2.5 Geology, Seismology, and Geotechnical Engineering

The geology, seismology and geotechnical engineering aspects of the Yenliao site are summarized below. More thorough discussions are contained in the pertinent subsections.

(1) Summary of Investigative Program

The Yenliao site is located approximately 40 km east of Taipei. Comprehensive site and regional geologic investigations have been conducted in accordance with U.S. Nuclear Regulator Commission Criteria outlined in Appendix A, Seismic and Geologic Siting Criteria for Nuclear Power Plants (10 CFR 100). The purpose of these studies was to evaluate the geologic and seismic conditions of the site for suitability of a nuclear power generating facility.

Several studies have been conducted as part of the feasibility and site selection studies for a nuclear power plant at Yenliao. Following the selection of Yenliao, site specific geologic investigations were conducted to determine the foundation conditions. Preliminary core drilling at Yenliao was performed between 1965 and 1979 during several site selection sequences. After selection of the Yenliao site in 1979, foundation investigations were performed in two phases. Phase I, carried out during 1980 to 1981, successfully identified an acceptable location for power block structures and yielded preliminary values for foundation physical properties. Phase II, performed during the latter part of 1982, explored foundation conditions beneath the structures in detail and provided data from which specific foundation design criteria were developed. In 1994, a geological re-examination and re-appraisal of the site and the adjacent area of the site was conducted by Geological Society of China to confirm its suitability. To date, the principal reports containing the results of these regional, site selection, and foundation condition studies at Yenliao are shown in Reference 2.5-1 through Reference 2.5-7.

The Phase II investigation has provided a thorough quantitative description of foundation materials in the Units 1 and 2 Power Block area. It also has provided limited quantitative and qualitative descriptions of the contiguous slopes surrounding the power block, and of the ground water conditions. The last report further confirmed that the site is at any rate well chosen, and from the geologic stability point of view, the site is acceptable from geologists and economists sides.

(2) Summary of Geology

The Yenliao site is located along the northeastern coastline of Taiwan. The site is within the Northern Foothills sub-province of the Rolling Hills province. The Hsuehshan Range sub-province of the Central Mountain Range province is located a short distance south of the site. The area is characterized by gently rolling hills, which rise to elevations of about 300 m. The power block area is located on a nearly flat terrace at the foot of the hills. Units 1 and 2 will be situated about 600 m from the shoreline, at an elevation of about 12 m.

The geology of Taiwan can be summarized as consisting of several thousand meters of Tertiary clastic sedimentary rocks which overlie pre-Tertiary metamorphic rocks. Extrusive igneous rocks primarily of Quaternary age, have been deposited atop this sequence.

Structurally, Taiwan is situated at the colliding junction of the Philippine and Eurasian tectonic plates. The northwestward-moving Philippine plate is being subducted beneath the Eurasian continental plate along the Ruyuku arc. The plate motion on Taiwan has resulted in the development of a major transform fault along the Longitudinal Valley. Primary motion is sinistral with significant compressional forces. The plate collision has resulted in development of a northwestward directed system of imbricate thrusts in the Tertiary sedimentary formations. The geology within 8 km of the site consists of Tertiary sedimentary formations, which have been deformed by the northwest-southeast directed compression. A series of imbricate thrusts and locally tight folds with northwesterly trends are found in the area. The thrust faults have steep southeasterly dips.

Detailed geologic mapping, trending, drilling, remote sensing analysis, and offshore geophysical studies have been conducted in the area to determine the capability of the faulting. Faults in the Kungliao area were found not to be capable using NRC siting criteria and need not be considered in the seismic design of the plant.

(3) Summary of Seismology

The seismologic and geologic investigations performed by Bechtel Corporation in 1992 to establish the accelerations for the Safe Shutdown Earthquake (SSE) and operating Basis Earthquake (OBE). This study has recommended 0.4g acceleration for SSE and 0.2g acceleration for OBE seismic design and was acceptable for the Lungmen NPS under ROC-AEC regulations.

(4) Summary of Geotechnical Engineering

The Units 1 and 2 area of the Yenliao site consisted of a soil veneer comprised of unconsolidated clay, silt and sand with minor amounts of cobbley gravel, which overlie a generally hard, well-indurated series of interbedded, fine-grained sedimentary rocks. As part of site preparation, excavation of the cut slope to the south and west of the power block area and the mass excavation grade work have been conducted. However the final reactor type, plant layout, unit locations, and plant design have not been determined at this time (May 1986). The recommended foundation design parameters provided in Section 2.5.4 are based on exploration and testing conducted assuming a plant grade of 12 m above sea level and a PWR reactor design with a Maanshan-type plant layout. Once final design and layout for the units are determined, the assumed parameters for foundations design will be evaluated. Therefore, foundation parameters are subject to re-evaluation upon completion of plant configuration.

(5) Conclusions

Geologic and seismic studies conducted to date at Yenliao have shown the site to be suitable for the design and construction of nuclear power generating Units 7 and 8.

Faults in the Kungliao area close to the site are not capable faults by USNRC siting criteria and need not be considered in the seismic design of the plant.

The groundwater quality investigation did not produce any evidence that the site is underlain at depth by warm, sulfurous, or acidic ground water which would pose corrosion problems.

The foundation rock is of suitable quality for support of the proposed plant structures.

Shear zones in the foundation rock reduce the quality of the foundation locally but are not expected to pose major problems for design or construction. To minimize differential settlements due to soft material in shear zones, foundation dental work may be recommended where appropriate. There is no evidence that these shear zones are capable faults. The foundation rock will be mapped in detail by an experienced onsite engineering geologist as excavation proceeds to evaluate the occurrence and age of shear zones.

A shallow water table is present in the overburden deposits above the foundation rock. If adequately dewatered, this should pose no problems for construction.

2.5.1 Basic Geologic and Seismic Information

In 1979, extensive investigations were carried out to determine the most suitable site for the fourth nuclear power plant. Four candidate sites, namely Yenliao, Laomei, Kuanyin, and Tawu were selected for the comparative studies. Siting considerations included location and topography, power transmission, future expansion, population, meteorology, oceanography, hydrology, geology, seismology, foundation conditions, site development, and environmental impact. Yenliao was determined as the most desirable site for the fourth nuclear power plant (Reference 2.5-3).

An intensive investigation program of geological and seismologic conditions for the proposed Yenliao site have been undertaken since 1981 by the Power Development Department and Nuclear Construction Department, Taiwan Power Company, in cooperation with National Science Council, Republic of China, Sinotech Engineering Consultants, Pacific Engineers and Constructors, Ltd., and numerous private companies.

According to the data requirements, the investigation program was conducted in two phases. The phase I investigation provided the basic geological and seismic data to evaluate the feasibility for licensing. The data acquisition program includes :

(1) Surface geological mapping
(2) Geological core drilling
(3) Groundwater observation holes and measurements
(4) Seismic refraction and reflection surveys
(5) Trenching and aditting
(6) Microseismicity study
(7) Laboratory testing

The phase II program is the site specific investigation which provides information and mechanical parameters for design purposes. The investigations include:

(1) Geological core drilling and permeability testing
(2) Geophysical surveys, including cross-hole and up-hole surveys, and refraction survey
(3) Excavation, geologic mapping, and plate bearing test in two vertical shafts
(4) Laboratory testing
(5) Groundwater monitoring and chemical analysis
(6) Mineralogical studies using petrographic and X-ray analysis

Details of investigation items and their purposes are listed in Table 2.5-1 and Table 2.5-2.

All investigations were completed in early December 1982. The results of study were analyzed and compiled in reports. In addition to the field investigations mentioned above, some additional references are listed in Subsection 2.5.1.3.

2.5.1.1 Regional Geology

2.5.1.1.1 General Physiography and Geologic Provinces of Taiwan

The main island of Taiwan is elongated and spindle-shaped, with the longitudinal axis extending roughly north-south for about 385 km in length. The maximum width is about 153 km. It is located about 150 km off the Fukian Coast of Mainland China, and is separated from it by the Taiwan strait. Reference 2.5-14 has identified physiographic features of Taiwan (Figure 2.5-1). From these four major physiographic divisions are recognizable. They are the Central Mountain system, the Rolling Hills, the Terrace Tablelands, and the Coastal Plains.

In the Central Mountain system, the Central Range forms the backbone ridge and is the main water divide between the eastern and western slopes of Taiwan. It bisects Taiwan island into two unequal parts, the western flank being about twice as wide as the eastern flank. The Central Mountain system is an anticlinorium which occupies about one-half of the island and is composed mainly of hard metamorphic rocks and indurated sedimentary rocks resistant to weathering and erosion (Reference 2.5-12). The Rolling Hills form a narrow belt surrounding the Central Mountain system and link the Terrace Tablelands and Coastal Plains in a continuous slope.

A subdivision of the Rolling Hills physiographic province, the Eastern Coastal Range, is separated from the Central Mountain system by a long, narrow rift valley. This valley is known as the Longitudinal Valley and is remarkably straight.

The topography of the Terrace Tablelands province is controlled by the underlying lithology and geologic structure, The rolling Hills are composed mainly of Neogene and Pleistocene sedimentary rocks which include moderately to poorly consolidated sandstone, shale, and conglomerate, and scattered lenses of limestone. Near the outer edge of the Rolling Hills Province the terrain is gradually reduced to terraced tablelands. The latter were formed by the coalescence of alluvial fans and uplifting of the general area at the end of Pleistocene time. The terraces range in elevation from 200 to 400 m, (Reference 2.5-14), and are largely covered by unconsolidated sand and silt deposits. Some terraces have been severely dissected by gully erosion.

The Coastal Plains are extensively developed in the south-western part of the island. They include the gently sloping lowlands and hills that extend from the tablelands to the ocean. This area is composed of alluvial basins, plains and valleys. Unconsolidated alluvial deposits and reef limestone of Quaternary age occur throughout the Coastal Plain. Radiometric age dating indicates that Pleistocene age (Reference 2.5-10).

In order to understand the geologic history of Taiwan, it is essential to study the rocks deposited in several geologically distinct regions during each geologic interval. Rocks of the same age are often represented by different faces due to different physical conditions in these regions. It is thus desirable to discuss first the major geologic provinces and their bearing on the geologic development of Taiwan. Each province is characterized by its distinct geologic and geographic features that can be readily distinguished on the geologic map. Taiwan can be broadly divided into three major geologic provinces (Figure 2.5-2).

(1) Central Range, this could be further subdivided into two subprovinces Western flank and crest zone including Husehshan and Yushan Eastern flank of the Central Range
(2) Western foothills
(3) Coastal Range

The Central Range province which forms the backbone ridge of this island as mentioned in the previous paragraph. On Figure 2.5-2 the Central Range is defined purely on the geologic point of view. This is the region including all the Tertiary submetamorphic rocks and the pre-Tertiary metamorphic complex east of a major boundary fault, the Chuchih (Laonung) fault. It is bounded on the east by the eastern longitudinal valley and the Pacific Ocean to the north. Much of the stratigraphy and structure in this province are still little known due to metamorphism and insufficient field mapping. This geologic province can again be subdivided geologically into two subprovinces, eastern and western. The latter is a broad Tertiary submetamorphic belt which is distributed along the western flank, the crest zone, and the southern part of the Central Range. It extends also as a narrow rim on the southeastern flank of the Range. The eastern subprovince is underlain by the pre-Tertiary metamorphic complex exposed largely on the eastern flank of the Central Range.

