THE EVALUATION OF SITE CHARACTERISTICS FOR GUANGDONG NUCLEAR POWER PLANT

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ABSTRACT

This paper gives an account of the features of the site of Guangdong Nuclear Power Plant (GNPP) in general and in particular evaluates the outstanding site characteristics related to nuclear safety and public health. It is composed of two parts: the first part describes the seismo-geologic conditions of the site and the other treats the atmospheric dispersion conditions. It also contains the discussion why the possibility of inhabitancy within 5km from the exclusion area boundary would not be affected.

I. GENERAL CHARACTERISTICS OF SITE

GNPP is a large-scale commercial coastal nuclear power plant in China. It is on the west coast of Daya Bay bordering the South China Sea, 45 km from Shenzhen and 53 km from Hong Kong (see Fig.1). As a result of investigations from 1979 through 1983, the site of GNPP is considered to be the best suitable one among some tens candidates.

GNPP is located at a relatively stable massif on which the recent tectonic activity, magmatic activity, hydrothermal activity, seismic activity and regional physico-geological phenomena are comparatively weak. The geologic texture of site area is comparatively integrated. It is a " Safety Island " of active tectonic zone.

The density of population around the plant site is classified as low density in Guangdong Province. There is no community of over 10,000 inhabitants within a radius of 5 km from the site center; neither is there any industries or establishments which would endanger the safety of the plant.

The length and width of Daya Bay is more than 20 km, with deep bottom and clear water, adequately meeting the requirements for the quantity and other conditions of circulation water supply. There is also a fresh water reservoir of 1,300,000 m^3 capacity for providing fresh water for station use.

Owing to the sufficient depth and stability of the sea-bed, a wharf will be built on the coast at the plant site, through which heavy equipment of the plant may be shipped by sea.

The plant, after completion, will be connected to China Light and Power Co's network through 400 kv transmission line, and to Guangdong network through 500 kv line. This plant is comparatively near the load center with resulting short distance of transmission of electric power, satisfying the conditions for economic and stable operation.

The site of GNPP is a coastal site with hilly land. Therefore, the conditions of atmospheric dispersion are complex, but will not affect the suitability of the site.

To sum up, the site of GNPP is a coastal site with favourable conditions within region of Guangdong Province, satisfying the requirements for safety and technico-economic needs. The coastal region in East China is bordering on circum-Pacific Seismic Belt and a complex meteorological phenomena exists there. Moreover, in the coastal region of East China, densely populated with flourishing cultural and economic environment, the seismo-geologic and atmospheric dispersion requirements will be very exacting, these will also cause the most attention from the public and safety authorities. During the process of site selection, great emphasis has been laid on these two safety-related problems. In the following chapters we shall bring out the salient points on these characteristics: namely GNPP's seismo-geology and atmospheric dispersion.

II. SEISMO-GEOLOGIC CONDITIONS

A. Regional Geologic and Seismic Characteristics

The site of GNPP is located geotectonically in a conjuntion zone of the second uplift belt of Neocathayian System of the East Asia Continent and latitudinal Nanglin tectonic belt. These two tectonic systems form a basic regional tectonic framework. In the process of agelong geological development, the region has undergone comparatively intense tectonic movements, so a complicated strain pattern has been formed by imposition and interference of numerous tectonic movements. The region, as shown in the seismic regionalization, is located in a seismic subregion of Southeastern Coast of South China seismic region, is a region with moderate-strong earthquakes, and belongs to a comparatively active region of crustal activity.[1]

It is a basic guidline in geology and seismology of GNPP site selection to find a relatively stable massif in such a region, i.e. to find a " Safety Island ", on which major construction works are located.[2] Because the Globe incessantly moves and changes ever since she is formed, so that being " active " is her nature and tendency in development. But, within certain time period, in certain area and under certain stress condition, the crust of certain locality will remain in relatively stable state. The main aspect of site survey procedure is to analyse crustal activity of each area. It is easier to evaluate the regional stability of each area by studying data which include surface geologic mapping, historic earthquakes, recent microearthquakes, deep structures and fault activity, thereby, the goal of selecting relatively stable area is achieved.

