	6.27E-09	5.40E-09
NE	5.73E-06	1.02E-06	4.36E-07	1.99E-07	7.24E-08	7.54E-09	1.94E-08	1.37E-08	1.05E-08	8.53E-09	7.17E-09	6.18E-09
ENE	7.37E-07	1.89E-07	9.29E-08	4.90E-08	2.29E-08	7.58E-09	5.88E-09	4.05E-09	3.07E-09	2.46E-09	2.04E-09	1.75E-09
E	2.74E-07	9.99E-08	5.64E-08	3.43E-08	1.74E-08	8.16E-09	5.03E-09	3.39E-09	2.51E-09	1.98E-09	1.62E-09	1.37E-09
ESE	3.07E-07	9.91E-08	5.27E-08	3.08E-08	1.28E-08	5.82E-09	3.71E-09	2.56E-09	1.95E-09	1.56E-09	1.30E-09	1.11E-09
SSE	3.18E-07	1.09E-07	6.03E-08	3.59E-08	1.46E-08	6.55E-09	4.11E-09	2.83E-09	2.14E-09	1.72E-09	1.43E-09	1.23E-09
S	7.32E-07	1.81E-07	8.63E-08	4.64E-08	1.94E-08	7.36E-09	5.66E 09	3.95E-09	3.01E-09	2.43E-09	2.03E-09	1.75E-09
SSW	1.21E-06	2.67E-07	1.28E-07	6.63E-08	2.75E-08	8.72E-09	7.47E-09	5.11E-09	3.85E-09	3.07E-09	2.55E-09	2.17E-09
SW	1.21E-06	2.68E-07	1.29E-07	6.85E-08	2.99E-08	9.94E-09	8.06E-09	5.47E-09	4.09E-09	3.25E-09	2.68E-09	2.28E-09
WSW	3.29E-07	1.37E-07	7.49E-08	4.16E-08	1.89E-08	8.90E-09	5.35E-09	3.63E-09	2.71E-09	2.15E-09	1.78E-09	1.51E-09
W	2.30E-07	1.02E-07	5.68E-08	3.36E-08	1.58E-08	7.85E-09	4.50E-09	3.04E-09	2.27E-09	1.79E-09	1.48E-09	1.25E-09
WNW	2.01E-07	9.63E-08	4.85E-08	2.75E-08	1.19E-08	5.51E-09	3.08E-09	2.07E-09	1.54E-09	1.21E-09	1.00E-09	8.48E-10
NW	4.19E 07	1.27E-07	6.44E-08	3.53E-08	1.52E-08	6.57E-09	4.06E-09	2.76E-09	2.08E-09	1.65E-09	1.37E-09	1.17E-09
NNW	5.85E-07	1.59E-07	7.79E-08	4.00E-08	1.59E-08	6.26E-09	4.08E-09	2.77E-09	2.08E-09	1.65E-09	1.37E-09	1.17E-09

6 Comparison between results of the current model and new model

During past about 20 years equations (1) to (5) are often adopted to estimate the annual atmospheric dispersion factor under normal operation condition in the environment impact report for siting of NPP in China. In order to compare the difference between results gained by the current model and our new model, a calculation of annual mean atmospheric dispersion factor with using equations (1) to (5) was done. Table 6 shows the results. The comparison between Table 4 and

6 shows that:

The values of the annual mean atmospheric dispersion factor for onshore wind given by the new model for each direction are almost 2.0 times of values of the current model, the range of the ratio is from 1.38 for ENE wind direction to 2.56 for ESE wind direction.

The maximum of the annual mean atmospheric dispersion factor given by the new model is 2.11E-6 s/m^3 and located of 500m downwind in SSW wind direction, but that given by the current model is 1.21E-6 s/m^3 and located of 500m downwind of SSW or SW wind direction; Hence it is not conservative if the latter is adopted to estimate the annual effective dose for critical resident group in the environment impact report for siting of NPP.

7 Conclusion

The occurring frequency of the internal boundary layer on site of Huian NPP is quite high.

A new model to estimate the annual mean atmospheric dispersion factor under normal operation condition for siting of coastal NPP in which the comprehensive effects caused by the internal bound layer and other factors is developed and established.

It is proved from the comparison between results obtained by the new model and current model that the ratio of value of annual mean atmospheric dispersion factor gained by the new model and the current model in which the effect of internal bound layer is not considered is about 2.0.

It is not conservative and suitable that the maximum of annual mean atmospheric dispersion factor gained by the current model is adopted to estimate the annual effective dose for critical resident on siting of a coastal NPP site as usual where the frequency of internal boundary layer is no able to be neglected.

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