The Western Foothills province is composed of Neogene clastic sediments. The rocks are mainly alternations of sandstones and shales with locally interspersed limestone and tuff lenses. The total thickness is 8,000 m or more (Reference 2.5-21). This is the most studied geologic province of Taiwan because of the extensive mineral exploration and other activities in this region. More detailed geologic mapping has been completed and more is known about structural details in this province than in the other two provinces.

The third geologic province is the Coastal Range in eastern Taiwan. This province is also underlain by Neogene sediments but of a different deposition environment as compared with the Neogene rocks in the Western Foothills. The rocks are characterized by the abundance of volcanic derivatives, poorly sorted clastic sediments, and chaotic deposits.

2.5.1.1.2 Tectonic Framework of Taiwan

Taiwan is part of the Ryukyu-Philippine island arc chain rimming the western border of the Pacific Ocean (Figure 2.5-3). The tectonic framework can be described in two different models, namely geosynclinal tectonics and plate tectonics. In the geosynclinal model, Taiwan is a typical mobil or orogenic belt and seismically active at present. The main island is the site of geosynclinal deposition on a Pre-Tertiary basement filled with Tertiary sediments to a thickness of more than 10,000 m. An older, Pre-Tertiary geosynclinal sequence was transformed into a metamorphic basement in late Mesozoic time. A second generation geosynclinal sequence was laid down on the basement from early Tertiary to early Pleistocene time.

In the recent plate tectonic theory, Taiwan is located on the juncture between the Eurasian plate on the west and the Philippine Sea plate on the east, that is, a continental plate on the west and an oceanic plate on the east. It can thus be divided into two major tectonic provinces (Reference 2.5-22). As shown in the tectonic map (Figure 2.5-4), the western province is called the foreland fold thrust belt in the geosynclinal model and is the continental margin of the Eurasian plate in the plate tectonic model. The eastern province is named the eugeosynclinal fold-thrust belt in the geosynclinal terminology and represents the leading edge of the Philippine Sea plate in the plate tectonic language. The western province or the continental Eurasian plate, which occupies almost the whole island, is subdivided into nine second-order tectonic units (Ho, 1982) from west to east as follows :

- W9 Quaternary cover rocks
    - a. Terrace gravel and alluvium
    - b. Pleistocene flood basalt
- W8 Pleistocene andesite
- W7 Outer fold-and-thrust zone
- W6 Inner fold-and-thrust zone
- W5 Intermontane troughs
- W4 Plio-Pleistocene Melange and younger sediments
- W3 Upthrust slate belt
- W2 Pre-Tertiary Metamorphic basement of the fold-thrust belt
- W1 Tectonic longitudinal valley

The eastern province is the site of the Coastal Range lying between the Longitudinal Valley and the eastern coast facing the Pacific Ocean. This range is about 135 km long with a maximum width of 10 km in the middle part. It is only 3 km wide at both the northern and the southern extremity. In the plate tectonic model, the Coastal Range is the remnant of a westward-facing Neogene island arc, the Luzon Island Arc, on the leading edge of the Philippine Sea plate (Figure 2.5-3). The Coastal Range is thus considered as the northern continuation of the Luzon Island Arc and the Luzon Trough to the south (References 2.5-30, 2.5-36, and 2.5-37). In Reference 2.5-30, it was concluded that the Coastal Range is the tectonized or fossil part of the Luzon Trough which has drifted slightly westwards from the line projected northward from the axis of the Trough.

The core of the Coastal Range and the two offshore islands are underlain by Miocene volcanic rocks of andesitic arc. Overlying the volcanic series, the main part of the Coastal Range is composed of imbricate thrust sheets of Miocene, Pliocene, and Pleistocene volcanogenic and flyschoid rocks. In the classical geosynclinal scheme the Coastal Range Would be Considered to be eugeosynclinal because of its tectonic mobility and seismicity, the thick flyschoid rocks, and the extensive distribution of volcanic rocks. This eugeosynclinal belt geologically contrasts with the miogeosynclinal fold-thrust belt in western Taiwan in the predominance of typical flysch deposition and abundance of volcanogenic and volcaniclastic rocks.

The geology and tectonic characteristics of the Coastal Range have been known in much detail since publication of a geologic map of the range in Reference 2.5-42 and an accompanying report (Reference 2.5-39). Subsequent geologic studies have appreciably improved early knowledge and understanding of this tectonic province. Although there are several stratigraphic classification schemes proposed by different workers, the nomenclature in Reference 2.5-39 has been widely adopted due to its practicability and priority. The general stratigraphic sequence pertinent to the analysis of the tectonic history of the Coastal Range is described in considerable detail in References 2.5-40 and 2.5-37. However, the Coastal Range is still a most challenging region and geologists differ in their interpretation of its stratigraphy, tectonics, and igneous history.

Three tectonic subunits have been classified for the Coastal Range eugeosynclinal belt on the tectonic map of Taiwan :

E3 Plio-Pleistocene ophiolitic melange
E2 Coastal fold-thrust zone
E1 Miocene and younger andesite

Each of these provinces was geologically independent of the other until they were structurally tied together by the plate collision at the end of the Tertiary (Reference 2.5-22). However, they are both characterized by prominent folds and thrust faults, separated by a median fault-bounded narrow valley that marks the collision suture.

As far as the new global tectonics is concerned, Taiwan is situated on a convergent and compressive boundary between two major tectonic entities, the Eurasian and the Philippine Sea plates (Figure 2.5-5). It displays the result of an active collision of an island arc (the Luzon Arc on the edge of Philippine Sea plate) with continental margin of Asia (on the Eurasian plate). The collision is a very young tectonic event and the present rate of plate convergence is about 7 cm/year in a northwest-southeast direction (Reference 2.5-43). Besides undergoing a collision with the Luzon Island Arc, Taiwan is also involved in the tectonics and thermal processes of the Ryukyu arc system at its northern end.

Taiwan is anomalous in the arc-trench systems of the western Pacific because it lacks many characteristic features of active arc tectonics. Study of bathymetric data and Bouguer anomalies shows there is no deep sea trench on either side of Taiwan. Systematic active andesitic volcanism is absent along the trend of the island. Intermediate and deep focus earthquakes are lacking and hypocenters do not clearly define a Benioff zone or a deep subduction zone in the vicinity of Taiwan. In addition, Taiwan is characterized by a continent facing or west-facing arc structure, as shown by its apparently reversed convexity, which is contrary to most of the other island arcs on the western Pacific. Elsewhere, along the curvilinear boundary between the Asian continent and the Pacific island arcs, the Eurasian plate usually overlies the Pacific plate or its subplates. Generally a Benioff zone is developed dipping toward the west and convex toward the Pacific Ocean. Only in Taiwan and western Luzon is the Eurasian plate overridden by the Pacific plate (the Philippine Sea Subplate, Figure 2.5-5). In these two exceptional regions, the Benioff zone dips toward the east or the Pacific Ocean.

From late Pleistocene to the present, Taiwan has undergone significant vertical uplift. The rates of uplift have been measured through radiometric dating of raised coral reefs. The average uplift rate for southern Taiwan and the Coastal Range is about 5 mm/year for the last 9000 years. Rates of uplift in the northern coastal area are from 2 mm/yr (1500BP to 5500 BP) to 5.3 mm/yr (5500 BP to 8500 BP). The rates are significantly lower in northern Taiwan since it is less tectonically active. The high uplift in eastern and southern Taiwan is consistent with island arc collision and high seismicity.

2.5.1.1.3 Major Structural Features of Taiwan

As shown on Figure 2.5-6, Taiwan lies among the islands that festoon the western border of the Pacific Ocean. It thus exhibits all the conspicuous structural features characteristic of an island arc. The main structural pattern of the island is that of an elongated arc convex toward the Asiatic continent, having a much longer south arm and short northeast arm. The Taiwan arc is bounded on the east by the Philippine Sea basin and on the west by the old massif of Cathaysia that forms the southeastern part of the Asia continent.

Contrary to most island arc structures in the western Pacific, the Taiwan are is convex toward the west or the China mainland and concave toward the Pacific Ocean. This westerly convex arc is situated between the easterly convex Ryukyu arc to the north and the Philippine are to the south, whose southern part is also convex toward the east. There have been different interpretations in the geological literature as to the meaning and significance or this reversed and peculiar arc structure in Taiwan.

The structural pattern and major structural lines in Taiwan conform closely to this arcuate structure of the main island. The rocks generally trend east-northeast along the northern short bend of the Taiwan arc. They strike north-south or north-northeast along the major south arm of the arc. During much of the geologic past, the Taiwan region was a geosyncline. The growth of this geosynclinal system has a long and complicated history. More discussion continues in Subsection 2.5.1.1.4.

As discussed in the previous section, all these major geologic and tectonic provinces of Taiwan are separated from each other by longitudinal faults that extend along the whole length of the island. They are mainly deep-reaching upthrusts dipping steeply eastward (Reference 2.5-30). At least some of the thrusts have a strike-slip component. These faults include the Chuchih fault between the western foothills and the Hsuehshan Range, the Laonung fault (south continuation of the Chuchih fault) between the western foothills and the Backbone Range in southern Taiwan, the Lishan fault between the Hsuelishan Range and the Backbone Range of the Central Range in north and central Taiwan, and the Central Range fault and the Coastal Range fault on the west and east sides of the longitudinal rift valley in eastern Taiwan.

2.5.1.1.4 Stratigraphy and Geologic History of Taiwan

The main island of Taiwan has been the site of geosynclinal deposition on a metamorphic basement filled with Tertiary sediments to thickness of more than 10,000 m. This geosynclinal trough maintains a general north-south trend. The axis of geosynclinal deposition has been shifting progressively westward with successive orogenic episodes. A considerable part of the Tertiary sediments in the Taiwan geosyncline has been subjected to different grades of induration or metamorphism. Large igneous intrusions are rare, but there are several important volcanic areas in northern Taiwan, eastern Taiwan, and the Taiwan strait.

All the rock formations on the main island of Taiwan occur in long narrow belts roughly parallel to the longitudinal axis of the island. These rocks are progressively younger in age from the central backbone range to the western foothills. The prevailing structural pattern of all the rocks is that of an elongated arc with its convexity facing the west or the Asiatic continent. The northern shorter bend of the arc strikes east-northeast and the southern major arm of the arc extends mainly north-south. All the major structural lines in Taiwan, including the important faults and fold axes, correspond fairly well to this arcuate structure throughout the whole island (Figure 2.5-7).

2.5.1.1.4.1 Metamorphic Complex

The oldest basement rocks in Taiwan consist of the metamorphic complex extending along the eastern slope of the Central Range. This metamorphic belt is made up of several kinds of schists and metamorphosed limestone with subordinate amounts of gneisses and migmatites which are found mostly in the northern part. The schists can be differentiated into three main categories: green schists, black schists, and siliceous schists. The metamorphic complex is generally divided into two belts : an east belt of black schists with a little green schists and a west belt of interlayered black schists, green schists, and siliceous schists. Metamorphosed limestone, gneisses, and migmatites are found mainly in the west belt. Scattered exposures of mafic to ultramafic rocks, mostly altered to serpentinite, are found in the east belt. These rocks were transformed from original beds of sandstones, siltstones, shales, limestones, and mafic volcanic to ultramafic rocks. They are poorly dated due to lack of fossils. A few fusulinids found in the marmorized limestone of this metamorphic series have been proved to be Permian in age (Reference 2.5-54). The metamorphic complex is considered as pre-Tertiary in general, possibly ranging in age from Late Paleozoic to Mesozoic. This metamorphic complex could be composed of a complicated mass of undifferentiated rock formations with varying geologic ages and including several periods of major or minor tectonic movements and igneous activities. It represents the oldest phase of geosynclinal development in Taiwan.