The area of GNPP is mainly controlled by Lianhuashan fault tectonic zone with northeast-trending. The Lianhuashan fault tectonic zone is broken into southern and northern branch. The northern branch, named Wuhua-Shenzhen fault zone, consists of many en echelon faults. It is 300--400km long, and strikes to NE 40°-- $60^{\circ}$and dips to northwest at an angle of 60°-- 80°. The fault zone is still active since the latest past. Its northern border has controlled Cenozoic Duozhu and Danshui basins. A M=4 earthquake occurred near Duozhu city in 1933. Weak and microearthquakes frequently occurred in southwest of Huidong, and eastern part of Danshui area. The southern branch, named Dabu-Haifeng fault zone, consists also of several en enchelon faults, It is about 200 km long, dips to southeast at an angle of 50°-- 60°, activated in historical and recent times. The greatest earthquake of M=5 occurred in Haifeng area in 1693 and 1874. In the recent years, small seismic swarms have been discovered near Meilong town, from which the greatest events are of M=3.9. The surface geologic mapping and extended aeromagnetic data suggest that the Dabu-Haifeng fault does not extend into Daya Bay. Depth structure of Lianhuashan fault tectonic zone and its neighboring area is simpler. Only two latitudinal depth faults are present under 20 km depth. The tectonic-geomorphological investigation of Lianhuashan fault tectonic zone indicates that the recent range of activity of the fault tectonic zone is becoming smaller from northeast to southwest. According to results of measuring of deformation of terraces and ^{14}C dating data of sediments of terraces, the recent rates of activity (7000 — 2000 a. ago) of the fault tectonic zone have been estimated. The maximum averaged rate is about 0.67 mm/a. and the minimum is 0.11 mm/a., classified as small range and low rate.

B. Geologic and Seismic Characteristics of Site and Its Neighboring Area

The area of site of GNPP is located at southwestern part of Lianhuashan fault tectonic zone and lies as a pentagonic block with unequal sides. The distance between the plant site and Wuhua-Shenzhen, Dabu-Haifeng fault zone is more than 20 km. The Mesozoic volcanic and granite bodies are extensively exposed in this area. The Paleozoic strata are mainly distributed in its central and northern parts, and the Cenozoic small downfaulted troughs are found in some localities. The structure of the area is controlled by northeast-trending. The Paleozoic stratum has been folded. Kuichong syncline and Paiyashan anticline are the main fold structures. Fault structures are relatively developed in the area. They are mainly NE-trending and next NW-trending, but relatively small in size. The tectonism which the area had undergone is closely related to that in the region. Caledonian and Indosinian oragenies produced fold basement of the latitudinal and NE-trending structures. But the tectonic traces have remained to small extent due to the coverage of later developed sediments and destruction by the magmatic activity. The latitudinal and NE-trending structures formed in early Yanshanian orogeny have made up a tectonic framework of the area. But the late Yanshanian and recent tectonism have produced NNE-and NW-trending structures and other superimposed structures. The crustal thickness in the area is 27 — 30 km and the deep discontinuities are distributed evenly without any deep faults and without such geologic structural background which might induce strong earthquakes. In an area with 50 km radius no earthquake of M=6 has ever occurred (see Fig. 2). Detailed surface geologic investigation, microearthquake monitoring and specific investigation of fault activity have borne evidence that no active fault is present and no microearthquake has been recorded in the area within 8 km radius of the plant site. In the area no recent volcanism was found, nor any warm springs and there is no recent regional landslides, collapses. Therefore, the area is a relatively stable block.