2.5.1.1.4.2 Tertiary Deposits

The metamorphic complex forms the basement of the Tertiary geosyncline of Taiwan which is the second generation of ten geosynclinal trough. The earliest sediments laid down in the Tertiary geosyncline are dominantly dark argillaceous sediments which were later indurated and metamorphosed, forming a thick dark gray argillite-slate-phyllite series (References 2.5-16 and 2.5-17). Sandy interbeds are locally found in this argillaceous series and in places alternations of argillite or slate and sandstone are well-developed. The sandstone is highly indurated locally approaching a quartzitic texture. Intercalated in this argillite slate sequence are also thick to medium beds of coarse-grained to medium-grained indurated to quartzitic sandstone, containing coaly or carbonaceous layers and dark gray shale interbeds. The white sandstone and carbonaceous facies are more common toward the northwestern part of the argillaceous belt which is locally called the Hsuehshan Range where two carbonaceous units are distinguished. Basaltic pyroclastics and minor lava flows are common in some parts of this argillite-slate belt. Small disseminated limy to marly lenses and thin conglomerate layers are also intercolated in the slaty rocks. All these rocks are exposed along the crest zone of the Central Range and its western and southeastern flanks.

Fossils are sparsely distributed in this undifferentiated metamorphosed shaly sequence. The prominent organisms are forminifers and mollusks. Their ages extend from Eocene to Miocene (Reference 2.5-44). However, convincing Oligocene organisms are rare. Recent findings on the basis of mollusk faunas show that Miocene organisms are more dominant than the Eocene fossils. Thus a large part of the argillaceous rocks could be of Lower Miocene age (Reference 2.5-46). Eocene foraminifers, on the other hand, occur mostly in the Yushan Range and south and also in the middle crest zone of the Central Range. However, it is very difficult to subdivide this thick shaly sequence into adequate mappable units with exact age assignment due to the monotonous lithologic succession, paucity of fossil, complicated structural features, and lack of recognizable datum planes for regional correlation.

Five lithostratigraphic units can be distinguished in the Hsuehshan Range coal-bearing formations and three argillaceous formations which are composed mostly of argillites, slates, and phyllites. Based on the study of foraminifers, the age of these formations has been ascribed largely to Oligocene and Eocene, and partly to Lower Miocene. However, recent mollusk studies indicated that the age of the upper three formations is mostly Lower Miocene (Reference 2.5-46). Only the lower carbonaceous unit may contain Oligocene faunas and the lowest slate formation is most likely Eocene.

The highest part and the southern part of the Central Range are geologically the least known areas in Taiwan. Only widely spaced route traverse mapping was carried out in these areas because of rugged topography and difficult accessibility. Although these two areas cover quite a large extent in the Central Range, only two broad stratigraphic units are distinguished on the map : The Miocene Lushan Formation and the Eocene Hsinkao Formation. The chief lithology of the two formation is still represented by metamorphosed argillaceous sediments, slates and phyllites, although sandstone interbeds are more dominant in the latter formation. Their structural and stratigraphic relations to the slates and phyllites in the Hsuehshan Range are still uncertain. These two formations could be in an unconformable contact (Chang,

1972) because there is an apparent stratigraphic gap on the map with no Oligocene between the rocks mapped as Eocene and Miocene. Yet no good evidence of any angular discordance has been discovered except a slight break recorded in some places.

Non-metamorphosed Neogene rocks are exposed on the western flank of the Central Range, and extend underneath the western coastal plain. Only fault contacts are known between the non-metamorphosed Neogene rocks in the western foothills and the metamorphosed Miocene to Paleogene argillaceous sediments in the Central Range. The stratigraphic and structural relations between these two Tertiary belts are still not clear. As the non-metamorphsed Neogene rocks in the western foothills and the metamorphosed Miocene to Paleogene argillaceous sediments in the Central Range differ markedly in degree of deformation as well as in lithofacies, they could have been deposited in two separate basins of the same geosynclinal cycle : an eastern basin and a western basin possibly with an intervening highland. A pronounced crustal disturbance may have taken place over a large part of the Taiwan geosyncline in mid-Tertiary time and affected mostly the eastern basin. This movement uplifted and transformed the Miocene and Paleogene argillaceous sediments in the basin into a cordillera which is the present Central Range. The pre-Tertiary metamorphic basement was also brought up along its eastern slope. Low-grade metamorphism accompanied this orogeny but no large igneous intrusion was recorded. Post-orogenic Neogene transgression was diverted into two separate basins on the west and the east of this Central Range cordillera.

The western Neogene basin existed as a shallow depression receiving Early Miocene sediments before and during the mid-Tertiary orogeny. After the orogeny, the axis of deposition of the Taiwan geosyncline shifted westward into this negative area following the uplift of the Central Range. This area then became the main site of continuous Neogene sedimentation in western Taiwan.

In the opinion of some geologists, the Paleogene and the Neogene sediments in western Taiwan are continuous (References 2.5-47 and 2.5-48) because no distinct evidence of unconformity and coarse orogenic sediments have ever been found in the Tertiary sequence. Only the axis of sedimentation in the Tertiary geosyncline was shifting constantly westward with upheaval of earlier formed sediments on the east. The difference in degree of metamorphism between the Miocene to Paleogene sediments in the Central Range and the Neogene rocks in the western foothills may merely reflect the great depth to which the old Tertiary sediments on the east were depressed and buried. Deep burial means great lithostatic pressure and hence higher degree of induration and metamorphism. These geologists believe the main orogenic disturbance in the Taiwan geosyncline possibly took place in Late Pliocene or post-Pliocene time.

The western Neogene basin was the site of continuos shallow-water sedimentation to an accumulated thickness of 8,000 m or more. The Miocene sediments may be divided into two types on the basis of inferred depositional tectonics : the shelf type and the geosynclinal or basin type. The strata of the shelf type are characterized by near-shore deposits of mixed marine and continental origin. They are mainly white arkosic sandstones, coals beds, dark shales, and thin interlaminations of silt, clay, and sand. The strata of the basin type were deposited under conditions of greater subsidence and rapid accumulation and are exclusively marine. They are represented by poorly sorted clastic sediments in a monotonous sequence of alternating calcareous sandstones subgraywackes, and dark shales. These two types of sediments are usually in interfingering or intertonguing relationships and occur in repetitive succession in the northern part of the western basin. They are characterized by three Miocene coal-bearing formations in rhythmic alternation with basin-type marine formations, forming three sedimentary cycles in the Miocene of northern Taiwan. In each cycle, one coal-bearing formation is overlain by an intervening sequence of marine strata.. Submarine volcanic eruptions made up of basaltic tuffs, lava flows, and other tuffaceous sediments are found in the Miocene formations of all these three cycles. They are most well-developed in the Lower Miocene of northern Taiwan.

The exposed pliocene sediments in northern Taiwan are mainly marine and of geosynclinal facies. The lower division is composed of dark gray shale or mudstone sequence, while the upper division is composed of alternating beds of shales, siltstones, and fine sandstones. Marine fossils are abundant in the rocks.

A marked change in the character of Neogene sedimentation in southern Taiwan is obvious. In general the Neogene rocks are progressively thicker and more shaly and of finer grain size from northern Taiwan toward southern Taiwan (Reference 2.5-49). The Miocene rocks in southern Taiwan are marked by the gradual absence of shelf facies (coal-bearing formations) to the exclusive development of basinward marine facies. This indicates the water in the basin was deepening southwards. The main lithologic types of the Neogene in southern Taiwan are represented by alternating succession of dark gray shale or claystone, mudstone, and a little sandstone. A mudstone series of more than 4,000 m thick was piling up in southern Taiwan during the Pliocene time. This mudstone represents a mass of submarine slump or mudflow probably caused by turbidity current in the southern part of the Neogene basin. Some biohermal to biostromal reef limestone bodies are scattered in the Pliocene to Upper Miocene rocks of southern Taiwan.

The Neogene geosynclinal sedimentation in western Taiwan ended with the deposition of Late Pliocene to Early Pleistocene conglomerate which precludes the incipient phase of a major orogenic parozysm. Strong and widespread orogenic movement occurred during and after the accumulation of this conglomerate formation in Early Pleistocene time in this western basin. Distinct post-orogenic deposits are represented by the lateritic and nonlateritic tableland gravel which covers and extensive area in all parts of western Taiwan. Southward the newly emerged Taiwan island was surrounded by sea water and reef limestones were formed around its southern rim. This is the Pleistocene organic limestone unconformably overlying all older formations in southern Taiwan.

After the Early Pleistocene orogeny, the Neogene rocks in the western basin were deformed by a combination of folds and thrust faults. No metamorphism and no plutonism took place. Tight and asymmertric folds and low-angle nearly parallel anticlines and synclines, usually bounded by longitudinal thrust faults. As a general rule, the anticlines mostly have a steep or overturned northwestern flank and the synclines have steep or overturned southeastern flank. A series of southeast-dipping imbricated thrust blocks was formed. Many of them are low-angle thrusts or nappes traceable for a long distance. The deformation was characterized by lateral compression from the east, and perhaps assisted largely by the influence of gravitational forces.

This imbricate thrust zone may be delimited in the west by several continuous en echelon sole faults which are the leading tectonic lines in western Taiwan. These sole thrusts form a structural front along which the strongly deformed thick geosynclinal sequences in the fold and thrust belt of the western foothills gave place to gently warped thinner sediments in the foreland toward the west. West of this structural front, typical foreland structures are recognized. Broad and gently folded structures are predominant. Faulting is also less prevalent and of small magnitude.

Although the rocks in the western foothills are strongly folded and steeply dipping, no formations older than the Lower Miocene are involved in the folding. The pre-Neogene basement has apparently not been affected or little disturbed by the tectonism. This shows that the Neogene rocks were deformed independently and sheared off from stratigraphically lower formation. The existence of this decollement surface underlying the imbricated fault zones has been recognized. It is a detachment plane separating the Neogene sequence from the pre-Neogene basement. Thrusting and folding in the western foothills are thus relatively shallow and affected mostly the uppermost part of the crust. This favors the gravitational gliding theory in the tectonic interpretration of western Taiwan (Reference 2.5-31).

During and after the Early Pleistocene orogeny, andesitic volcanic eruption took place in northern Taiwan and also in the northern and northeastern offshore islands. The volcanic activities formed two important volcano groups in northern Taiwan : the Tatun volcano group in the west, characterized by andesitic flows; and the Chilung volcano group in the east, marked by dacite flows and associated gold and copper deposits (References 2.5-27, 2.5-28, and 2.5-18). Almost at the same Pleistocene time, plateau basalt was extruded out from the fissures of the Pleistocene to Neogene sediments on the Penghu island group in the Taiwan Strait. Extensive basaltic lava flows cover the entire island group except one southwest islet. The lava flows formed typical mesa-type landforms. These volcanic flows seem to be largely anorogenic.

The present Coastal Range in eastern Taiwan is the site of a Neogene geosynclinal basin east of the Central Range and separated from the latter by rift valley. The early geologic history of the eastern basin is little known because it is represented now only by a narrow strip of the Coastal Range which is fault-bounded on both sides. Different sedimentation facies and geologic history have been recognized in the eastern Neogene basin as compared with the western Neogene basin. All the deposition in the Coastal Range is typically geosynclinal (Reference 2.5-39). It is also characterized by more intense igneous activities. The eruption of widespread andesitic lava flows marked the beginning of the Early Miocene history in this east basin. These andesitic flows form and igneous complex of composite activities exposed mainly in the middle part of the Coastal Range covering an area of nearly 22 sq km.. Small outcrops of this igneous complex are also found in other places of the Coastal Range. The two southeastern offshore islands, Lutao and Lanhsu, are also formed of this andesite and this pyroclastics. The eruption of the andesite was followed by the accumulation of a thick sequence of andesitic agglomerate and other tuffaceous sediments reaching 1,500 m thick. Overlying this volcanic series are Upper Miocene to Pliocene clastic sediments represented by dark gray shaly rocks, poorly sorted sandstones, and conglomerates. These sediments attain a great thickness of 3,000 m. Limestone lenses yielding Early Miocene foraminifers are present in places at the contact between the thick agglomerate series and the overlying clastic sediments, indicating that the agglomerate formation is mostly of Early Miocene age. Numerous primary sedimentary structures caused by penecontemporaneous deformation and possible turbidity current deposition have been found in these clastic sediments.

2.5.1.1.4.3 Late Pliocene-Early Pleistocene Orogeny

The Early Pleistocene orogeny brought up a widespread emergence of the land area in Taiwan. In Pleistocene time, local marine transgression still took place over many areas on the borders of the rising land area. Reef limestone kept growing around the rim of the early emerged Taiwan island, mainly on the Hengchun peninsula. In other places mainly continental detritus were laid down. Lateritic to non-lateritic terrace gravel covered a considerable part of this island, unconformable to all older rocks. Probably as a result of extensional relaxation of compressional forces after a major orogeny, mild and intermittent regional uplifting, block faulting, broad warping, and tilting are characteristic of the Pleistocene history in many places. Taiwan lies in the mobile belt of young tectonic activities. A continuation of crustal mobility from the Early Pleistocene orogeny to the present is manifest. The frequent occurrence of earthquake shocks also indicates crustal unrest up to recent time. Strike slip faulting and recurrent displacement along existing ruptures are common after each large earth movement.

A chaotic and non-stratified, muddy to clayey formation containing many exotic blocks of different sizes, ages, and lithologies was probably emplaced in Late Pliocene to Early Pleistocene time in the Coastal Range (Reference 2.5-51). This formation may have resulted from a submarine gliding in which massive mudflows with various Miocene and Pliocene rock fragments and exotic blocks of an ophiolite suite slid down along the surrounding highlands. This massive chaotic unit is a typical melange including abundant blocks of oceanic crust and upper mantle material. Early Pleistocene may be the time of major orogenic episode in eastern Taiwan. Also in the Late Pliocene to Early Pleistocene time, a massive piedmont deposit was laid down along the eastern front of the Central Range, generally intertonguing with the chaotic melange formation toward the east. Fault contact between these two formations is recognized along the Longitudinal Valley. The piedmont deposit is represented by a conglomerate formation which crops out mainly in the hill Pinanshan northwest of the Taitung city.

It is composed of pebbles derived from the metamorphic complex of the Central Range west of the Taitung valley. Total thickness of the conglomerate is estimated to be nearly 1,400 m. After the Early pleistocene orogeny, the sediments in the eastern Neogene geosynclinal basin were folded, faulted, and uplifted into mountains.

The Neogene rocks in the Coastal Range were folded into subparallel anticlines and synclines cut by several longitudinal faults. The tectonic characteristics is marked by the predominance of allochthonous elements. Two huge gliding masses cover a large part of this Range. The lower one is the Lichi melange. In eastern Taiwan, this is the youngest melange known in the world that has not been subjected to any deformation and metamorphism after its formation. It shows exactly the nature and characteristics of a typical melange when it was first laid down without further modification and deformation. The second gliding mass is the Coastal Range nappe overlying the Lichi melange. Its total length could be nearly 100 km, approximately covering the southern two-thirds of the Range.

2.5.1.1.4.4 Quaternary

The Quaternary deposits are mainly surficial veneers and valley or basin fillings consisting of fluvial, lacustrine, or marine sediments. They show such landforms as coastal or river terraces and alluvial plains. The Pleistocene deposits are represented largely by terrace deposits which are extensive in the rolling hills and coastal terraces of western Taiwan and the Hengchun peninsula. A uniform sequence of terrace development is recognized in western Taiwan, remarkably dissected into several terrace levels. The terrace deposits occur also in several inland basins, the eastern longitudinal valley, and some offshore islands.

The problem of the stratigraphic boundary between the Pliocene and the Pleistocene strata has been discussed very often but has not been solved as yet. It is a very difficult task to establish the division of the Quaternary deposits in Taiwan where the glaciation was extremely poor and continuous zonation on marine faunas is incomplete. The Toukoshan Formation is the oldest Pleistocene unit in Taiwan and is distributed extensively in western Taiwan.

The Toukoshan Formation is chiefly early Pleistocene but may be Late Pliocene in part. This formation is tentatively ascribed to Plio-Pleistocene. The next older Pleistocene unit is the Tananwan Formation which is believed to rest unconformably on the Toukoshan Formation and other older units. All the Pleistocene rocks younger than the Tananwan Formation are generally flat-lying. They are unconformable to the Toukoshan Formation or other Tertiary strata (Reference 2.5-21).

Lin (References 2.5-10 and 2.5-32) was the first geologist to summarize the Quaternary geology of Taiwan and classified the Quaternary sediments into a large number of rock units. However, some of these units still have unknown relations to one another and pose problems in accurate correlation. Much study will be required to synthesize the fragmentary data of the Quaternary deposits distributed in widely separated parts of Taiwan before a satisfactory classification scheme can be attained. The present classification of the Quaternary deposits is more or less hypothetical and involves many problems to be solved by future studies.

Based mainly on mappability and lithology, the Quaternary deposits in Taiwan are subdivided into six main divisions on the present map: four in the Pleistocene and two in the Recent or Holocene. Other Pleistocene deposits which are exposed only as small isolated outcrops or not of mappable significance are not shown on the map. There are also a large number of Holocene units proposed in Reference 2.5-10. These units are generally too thin and limited in occurrence to be mappable.

2.5.1.1.5 Volcanic Deposits of Northern Taiwan

Two important pleistocene volcanic eruptions took place in northern Taiwan. They resulted in the so-called Tatun Volcano Group and Chilung Volcano Group. However, no volcano is known to be active in Taiwan in the historical record, but these volcanoes may not be entirely extinct as geothermal evidence is still extensive there.

The Tatun Volcano Group Comprises a series of andesite volcanoes in the northernmost part of Taiwan, the nearest being 15 km north of Taipei City about 40 km from site. About 20 volcanoes and volcanic cones are included in this group. Craters may or may not be preserved at the summit of the cones. A few have been eroded to craterless volcanoes or were erupted as volcanic domes due to high viscosity of the lava. This group of volcanoes was built by successive eruptions of andesitic flows, volcanic ashes and coarse pyroclastic ejecta. They are mainly strato-volcanoes built on a Miocene basement. The most common andesitic lavas in the Tatun Volcano Group are augite andesite, hornblende andesite, and hypersthene andesite or combinations of these.

The Chilung Volcano Group is found in the Miocene rocks on the northeastern coast of Taiwan and to the east of Chilung harbor and distance from the site of about 10 km. This group is mainly quartz andesite or dacite flows and some pyroclastics. Ore-forming fluids accompanying the dacite intrusions have deposited valuable gold and copper ores in the host rocks or at the contact margin, forming the three famous gold and copper production areas at Chinkuashih, Chiufen, and Wutankeng. The age of the most recent volcanic activity is about 0.290.10 Ma according to the dating evidence (Reference 2.5-50).

2.5.1.2 Site Geology

Detailed surface and subsurface geological and geotechnical investigations pertinent to the safety, design, and construction of a nuclear power plant have been undertaken at Yenliao site. A surface regional geologic mapping covering the site area and its vicinity was carried out by Mr. S. .F. Tsan, Central Geological Survey of Taiwan (Reference 2.5.51). More thorough geologic mapping to confirm the results of the said regional geologic mapping for the site selection studies was performed by the joint efforts of Taiwan Power Company and Bechtel geologists. In 1988, the Central Geological Survey published a series of geological maps for northern Taiwan, including the site area (Figure 2.5-8). In 1994, the Geological Society of China also presented a geological map of Aoti area in its study (Figure 2.5-9) (Reference 2.5.7).

According to the reports (Reference 2.5-53), the foundation rocks of the site are Wentzkeng formation (or Tatungshan formation) and Mushan formation, mainly consisting of indurated argillite with sandstone and arkosic sandstone with siltstone or shale. The lithologic characteristics of Wentzkeng formation and Tatungshan formation are almost the same. Previous studies have correlated Wentzkeng formation with the Tatungshan formation, and Mushan formation as Wuchishan formation. The stratigraphy and correlation will be discussed in detail in Section 2.5.1.2.2

2.5.1.2.1 Physiography

The Yenliao Site is situated on the northeast coast of Taiwan where the Hsueshan Range sub-province of the Central Mountain Range meets the Pacific Ocean.

The two principal drainages in the area are the Keelung-ho and the Shuang-Chi Rivers. The Shung-Chi follows a generally east-west course discharging into the Pacific at Fulung about three km southeast of Yenliao site (Figure 2.5-9). The Chi-lung River, farther from the site, flows in an east-northeast direction, then abruptly veers back to the west where it discharges into the Tanshui River in the Taipei basin. The Shuang-Chi River approaches the area flowing east-northeast along a long structural valley which terminates at the town of Shuang-Chi about 6 km west of Yenliao. Here the river turns to the south, then resumes its easterly course, passing Kungliao and discharging to the sea at Fulung. The gradient of the Shuang-Chi River is very low. Mr. T. L. Hsu, former acting director of the Central Geological Survey, reported in a paper on the neotectonic significance of fluvial landforms (Reference 2.5-38) that the Shuang-Chi River is graded for 74% of its total length. This suggests a lack of strong regional uplift in the Shuang-Chi drainage basin in the recent geologic past.

Within 5 miles of Yenliao, the area can be divided topographically into two parts: that north of the Shuang-Chi River, and that to the south of the river (Figure. 2.5-8). The northerly part, which includes the site, is characterized by ridges and valleys developed in a structurally complex sequence of sedimentary rocks. Dip slopes are gentle, and anti-dip slopes are often very steep when developed along jointing in resistant beds. Overall, the geomorphology may be described as "middle-age," being somewhere between youthful and mature. The highest hill reaches a maximum elevation of 301 m, approximately 3 km west of the site. The area south of Shuang-Chi River can be classified as having youthful topographic features, partly due to more resistant lithologies present there, and partly due to a probably higher rate of uplift during early Pleistocene time, resulting from activity on the Chuchih fault. The oldest rock unit south of the river, and the one which often has the controlling influence over topographic development, consists of very well indurated siltstone which has been locally metamorphosed into argillite. Quartzite beds are also present in this unit. The result of the early Pleistocene uplift is the development of deeply-incised, steep-sided drainages and angular peaks.