The plant site is located on the southeastern

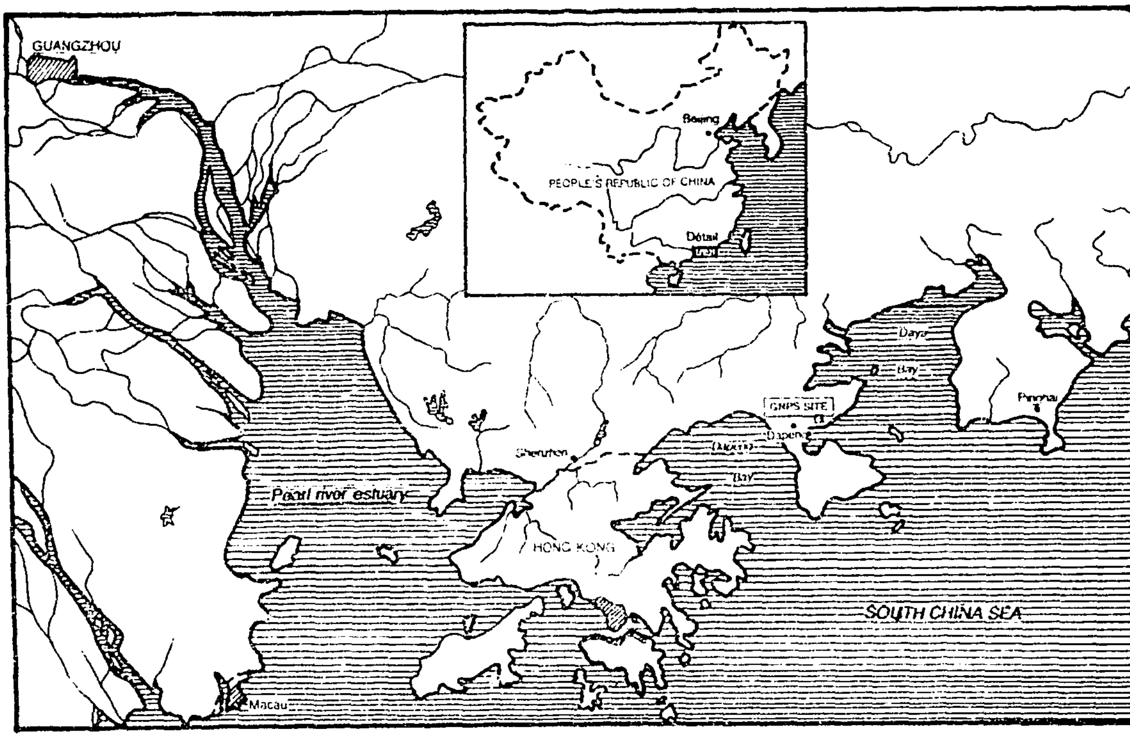

Fig. 1 The Site Location Map

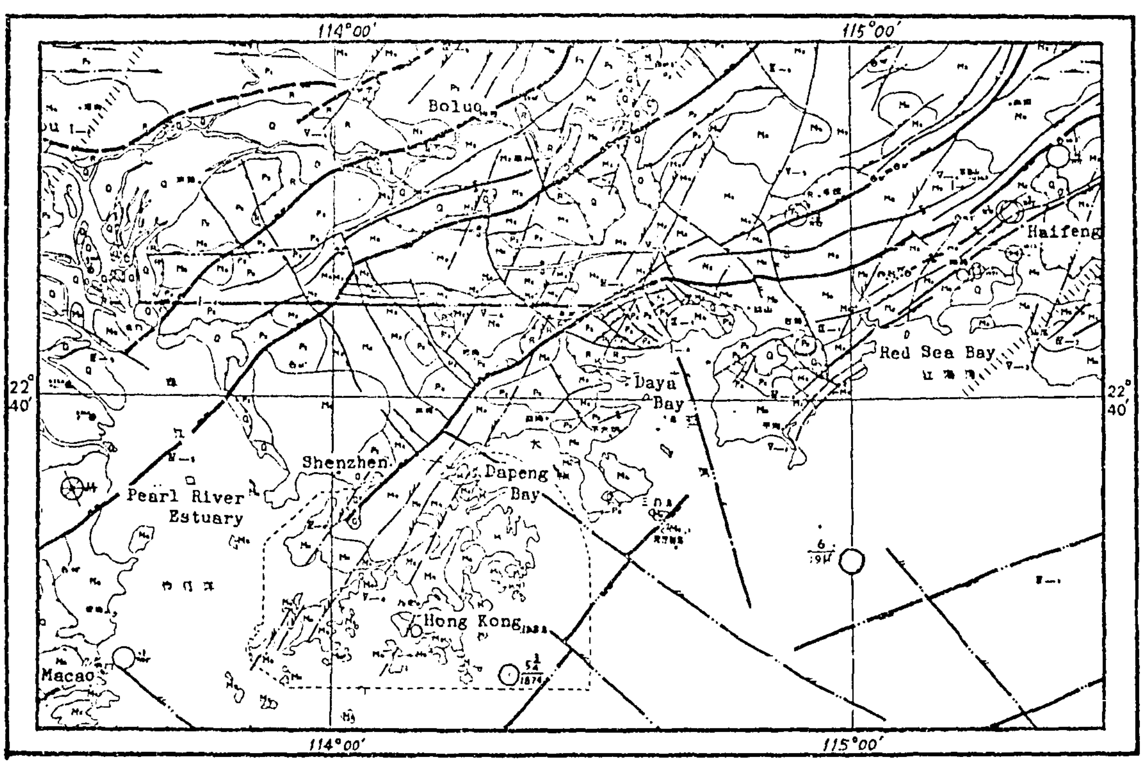

Fig. 2 The Regional Seismo-geologic Map of Site

flank of the Paiyashan anticline, which consists of greyish sandstone, silty shale and sandy conglomerate of middle Devonian. Axis of the anticline is in NE 50°—60° direction, and plunges to northeast. The southwestern edge of the plunging Paiyashan anticline is intruded by late Jurassic magmatic rocks. The intrusion of granite caused the sedimentary rocks to be metamorphosed to different extent in contact zone, which have formed three obvious zones in the area of site: hornfels zone, hornfelsic sandstone zone and weakly metamorphosed sandstone zone. The bed rock of nuclear island is hornfels, of conventional island is hornfelsic sandstone and of pumping station is weakly metamorphosed sandstone. In the site area of 2.5 km radius, faults do not develop and are small in size. No faults more than 1.5 km long have been found. Within the site area, there are no faults near the main buildings. Only on the southeast of the site at the sea shore two small faults have been found, the visible length is 70 m and another is 20 m.

Hydrogeological condition of site area is rather simpler. There are no surface water bodies of appreciable size near the site area. The ground water belongs in veined fissure water. Its outflow is very small and its flowing distance is short. The ground water discharges to sea directly and does not recharge into any other groundwater resources.

Consequently, engineering-geological condition of GNPP site is good. According to seismotectonic method and comprehensive probability method, the site maximum horizontal ground acceleration for Safe Shutdown Earthquake at zero period is 0.2 g, the maximum horizontal acceleration for Operating Basis Earthquake at zero period is 0.1 g, and in the period of operating GNPP life time the probability exceeding Operating Basis Earthquake is 0.03.

As mentioned above, site of GNPP is located at the " Safety Island " in comparatively active region of crustal activity. The " Safety Island " is a relatively stable block, which can adequately meet the demand for the safety of nuclear power plant.

III. ATMOSPHERIC DISPERSION CONDITIONS

An on-site meteorological investigation program consisted mainly of the meteorological measurements from a 102 m tower was conducted in order to assess the atmospheric dispersion conditions of the site. The results from analyses of the hourly observed data during the period from 1 September 1984 to 31 August 1986 are given below.

A. Wind Field Construction

The wind rose of the site indicates that onshore flows occur over 55% of time and the prevailing wind is easterly with frequency rated at 20%. The northeasterly wind only take up 5%, and it means that the opportunity for wind to blow from the site to Hong Kong directly is very small indeed.

It can often be observed that there is the obvious phenomenon of the sea-land breeze recirculation at the site, especially on days of warm weather. Besides sea breeze which occurs during daytime, there is another pattern of onshore flow which is called onshore gradient flow induced by the large-scale pressure gradient. By similar reason, besides land breeze which occurs during the night, there is another pattern of offshore flow called offshore gradient flow. The percentages of time in a year of sea and land breezes and onshore and offshore gradient flows are 26.5, 28.1, 28.7, and 16.7% respectively, with the corresponding windspeeds of 3.3, 2.4, 4.4 and 3.2 m/s.

Both sea and land breezes have comparatively small depths, averaged 440 and 280 m respectively, but for onshore and offshore gradients flows they are all deeper than one kilometer. All together we obtained 70 sets of trajectories of equilibrant balloon. There was no distortion among all 25 sets of trajectories during onshore gradient flow within the observed ranges. However, all 23 sets of trajectories observed during sea breeze obviously appeared to be distorted and turned back at 1—3 kilometers from shore. Fig. 3 gives an example of the photographs of smoke releases during sea breeze. It can be seen in this figure that the plume rises vertically with the air of the sea breeze front after it extends for a distance of 1.5 kilometers from shore.

The above observed results indicate that the distance from shore at which the sea breeze front would reach may be only a few kilometers. On such occassion, the application of the Gaussian straightline trajectory model to larger distances than a few kilometers would result in a conservative estimation of the average ground-level concentrations. Meanwhile, further analysis shows that, after rising with the air of the sea breeze front, the plume would move in reverse and be adequately diluted at the heights of several hundred meters above ground. When the plume again comes into onshore flow along with the recirculation of sea breeze, its contribution to groundlevel concentration will be lower by 2—3 orders of magnitude than its initial value.

In order to determine the possible penetration distances of onshore gradient flows, the simultaneously observed wind data from the meteorological station in Shenzhen, which is 45 km at the west of site, were collected. The correlative analysis of hourly wind data indicates that the onshore gradient flow from the east of site would penetrate inland by 40–50 kilometers.

B. Coastal Internal Boundary Layer

Coastal internal boundary layers may be caused by differences in surface temperatures (thermal internal boundary layers) or by differences in surface roughnesses (roughness internal boundary layers) between land and water, or by the combined effects of these two properties. The statistics of the windspeed and temperature profiles observed at the tower gave that the thermal internal boundary layers and/or rounghness internal boundary layer occurred at 37% per year which was approximately two thirds of the frequency of onshore flows. For this reason, it is clear that the coastal internal boundary layer is the key to recognizing the characteristics of atmospheric dispersion at the coastal site of GNPP.

The growth characteristics of the coastal internal boundary layers at the site have been revealed by 62 sets of fumigation data obtained from smoke releases and the corresponding meteorological information. An empirical equation is presented for predicting the heights of the bundary layers:

$$H(x)=\Omega(R_D)^{0.5}(\alpha C_p \rho u)^{-0.5}(x)^{0.5}$$

where

$H(x)$=height of internal boundary layer as a function of downwind distance,m,

R_D=solar radiation, Cal $m^{-2}s^{-1}$,

α=the potential temperature lapse rate of the onshore flowing air, $K.(100m)^{-1}$, measured by the upper sensors of tower,

C_p=specific heat, taken as 0.24 Cal $g^{-1}K^{-1}$,

ρ=air density, taken as 1250 $g.m^{-3}$,

u=the mean windspeed in the internal boundary layer, $m.s^{-1}$, measured at a height of 10 m at the tower,

x=downwind distance from shore, m,

Ω=a correction coefficient to adapt the equation to observed data, assigned a numerical value of 5.