The proposed site is adjacent to the coast and is situated in an area of gentle undulating hills and terraced rice paddies, covering approximately 200 hectares or 2 sq km (Figure. 2.5-10). The Units 1 and 2 Power Block area is located in the southern portion of the site, and occupies about 182,400 sq m. The center of the Power Block area is about 600 m form the shoreline. The ground surface in the Power Block area varies slightly in elevation, averaging about 12 m above mean sea level. The site is named after Yenliao, a very small village located near the site. The Units 1 and 2 Power Block area is traversed by a small perennial stream which flows to the ocean. The coast is gentle and concave to the west. It is characterized by outcrops of siltstone and sandstone, and sandy beaches.

2.5.1.2.2 Stratigraphy

Within 5 miles of the site, the rock formations exposed are mainly the sedimentary rock from Oligocene to Miocene in age and some Pleistocene volcanic rocks and detritus.

The sediments deposited at the site during late Oligocene through early Miocene time were divided into seven lithostratigraphic units. The Oligocene is represented by the upper portion of the Tatungshan Formation. This rock unit is very thick in other parts of Taiwan, but only a small portion is represented at the site. South of the Chuchih fault, in the Central Range Province, the Tatungshan Formation (Oligocene) is the lowermost unit studied. It is conformably overlain by the Nankang Formation, in turn comfortably overlain by the Fangchiao Formation (both Oligo-Miocene transition). North of the Chuchih fault, in the western Foothills Province, the name Tatungshan Formation is retained as the lowermost unit studied. It is conformably overlain by the Wuchishan Formation, which in turn is overlain by the Mushan Formation. Both of these two units are placed in the Oligo-Miocene transitional zone. The Taliao Formation (Miocene) conformably overlies the Mushan Formation, and the Shihti Formation (Miocene) comformably overlies the Taliao rocks. The correlation of the stratigraphy by different studies in the site area are listed in Table 2.5-3. The lithologic features of these formations are described in the following subsection.

2.5.1.2.2.1 Tatungshan Formation

This is the oldest unit exposed in the site area. The lower part of this formation is composed of dark gray to black argillite closely interbedded with gray fine-grained sandstone and muddy siltstone. Contact between the argillite and the sandstone or muddy siltstone is rather transitional. The upper part of the formation is represented largely by dark gray compact argillite and sandy shale with fewer interbeds of sandstone or muddy siltstone. The argillite and mudstone are commonly massive when wet but show good fissility and cleavage surface on drying. Bedding is usually indistinct but fracture and slaty cleavage are more or less developed. References 2.5-56 and 2.5-53 named the rock formation at the site as Wentzkeng Formation in the northern part of Chuchich fault and Tatungshan Formation in the southern part (Figure 2.5-8). Later, it was confirmed that the formation exposed at the site is identical with the Tatungshan Formation (Figure 2.5-11). The total thickness of the Tatungshan Formation is estimated in the order of 1,500 m or more (Reference 2.5-21).

2.5.1.2.2.2 Wuchishan Formation

According to Reference 2.5-21, the Wuchishan Formation is the oldest Miocene unit exposed in northern Taiwan and Mushan Formation conformably overlies the Wuchishan Formation at a transitional contact. Lithologically the Mushan Formation is quite similar to the underlying Wuchishan Formation and differentiation of these two units is often very difficult. Therefore PECL/TPC (Reference 2.5-6) named the rock exposed at the northern part of Chuchih fault as the Wuchishan Formation.

This formation is mainly the massive to thick-bedded, white, medium-to coarse-grained sandstone, The sandstone is mostly orthoquartzite or protoquatzite and partly feldspathic sandstone. A few medium beds of conglomeratic sandstone occur in the lower and upper parts and grey to light bluish grey subgraywacke. Sandstone is found in the middle part. Dark grey shale and alternations of sandstone and shale are interbedded with the white sandtsone. Coaly to carbonaceous lentils or streaks are scattered in the dark grey shale but of no mining value. The exposed thickness of this formation along the northern coast is about 1,000 to 1,400 m (Reference 2.5-53).

2.5.1.2.2.3 Mushan Formation

Lithologically, the Mushan Formation is quite similar to the underlying Wuchihshan Formation and differentiation of these two units is often difficult. In field mapping a thick bed of dark grey shale exposed in the upper part of the Wuchishan Formation is considered as a good horizon marker to indicate the base of the Mushan Formation. The shale is approximately 40-50 m thick. White orthoquartzite to protoquartzite sandstone is still predominent in the Mushan Formation and the sandstone is commonly cross-bedded. However, the sand grains in the Mushan sandstone are finer and less compacted than those in Wuchishan sandstone. Dark grey shale or carbonaceous shale and interlaminations or interbeds of sandstone and shale are the other characteristic rock type in the Mushan Formation. The total thickness of the formation is nearly 650 m in the measured section along the northern coast.

2.5.1.2.2.4 Taliao Formation

This formation is characterized by its monotonous sequence of thick-bedded to massive sandstone alternated with thin and thick beds of shale and silty shale, the sandstone-shale ratio being 1:1 or 1.5:1. The sandstone is light grey to light bluish grey and fine-grained mostly subgraywacke or graywacke and partly protoquartzite. The shale is dark gray and is more prominent in the lower part. In northernmost Taiwan, one calcareous sandstone member of 50-60 m thick occurs in the middle of the Taliao Formation. This thick sandstone member often forms salient homoclinal ridges and invariably constitutes most of the headlands or promontories along the northern coast. Taliao Formation is divided into three members in geologic mapping. Both the upper and the lower members are composed of thick-bedded sandstone alternating with dark gray shale and silty shale yielding abundant marine fossils. The thickness of the Taliao Formation in northernmost Taiwan is 500-550 m.

2.5.1.2.2.5 Shihti Formation

This formation, more specifically consists of sandstones, siltstones, shale, and thin coal beds. The characteristic rock type is a lamination of sandstone, siltstone and shale represented by irregular bands of white silt or sand and dark gray shale ranging in thickness from a few millimeters to several centimeters. These interlaminated beds are distinctive of a coastal tidal-flat to lacustrine environment. The shale is dark gray or grayish black and often carbonaceous. It grades into claystone where the fissility disappears. The sandstone is mostly feldspathic, light gray to white, and fine-to medium-grained. Massive and thick white sandstone in the lower part of the formation often forms precipitous scarps and provide good lithologic markers. Coal beds and layers are abundant throughout the whole formation.

2.5.1.2.2.6 Volcanic Rocks and Detritus

About 5-10 km north of the site there are some volcanic detritus and igneous rock forming the so-called Chilung Volcano group. The igneous rock is mainly quartz andesite or dacite flows. Ore-forming fluids accompanying the dacite intrusions have deposited valuable gold and copper ores in the host rocks which were the famous gold and copper production in the northern Taiwan. Tuffaceous material and some pyroclastic rock are distributed around the sloping area of Chimuling. According to the recent study, the age of volcanism is about 900,000 years.

2.5.1.2.2.7 Recent Sediments

Terraces and alluvial deposits and some sand dune are exposed along the river banks and coast area. They are mainly gravel, sand, silt, and clay.

2.5.1.2.3 Geologic Structure

The geologic structure of the site area is rather complicated. There are many horizontal and plunging anticlines and synclines and a great number of faults and folds that strike NEE to EW or NW to NS. The structural evolution of this complicated expression can be outlined briefly as follows: During early Oligocene, the area was under a stage of regression. From Oligocene to early Miocene it was invaded by a transgression. Later in early Miocene there occurred a broad regression, forming a paralic deposit of great areal extent (the Mushan and the Aoti Formations).

During Miocene time, the Foothills underwent three complete cycles of regression and succeeding transgression. The Hsuehshan Range terrain, however, began to rise, with the Chuchih fault as its front or leading edge. Since the Plio-Pleistocene, the Philippine Sea Plate began to move northwestward and collided with the Eurasian Plate. This is also the collision of the Ryukyu Arc with the Asian Continental margin. The collision resulted in the subduction of the Philippine Sea Plate underneath the Eurasian Plate along a Benioff zone that dips approximately 50 degrees to the north. Because of this strong plate to plate convergence, the very thick pile of sedimentary formations were folded and faulted. Meanwhile, magma resulting from partial melting of the subducted oceanic plate welled up and formed the Chilung Volcano group. Thus the Chilung Volcanoes represent the product of arc magmatism; hydrothermal solutions derived from differentiation of magma contributed to the famous gold and copper deposits in the Chinkuashih area.

2.5.1.2.3.1 Folds

The most prominent fold within 8 km of the site is the Yintzulai syncline. This regional structure extends for tens of km in northeast Taiwan and has been described in Reference 2.5-54, and later in Reference 2.5-21, and many others.

The Wentzkeng anticline is in the south of Lungtung trending in NE-SW direction. The extension of the fold axis is truncated by an unnamed local fault. The Yintzulai syncline axis is in the southern part south of the Shuang-Chi River and Chuchih fault. The axis has a variable trend between east-west and northeast-southwest directions. The plunge of the fold likewise varies but is generally to the east. West of Kungliao, the north limb of the syncline is very steep with dips on the order of 40 to 70 degrees, while the south limb is fairly flat with dips varying from 0 to 20 degrees.

2.5.1.2.3.2 Faults

The Yenliao site area is characterized by the development of a series of imbricate thrust faults (Figure 2.5-8). Many faults exist in the region and most of the important ones trend generally northeast to east. Most of these faults, developed during the Penglai orogenic event which reached its peak in late Pliocene to early Pleistocene time (Reference 2.5-20). A number of important faults, particularly for those faults within 8 km of the site, namely Chuchih fault, Aoti fault, Shuangchi fault, Kungliao fault, Fangchiao fault, Wentzkeng fault and other small faults, have been mapped by previous workers in the area of Yenliao site and confirmed by the surface mapping during the site investigations. An intensive and thorough investigation conducted by geologists from Pacific Engineers and Constructors, Ltd., with special assistance from geologists of Taiwan Power Company has been satisfactorily completed. Techniques employed for the fault studies included field mapping, seismic refraction, core drilling, remote sensing, age dating, petrographic analysis, excavation of exploratory trenches and adits. For more detailed discussion, please refer to the Site Selection Report (Reference 2.5-2).

In 1994, the study conducted by Geological Society of China concluded that those faults occurred probably at the outset of Pleistocene. They are so well constrained in terms of age that these faults have either been non-active since 0.9 MA or since at least 45,000 Y.B.P.(Reference 2.5-7).

Some important faults that are significant to the siting of the plant and safety of the structures will be described further in Section 2.5.3.