C. Calculation of Dispersion Factors

The yearly averaged and short-term atmospheric dispersion factors have been calculated by using Gaussian straight-line trajectory models. The lateral and vertical plume spreads used in dispersion calculation were respectively determined by σ_θ and ΔT Classification schemes for atmospheric stabilities. The σ_θ scheme gives that, owing to the effect of irregular and rugged terrain and the wind meander under low windspeed conditions, over 74% of time in a year the unstable classes occur in horizontal directions, thus the horizontal speed of plume would be considerably increased. On the other hand, the ΔT scheme gives that the intensity of convections in vertical direction seems to be somewhat weak and the neutral or stable classes take up 85% of time. This is also one characteristic of meteorological conditions of coastal site for power station.

A number of factors such as plume rise, mixing height, building wake and the year-to-year variation of meteorological parameters have been taken into account in dispersion calculations. Here, it must be pointed out that, in the calculations of yearly averaged factors, the effect of coastal internal boundary layer should be considered for downwind distances up to 5 km during onshore flow. A particular fumigation phenomenon was unexpectedly found in smoke photograph. As shown in Fig. 4, when the plume entered into the coastal boundary layer, it became inclining downward with increased diffusibility and then extended near the ground. This situation was different from that given by conventional fumigation model which assumes that the fumigated plume would be well-distributed in vertical direction. In this regard the estimation of fumigation concentrations have been performed with reference to a recent study about the behaviour of an elevated plume within a convective boundary layer. This study gives the ground-level concentrations twice as large as those given by the conventional model. The results indicate that fumigation processes may cause the hourly averaged concentrations to be several times bigger or even bigger by several orders of magnitude. So, it is important to decrease the gaseous effluents in routine releases as much as possible in order to implement the principle of ALARA. However, the effective height of plume and the slope of internal boundary layer usually vary with meteorological conditions, so the positions in which fumigation would occur will be distributed over a wide range of area, which would cause no obvious increase in yearly averaged ground-level concentrations at downwind direction of onshore flow.

D. Estimation of Dose Equivalent

According to the yearly averaged dispersion factors and the designed values of gaseous effluents in routine releases, the dose equivalents of individuals at the locations within 5 km from the exclusion area boundary have been estimated. The estimation gives that the effective dose equivalent from gaseous effluent of the maximum exposed individual offsite is 0.6 μSv. On the other hand, according to the calculated short-term dispersion factors and the realistic assumption for assessing the source term of LOCA, the potential accident consequences have been estimated. The estimation gives that the whole-

Fig. 3 The Plume Rises Vertically with the Air of the Sea Breeze Front

Fig. 4 A Particular Fumigation Phenomenon in Smoke Photograph

body dose equivalent received by individual at the exclusion area boundary for 2 hours immediately following accident is 3.9×10^{-4} Sv, and the thyroid dose equivalent is 3.3×10^{-2} Sv.

The above results indicate that although the presence of sea and land breezes and coastal boundary layer significantly increase the complexity in atmospheric dispersion at the site of GNPP, the predicated yearly dose equivalents are far below the specified limits and the possibility of inhabitance within 5 km from the exclusion area boundary would not be affected, and that the population who resides in the surrounding area of the site would not receive any unacceptable consequence associated with postulated accidents.

IV. CONCLUSION

The site for GNPP is, in every respect, comparatively suitable for construction of a nuclear power plant. It adequately meets the requirements of composite assessment for safe, technological and economical operation.

Although the coastal region in east China is classified as mobile belt with moderate-strong earthquakes, it is still possible to select relatively stable massif in which major construction works are located. The main aspect of siting process is the concept of " Safety Island " which is applied to the comprehensive analysis of regional stability.

The coastal internal boundary layer is the key to recognizing meteorological processes in coastal sites in East China. Though the presence of sea and land breezes and coastal internal boundary layer significantly increases the complexity in atmospheric dispersion at the site of GNPP, suitability of the site is not affected. The predicted yearly dose equivalents are far below the specified limits. It can be expected that the population who reside in the surrounding area of the site would not receive unacceptable consequence associated with postulated accidents.

In the siting process of GNPP, the procedures and conclusions of the assessment about these two characteristics are significant and useful for the siting of nuclear power plants such as those found in the East China coastal region.

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