2.5.1.2.4 Geologic History of the Site Area

Sometime in the late Mesozoic, the Yenshanian orogeny on mainland China indurated, distorted, and uplifted a thick sequence of sediments resting in the epicontinental sea. These rocks would later become what we now refer to as the pre-Tertiary basement complex. After repeated transgressions and regressions of the sea, with subsequent deposition/erosion cycles, the uneven basement began to subside and take on sediments. The first of these may have been deposited in the Paleocene. but certainly no later than early Eocene. These sediments consisted of fine-grained sand and silt with occasional intercalation of shale. The silt was the dominant type during the mid-to-late Oligocene Epoch, and this was to become slightly metamorphosed sometime during a mid-Tertiary orogenic pulse and would later be known as the argillite slate series over much of eastern Taiwan. In the site study area these rocks are identified as the Tatungshan Formation.

After late Oligocene, deposition continued apparently without interruption, but the source rocks or area changed, as evidenced by the shifting from silt as the dominant sediment type to fine-and medium-grained sand. This shift in provenance probably began in later Oligocene, or possibly in early Miocene. Deposition almost certainly continued into the Miocene; hence these rocks are referred to as "Miocene sandstone" to distinguish them from the older Tatungshan rocks. These sediments are now known in the site area as the Nankang-Wuchishan correlative units and are overlain by the Fangchiao-Mushan correlative units. Some workers have suggested that a hiatus may have occurred between these two units, but this study could not contribute substantiating evidence.

The first proven Miocene rocks are represented in the site area by the Taliao Formation and by a very small amount of overlying Shihti Formation Deposition of these rocks continued in other parts of the western geosynclinal basin , but on its eastern border, deep tectonic forces were already at work and would eventually lift the sedimentary layers out of the sea, thrust them one onto the other and create the island province of Taiwan. These forces were brought about as the Philippine Sea plate collided a northwesterly direction with the Asian Continental plate. This occurred in post-Miocene time and continued into the Pleistocene. Volcanism accompanied this collision and the northern part of the site area is now strewn with volcanic debris large volcanic rock boulders and other detritus. A chonolith was emplaced just outside the study area. This intrusive body is very likely the source for the volcanic debris.

Between the latter part of the Oligocene (after deposition of the Tatungshan) and the middle part of the Miocene, sea level fluctuated several times. This is first indicated by the different lithologic character and reduction in the number of fossils in the Nankang-Wuchishan rocks. Quite likely the seacoast was emerging slowly and the emergence continued until the Fangchiao-Mushan depositions were nearly complete. At this time the coast was most likely a wide-spread tidal flat in which moderate quantities of vegetation were accumulating to later become the carbonaceous shale and coal beds of the Mushan Formation. The coast then slowly submerged and again marine life proliferated while sediments continued to be deposited on top of the Mushan unit, forming the Taliao Formation. Another cycle of coastal emergence again created a shallow water environment conducive to growth and ultimate coalification of large quantities of vegetation. These formed the several coal beds of the Shihti Formation.

There were undoubtedly numerous minor transgressions and regressions within the major pulses described above. These would account for the sandstone and siltstone interbeds which separate the many coal beds. Whether these were eustatic changes or tectonically induced is not clear, but it seems reasonable to assume that both processes were at work, sometimes jointly and sometimes independently throughout the whole Cenozonic Era.

After the final uplift exposed the rocks to the elements, mass wasting began and continues today. These have left the consolidated rocks capped with a veneer of laterized soil, alluvium, colluvium, terrace deposits, dune sands, and volcanic debris.

2.5.1.2.5 Site Groundwater

During phase I and phase II exploration, groundwater conditions have been carefully and thoroughly studied by the monitoring program implemented at the site. The program currently consists of a total of 12 domestic wells plus 37 additional wells that were converted to observation wells from exploration borings or installed specifically for groundwater measurements. Table 2.5-4 lists all wells for the program and Table 2.5-5 lists their average monthly groundwater levels for the period August 1980 through July 1982. The wells are identified by number and by letter prefix plus a number. The prefix "A" designates domestic wells, the prefix "B" designates wells installed by the TPC Hydrology Department, the prefix "PB" designates phase II exploration borings that were converted to observation wells, and the numbered wells without a letter prefix designate exploration borings that were converted to observation wells during phase I or earlier investigations.

Two of the wells (25 and 42) were abandoned in 1981 and are no longer included in the program. Locations of all wells around the site area are shown on Figure 2.5-10, and within the Units 1 and 2 Power Block are shown on Figure 2.5-12.

Data accumulated during the past two years show that ground water is present at the site under water table conditions. Contour map of the water table have been compiled (Figure 2.5-13) and indicate that the ground water flows generally eastward (i.e., seaward) under an average hydraulic gradient of approximately 0.03. The gradient is somewhat steeper in the western part of the site where surface elevations are highest, but it progressively flattens to the east where surface elevations level out.

The water table aquifer is mad up almost entirely of the unconsolidated overburden sediments. A portion of the water is stored in the partially decomposed weathered zone of the bedrock and in the joints and partings of bedrock itself. The thickness of the overburden and weathered rock has been plotted as isopach maps, Figures 2.5-14 through 2.5-17.

Recharge to the aquifer is primarily by direct infiltration of precipitation. A secondary source of recharge is from the small perennial stream which traverses the Power Block area between Units 1 and 2. The stream appears to be influent along the western part of its course but changes to effluent at least along a portion of its course near the east end of the Unit 1 Turbine building. This is indicated by well number 28 where an anomalously low reading suggests that the stream is being fed from the water table, forming a small-scale groundwater sink.

Since Yenliao is primarily a bedrock site, the permeable overburden material, will be removed, no pump testing has been performed to determine transmissivities or storage coefficients in the water table aquifer. However, as part of an effort to assess the potential for groundwater problems that might occur during construction, a total of 156 permeability tests were performed in the bedrock materials in selected core holes during the phase II coring operations. The method of testing was based on the single-packer test procedures delineated in the U.S. Department of Interior Bureau of Reclamation Earth Manual, Designation E-18. Results of the packer tests Show that the permeability of the bedrock site underlying Units 1 and 2 is in the range of 10-4 to 10-7 cm/sec. most commonly encountered values were 10-5 and 10-6 cm/s. This ability of the bedrock to transmit water is attributed entirely to the presence of joints, shears, shear-related fractures, and bedding cleavage. All intact rock units at Yenliao in condition are considered to be essentially impermeable.

Also as an effort to identify potential groundwater problems during construction, seasonal fluctuations of groundwater levels in the water table aquifer were studied as part of the phase II program. Average monthly groundwater levels in selected wells for the period August 1980 through July 1982 were plotted on hydrographs, along with average monthly rainfall levels for the same time period. These data are summarized in Table 2.5-5. The hydrographs show that rainfall at the site generally corresponds to the regional patterns of fairly low precipitation in the hottest part of the summer (July and August) and highest precipitation in or near the month of November. From November to January, there is a gradual drop-off, followed by a moderate increase up to the summer months.

Several of the observation wells show groundwater levels that change in almost direct correspondence with rainfall. This is normally indicative of rapid infiltration and is also usually a sign of high permeability of the surface materials. However, caution should be exercised when applying this interpretation to the Yenliao site. Until recently, a large portion of the site area was used for agriculture, primarily rice growing, and the flat paddies and the levees that enclose them tend to artificially enhance infiltration conditions and impede normal run-off. During the past year, the land has been acquired by TPC and the agriculture activity has greatly decreased. Much of the rice paddy area is now covered with uncultivated vegetation and substantial numbers of the paddy levees have been demolished by equipment movement and erosion. As a result, infiltration and run-off relations are reverting to more pristine conditions, which entails higher run-off and less infiltration. This change in surface conditions is probably the reason that some of the observation well water levels shown on the hydrographs appear to respond to rainfall less conspicuously form the latter part of 1981 onward. Quantitative evaluations for infiltration and run-off were not considered essential for the phase II program, hence none were made. Qualitatively, the Power Block area may be described as an area in which surface conditions are in a state of change which will result in higher run-off and less infiltration and slower changes in groundwater levels than in the recent past.

Water quality tests were conducted on numerous samples from observation wells, domestic wells, nearby streams and rivers, and from the sea. The testing was conducted by the TPC Electrical Research

Department and the results are summarized in Table 2.5-6. In general, the groundwater samples showed no unusual characteristics nor chemical constituents which would require special consideration in construction or design of structures. The groundwater can be generally characterized as a calcium-magnesium-bicarbonate-type water. Iron content appeared to be somewhat high in the observation well samples, and this may be of some concern in placing metal pipes or conduits outside the Power Block area. All samples were slightly alkaline, ranging in pH from 7.0 to 8.2. Seven coliform tests were performed for one domestic well and showed positive for six of the seven tests.

More detailed appraisal of the groundwater at this site is discussed in Section 2.4.12.

2.5.2 Vibratory Ground Motion

The seismologic and geologic investigations carried out to establish the accelerations for the Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE) are documented in the Bechtel Report, "Fourth Nuclear Power Plant, Reevaluation of PSAR Section 2.5.2," prepared for Taiwan Power Company in October 1992 (Reference 2.5.59). The specific areas of review in this report include Seismicity (Subsection 2.5.2.1), Geologic and tectonic characteristics of the site and region (Subsection 2.5.2.2), Correlation of earthquake activity with geologic structure and tectonic provinces (Subsection 2.5.2.3), Maximum earthquake potential (Subsection 2.5.2.4), Seismic wave transmission characteristics of the site (Subsection 2.5.2.5), Safe shutdown earthquake (Subsection 2.5.2.6), and Operating basis earthquake (Subsection 2.5.2.7).

The report summarizes the investigations of the suitability of the Yenliao site for construction of Lungmen NPS using data from 1966 to 1986 and has recommended 0.4 g acceleration for SSE and 0.2 g acceleration for OBE seismic design.

"Electricity Generating Plan for No. 4 Nuclear Power Plant 1 & 2 Units - Evaluation Report on Environmental Influence," November 1991, Taiwan Power Company, Section 2.5.5 (Reference 2.5.57) also concludes that 0.4 g SSE and 0.2 g OBE acceleration for seismic design are acceptable for Lungmen NPS under ROC-AEC regulations.

2.5.3 Surface Faulting

Several major faults exist within a 5 km radius of the Yenliao site. During the Site Selection Study of 1979, the site investigating team recognized and mapped these faults both from newly acquired field data and from the work of previous investigators. These structures carry the unofficial names of Aoti-Shuangchi, Chuchih, Fangchiao, and Kungliao faults. Of those named, the Chuchih fault is the most important from a structural standpoint because of the following:

(1) It is a tectonic boundary between the Paleogene submetamorphic belt of the Central Range Province and the Neogene sediments of the Western Foothills Province.

(2) It is a high-angle thrust fault whose trace has been postulated as traversing the entire length of the island.

Several references, including Reference 2.5-20, suggest that the Chuchih fault is continuous from northeastern Taiwan to the southernmost tip. It has also been suggested by some workers that the Chuchih fault may be active within the context of USNRC definition. Extreme topographic relief, dense vegetation, and inaccessibility have prevented detailed mapping of the Chuchih fault trace in several regions of central Taiwan; hence, the continuity of the trace has not been firmly established. Nevertheless, since the postulated trace traverses a region within a few kilometers of the site, special attention was given to the age-dating, location, and general structure of this and other known faults in the area.

The entire Kungliao fault study of the Yenliao site is discussed in References 2.5-15 and 2.5-21. Further study conducted by the Geological Society of China (1994) confirmed that those faults within 5 miles (8 km) of the site and some sheared zones or disturbed zones found at the site are inactive since 0.9MA or since at least 45,000 YBP.

2.5.3.1 Geologic Conditions of the Site

Geologic conditions of the site and its vicinity have been described in detail in Subsection 2.5.1.2. The geotechnical features and mechanical properties of the foundation material for the plant structure are discussed further in Subsection 2.5.4.

Shears ranging in thickness from a few centimeters to several meters were encountered in the majority of the Phase II core holes. Most of these zones are either localized, i.e. restricted to a very limited area, or they are at depths substantially below structure base levels and hence have no influence on the foundation properties. A few of these zones, however, appear to be relatively near the ground surface and of such thickness as to merit attention and caution. Geologic section A-A' (Figure 2.5.18) shows a generalized concept of the potential for projecting several shear zones to the top surface of bedrock. These projections are interpretive and cannot be established with a high degree of accuracy with available data, although several of these shears appear to be confirmed by the presence of low velocity zones indicated by the seismic refraction survey.

As pointed out in previous section, the sedimentary rock layers along the east coast of Taiwan have been tilted and compressed by large scale tectonic forces. The rock sequence at Yenliao has been subjected to the same regional stresses common to eastern Taiwan. This combination of uplift and crustal shortening has, in many areas, caused beds to glide over each other in response to the shear stresses brought on by the uplift-compressive mechanism. In areas where such gliding has occurred, the frictional forces along the glide planes have produced a crushing, grinding action which has altered to one degree or another the structure, texture, and crystallography of the original rock. Such zones are generally referred to as shears or shear zones and are characterized by the presence of intense fracturing of the original rock, in-place crushing of the original rock, the development of slip surfaces, or some combination of these features.

Crushing and fracturing can occur at some distance away from the actual plane of movement, but the other features occur on or very near the glide plane. All studies show no evidence that these shear zones are capable faults. Discuss evidence.

The presence of the shears at Yenliao is not expected to pose a major problem with the foundation materials. Some treatment of these shears may be required, but such treatment is well within current foundation technology and is not expected to be extensive. It is believed that surface faulting considerations are not required in plant design.

Two shafts were excavated in the vicinity of the Unit 1 and Unit 2 containment area. The bedrock portion of each shaft was logged on a scale of 10:1 for description of geologic condition of the site; logs are shown on Figure 2.5-19 and Figure 2.5-20.

2.5.3.2 Evidence of Fault Offset

Detailed and intensive fault investigations were carried out in the site area. No evidence of fault offset at or near the ground surface was discovered. As mentioned in Section 2.5.3, some minor shears ranging in thickness from a few centimeters to some several meters were found in the core holes. They are mostly localized and are at depths far below structure base levels.

Shear zones in the foundation rock reduce the quality of the foundation locally but are not expected to pose major problems for design or construction. To minimize differential settlements due to soft material in shear zones, foundation dental work may be required where appropriate. There is no evidence that these shear zones are capable faults.

2.5.3.3 Earthquakes Associated With Capable Faults

A detailed discussion of seismicity and seismotectonics of Taiwan is undertaken in Subsection 2.5.2. As mentioned previously, there is no capable fault at or near the site area.

All known earthquake events located within 8 km of the Yenliao site are shown on Figure 2.5-21 and are listed in Table 2.5-7. There are no linear features indicated by the epicenters that might suggest active faulting near the site. It is concluded that there are no earthquakes associated with capable faults.

2.5.3.4 Investigation of Capable Faults

As discussed in Subsection 2.5.1, some important faults have been mapped by previous workers in the area of Yenliao site. An initial phase of the study consisted of 5 months of field work to collect as much surface and subsurface data as possible early in 1979. Additional field work and further studies by means of field mapping, core logging, trenching, aditting, remote sensing, age-dating, and petrographic analysis were conducted in May-June 1981 (Reference 2.5-21). More detailed discussion supporting this conclusion is reported on the following Subsection 2.5.3.8. Summarize conclusions.

2.5.3.5 Correlation of Epicenters with Capable Faults

Detailed geologic investigations of faults in the site area (Reference 2.5-21), have not identified any capable faults within 8 km of Yenliao. Section 2.5.3 and Section 2.5.3.8 present the results of these investigations. As discussed in Section 2.5.2 and 2.5.3.3 there is no apparent alignment of earthquake epicenters along mapped faults; however, due to the complex structural relationships in the area, the subject requires additional study.

2.5.3.6 Description of Capable Faults

Previous detailed investigations in the site area have not identified any capable faults within 5 miles of the Yenliao site. See Section 2.5.3.8 and Reference 2.5-21.

2.5.3.7 Zone Requiring Detailed Faulting Investigation

As mentioned in Section 2.5.3, northeastern Taiwan is characterized by the development of an imbricate thrust belt. The early phase of faults study consisted of 5 months of field work to gather as much surface and subsurface data as possible. Following this effort, additional field work at the phase I site study was satisfactorily completed. The evaluations and overall conclusions are discussed in the following section.

2.5.3.8 Results of Faulting Investigation

Many important faults, namely Chuchih fault, Aoti and Shuangchi faults, Kungliao fault, Fangchiao fault, Wentzukeng fault, and some other smaller faults exposed near the site area, were carefully studied (References 2.5-15 and 2.5-21). The evidence and their significance are discussed in the following subsections.

2.5.3.8.1 Chuchih Fault

The Chuchih fault is considered by most Taiwan geologists to be the most important fault in northeast Taiwan. It forms the tectonic boundary between the Paleogene submetamorphic belt of the Hsueshan Range and the Neogene sediments of the western foothills, two major geologic provinces. The Chuchih fault is a high-angle thrust fault with a surface trace extending for many kilometers.

It has been postulated to connect with other similar high-angle thrusts further to the south, forming a more or less continuous tectonic break which runs the length of the island (Reference 2.5-20). It should be pointed out, however, that geologic mapping in the central part of Taiwan is not detailed in many areas due to the extreme topographic relief and inaccessibility of these areas. Therefore, the postulated continuity of the Chuchih fault is tenuous in many places. The official geologic map of Taiwan compiled by Ho (Reference 2.5-20) shows a complicated system of intertwining fault traces south and west to the Yenliao area, and it is difficult to tell which of these is intended to represent the Chuchih fault. If the Chuchih fault is defined as the tectonic boundary between Paleogene and Neogene rocks, then it clearly cannot be a single continuous discrete fault, but must be a complicated system of different faults.

In the Yenliao area the Chuchih fault borders the valley of the Shuangchi River along the south side. It has an east-west trace which bends to the southwest several kilometers west of the study area. The surface trace of the fault can be seen on air photos but is difficult to see from the ground. Within the study area the Chuchih fault is nowhere exposed in outcrop due to dense vegetation, deep weathering, and alluvial cover. A program of trenching was carried out during the Site Selection program and the existence of the fault was confirmed by trench (No. 7) west of Kungliao. Trench No.7 encountered an extensive shear zone coincident with the trace of the fault seen on air photos.

Neither the dip of the fault nor the magnitude of displacement has been determined in the field, but the relative straightness of the surface trace suggests a high angle of dip, and the formational relationships on opposite sides of the fault indicate that a substantial amount of displacement has occurred. The rocks south of the fault have been moved up relative to those on the north so that Oligocene Tatungshan Formation lies above younger Miocene rocks. It is worthy to note that recent paleontologic studies in northern Taiwan conducted by Professor Y. M. Cheng and Mr. C. Y. Huang (Huang, personal communication) have resulted in the conclusion that the Tatungshan and Mushan Formations are not as far apart in age as previously thought. The magnitude of displacement on the Chuchih fault may not, therefore, be as great as has been generally assumed in past.

2.5.3.8.2 Aoti and Shuangchi Faults

The Aoti and Shuangchi faults will be discussed together since their traces are virtually coincidental and most workers have considered them to be a single fault. The existence of a fault at Aoti has been a controversial subject in the past. In order to resolve the issue of the Aoti fault, a number of different avenues of investigation were pursued. These included a paleontological study, special offshore geophysical studies, trenching, excavating an adit, and the drilling of an angle core hole.

While the adit excavation was in progress, offshore seismic reflection profiles were run to determine whether a fault structure in the rock extended seaward from Aoti harbor. The geophysical data indicated the presence of a channel in the rock surface projecting offshore from Aoti harbor. A fault in the rock could not be clearly seen but the coincidence of a channel at this location certainly added to the probability of a fault existing in the rock (References 2.5-57 and 2.5-6 of Section 2.5.1).

Professor Y. M. Cheng and Mr. C. Y. Huang of National Taiwan University studied both macro- and microfossils from the rocks along the coast, both to the north and south of Aoti harbor. The results of their detailed study conclusively showed that the rocks north of Aoti are geologically younger than those south of Aoti. Since the rocks dip to the south, this structural evidence requires the existence of a fault contact at Aoti harbor. Finally, the exploratory adit, excavated beneath the topographic saddle west of Aoti, penetrated the fault and confirmed its existence. An angle core hole, drilled near the adit location, also penetrated the fault and provided another point with which to establish the trend of the fault.

Further to the west, the Shuangchi fault, like the Aoti fault, cannot be seen in surface outcrops. West of Shuangchi there is evidence of faulting exposed in road cuts but the precise nature of this faulting is not clear. The primary evidence for the Shuangchi fault includes stratigraphic relationships and a strong linear expression on air photos. The linearity noted on the photos suggests that this fault has a relatively high angle of dip near the surface, which would be different from that of the Aoti fault. The sense of movement is the same as the Aoti fault; i.e., the south side is upthrown. West of the study area, the Aoti-Shuangchi fault(s) are shown on published geologic maps as being terminated by the Chuchih fault (for example, see Reference 2.5-15).

The principal reason for differentiating the Shuangchi and Aoti faults involves the interpretation of the inferred kungliao fault (to be discussed next). The question of whether the Aoti and Shuangchi faults are the same fault or different faults is not significant to assessment of the Yenliao site as either interpretation leads to the conclusion that the fault(s) is not a capable fault according to USNRC guidelines.

2.5.3.8.3 Kungliao Fault

During the site selection study the Kungliao fault was mapped as an arcuate, concave-seaward structure extending from Kungliao northwestward to the Aoti fault. It was a structurally-inferred fault for which no physical evidence was found in surface exposures. There was circumstantial evidence to support its existence, but the Kungliao Area Fault Study did not provide corroborating evidence. However, the study did not alter the original conclusion. The lack of physical evidence for this fault, the absence of air photo and satellite imagery expression all indicate that if it exists, the Kungliao fault is certainly not a major active fault and hence is not significant to the siting of the plant. What is of interest, however, is the role which the Kungliao fault might play in terminating the Chuchih fault and thereby helping to date known structures in the area.

2.5.3.8.4 Fangchiao Fault

The Fangchiao fault trends in a northeast direction, passing beneath the town of Kungliao and projecting offshore. It shows up as a strong linear trend on satellite imagery and air photos. Field evidence for the fault includes topographic expression, disturbed bedding, stratigraphic relationships on either side of the fault, and core hole data retrieved during the Kungliao fault study.

The Fangchiao fault first appeared on Yen's map (Reference 2.5-54), and subsequently on others (References 2.5-55 and 2.5-19), and has been mapped by the Central Geological Survey (Reference 2.5-56). The fault apparently has a high dip angle as evidenced by the straightness of its surface trace. It has components of both left lateral and vertical displacement with lateral displacement of the north-dipping axis of the Yingtzulai syncline. This apparent contradiction is solved by introducing vertical displacement along the fault.

2.5.3.8.5 Wentzukeng Fault

The Wentzukeng fault is about five kilometers north of Yenliao site. It is exposed along the shoreline as a fairly wide zone of highly disturbed rock. Some evidence of rock disturbance offshore in this area appears on the geophysical records. Inland from the coast the fault is covered by old volcanic detritus and its precise nature and location are not known. There is no evidence on satellite imagery or air photos for recent movement on the fault.

The Wentzukeng fault is not a capable fault by USNRC guidelines and is not significant to the siting of a nuclear power plant.

2.5.3.8.6 Other Faults

There are numerous other smaller faults throughout the area. Many of these are very old and are basically intraformational, having rocks of the same age on either side. Where these faults intersect the more important faults, they are invariably terminated. Many of these smaller faults are inferred, and their locations are uncertain. None of them is significant to the siting of the plant.

2.5.3.8.7 Summary of Fault Studies

The intensive studies of these faults mentioned above including vertical and angle bore holes, trenches, field mapping, petrographic analysis, remote sensing, and carbon-14 age dating, have been performed in the site investigation. The main objectives of these studies are:

(1) Define the truncation hierarchy of the Fangchiao, Chuchih, and Kungliao faults to determine which of these is the youngest fault.

(2) Determine whether terrace deposits in the area overline the youngest fault.

(3) Age-date the terrace deposits.

(4) Determine whether the terrace deposits have been disturbed by faulting, thereby establishing an upper limit on the age of last movement of the faults in the area.

All of these objectives were satisfactorily accomplished. The truncation hierarchy of the Fangchiao, Chuchih, and "Kungliao" faults was more clearly defined, although the "Kungliao" fault may not exist as it was originally mapped.

Taiwan geologists as well as the site selection investigators, via structural inference, mapped the Kungliao fault as an arcuate, north-trending fault that is truncated by the Aoti fault to the north and the Fangchiao fault to the south. The fault study program produced no data to confirm the existence of this arcuate trace as previously mapped. The program did, however, confirm the existence of a fault in the small valley behind the Kungliao Grammar School. This fault was designated as fault "K" for reference purposes. Fault "K" truncates the Chuchih fault (or a splay from the Chuchih), and hence demonstrates that the Chuchih is not the youngest fault in the area (see Figure 2.5-22).

The exact trace of fault "K" could not be determined with the data produced by this program. However, the fault necessarily must trend to the south or southeast and in so doing is itself truncated by the Fangchiao fault. The fangchiao fault truncates the "K" fault which in turn truncates either the main trace or a splay of the Chuchih fault. Besides truncating the "K" fault, the Fangchiao fault beneath the alluvium of the Shuangchi River Valley in the vicinity of Kungliao. The Fangchiao fault is, therefore, convincingly established as the youngest fault in the area (see Figure 2.5-22). Because the Aoti-Shuangchi fault(s) is truncated by the Chuchih fault west of the study area, this fault is also tied into the fault-age network and is shown to be older than the Fangchiao fault.

The results of drilling and trenching established clearly that the Fangchiao fault passes beneath terrace deposits in the saddle area northeast of Kungliao. The effort to age date the terrace deposits was successful in that a deposit of black carbonaceous material was found in these deposits a short distance east of Kungliao Grammar School. Two samples of this material were dated by Carbon-14 age-dating processes. One sample was found to be approximately 30,000 years old. The second sample showed no C-14 activity, suggesting an age greater than C-14 limits of 37,000 years. This age generally supports the estimate of 100,000 years old for the terrace, proposed by Mr. T. L. Hsu of the Central Geological Survey (oral communication-1979).

Some trenches (9 and 11) demonstrated that the terrace and colluvial deposits overlying the Fangchiao fault are undisturbed by faulting and are therefore younger than the age of last movement on this fault. The last movement on the Fangchiao fault, the youngest fault in the area, is therefore older than 30,000 years and possibly older than 100,000 years.

In summary, the data produced by the fault studies is adequate to state with a high level of confidence that there are no capable faults in the vicinity of Yenliao.

2.5.4 Stability of Subsurface Materials and Foundations

Subsection 2.5.1 provides specific investigation pertinent to engineering properties of the foundation material at the Lungmen NPS site located at Yenliao. The exploration task, purpose, quantities, and results are shown in Tables 2.5-1, 2.5-2, 2.5-8, 2.5-9, and 2.5-10. The exploration program mostly confined to the Lungmen NPS power block area included drill holes, seismic survey, exploratory shaft for in-situ plate load test, laboratory testing, groundwater studies, petrographic studies, and paleontological studies. The results of the investigation and data analysis are compiled in reports entitled, ”Report of Foundation Conditions for Yenliao Nuclear Unit 1 and 2 , Volume I, II, III, June, 1983” and “Recommended Foundation Design Parameters for Yenliao Nuclear Unit 1 and 2, June 1983,” References 2.5-6 and 2.5-58, respectively. Recently the subject was revised as shown in Reference 2.5-7.

2.5.4.1 Geologic Features

Geologic features of the Lungmen NPS site including geologic structure and history are discussed in Subsection 2.5.1. The important faults within 8 km radius of Lungmen NPS site are Chuchih fault, Aoti fault, Shuangchi fault, Kungliao fault, and Fangchiao fault which truncates the “K” fault. Chuchih fault is considered by most geologists as the most important fault in northeast Taiwan (Figure 2.5-25). Fangchiao fault is the youngest fault in the area but is older than 30,000 years and therefore, is not a capable fault according to USNRC guidelines (Reference 2.5-3). Surface faulting at Lungmen NPS site is discussed in Subsection 2.5.3.

The Lungmen NPS site is situated in an area of gentle undulating hills and terraced rice fields, covering approximately 200 hectares or 2 sq km (Figure 2.5-24). The Lungmen NPS power block area is located in the southern portion of the site, and occupies about 182,400 sq m. The center of the power block is about 600 m from the shore line. The ground surface in the power block area varies slightly in elevation averaging about 12 m above mean sea level. The power block area is traversed by a small stream which flows to the ocean. Its present course will be altered during construction. The coast line is gentle and concave to the west. It is characterized by rocky outcrops of siltstone and sandstone, and sandy beaches.

An intensive investigation program for the specific foundation design parameters has been performed and is reported in "Geological Re-Examination and Re-Appraisal of the site and Adjacent Area of Atomic Power Plant No. 4, Summary Report," by Geological Society of China, January 1994 (Reference 2.5-7) and "Electricity Generating Plan of No. 4 Nuclear Power Plant 1 & 2 Units, - Evaluation Report of Environmental Influence, Revised Version," (English translation) by Taiwan Electric Power Co. (Reference 2.5-57). A thorough and valuable information of the site geology and foundation condition obtained from field and laboratory studies is included in these reports. These reports have re-affirmed the suitability of Yenliao site for Lungmen NPS. No evidence of subsidence has been found. The amount of unrelieved residual stress was also found insignificant based upon the results of creep loading and unloading tests discussed in report of foundation condition (References 2.5-6 and 2.5-58). The geological loading history, zones of structural weakness and joint patterns have been thoroughly reviewed in the three reports cited above. The foundations of Lungmen NPS Category I structures shall be laid on sound rock. The water table is found to be very high and as such the rocks are saturated and dewatering is required during construction and during plant operation (Reference 2.5-5, Vol. I). However, the rock strata at Lungmen NPS site has not been found hazardous or unstable (Reference 2.5-5, Vol. I). The site rocks meet the stability criteria of SRP Section 3.5.4.

2.5.4.2 Properties of Subsurface Materials

2.5.4.2.1 Soil Types

Soil in the area can be divided into plain soil, shore sands, and hill soil which has the largest quantity. Plain soil, composed of alluvium, whose host rock includes clay slate, sandstone, and shale, is mainly found in Shangchi valley, which is very narrow. Hill soil, which is acidic, includes red brown loam, yellow brown loam, yellow gray loam, and stony soil of yellow brown and yellow gray colors (refer to Table 2.5-6 for one of the drill hole logs). Shore sands are found along the coast and were formed during the quaternary period from sandstone.

2.5.4.2.2 Rock Strata

The rocks at the plant site belong to Tatungshan strata and Wuchishan strata (Reference 2.5-5). According to drilling results, the rock wall is made up of siltstone, sandstone, and well cemented shale. The mineral components are quartz, clay, and calcite, mixed with small quantities of mica, feldspar, pyrite and microlimestone. The rocks have high compressive strength. The change in seismic wave velocity indicates joints and cleavages in the rocks.

2.5.4.2.3 Discussion of Underlying Material

Except in outcrop areas, the Lungmen NPS site is covered by a veneer of unconsolidated sediments ranging in thickness from 1 to 7 m (Figure 2.5-14). The overburden consists primarily of clayey silt and sand with minor amounts of gravel, pebbles, and cobbles. The sands include recent fluvial deposits and older beach sands. The presence of beach sands is one of several pieces of evidence which suggest that the east coast of Taiwan is an emergent coastline of fairly recent geologic time.

Most of the site area has undergone agricultural activity for an indeterminate period, and other areas are covered with various species of grasses and shrubs. As a result of the abundant vegetation, the upper 1/2 to 1 m of overburden contains significant quantities of organic matter in various stages of decomposition. This zone of organic soil is generally referred to as the “A” horizon and is usually found to be unsuitable as either a foundation material for large structures or as backfill material.

The “B” horizon is the soil zone between the “A” horizon and the bedrock (refer to Figure 2.5-15 for contour map of overburden/bedrock contact). It consists mainly of clay, silt, and sand that has been enriched by aluminum and iron leached from the overlying materials. The leaching process has imparted to the material a moderately variegated color pattern consisting of several hues of red, brown, and yellow. No laboratory or field testing was performed on this or any of the overburden material, but field observations in trenches, shafts, and core samples indicate that the density of this horizon is relatively low. This factor, along with the presence of cobbles and a few boulders, makes its use as a backfill or founding material questionable. Further, the “B” horizon is entirely saturated by ground water, which introduces a potential for liquefaction and hydrostatic stresses unless adequately drained. Therefore, all Lungmen NPS power block structures will be founded on the bedrock and not on the soils of the “B” horizon.

The uppermost horizons of bedrock at the site have been subjected to weathering processes throughout much of their geologic past. As a result, a thin layer of weak, partially decomposed rock has developed between the “B” horizon and fresh, competent bedrock. This zone is usually referred to as the “C” horizon and its thickness at the site varies between 0 and 6 m. Figure 2.5-16 illustrates the thickness of this zone.

The strength, particularly the bearing capacity, of the rock in the “C” horizon varies considerably, usually as a function of weathering intensity. The geologic logs record weathering intensity at the site on an arbitrary scale of 0 to 5, with w-0 assigned to fresh, unweathered rocks and w-5 assigned to rocks that have undergone complete alteration to soil or to soil-like condition. W-1 is generally assigned to rocks that have undergone “slight” weathering, a condition frequently characterized by nothing more than the presence of iron-oxide stains. Rocks in the w-1 category have usually not lost a significant amount of their bearing capacity and as such are probably suitable in most cases for foundations for all permanent structures.

A great deal of judgment is involved in selecting the w-2,w-3,w-4, and to some extent, w-5 categories establishing the weathering intensity of rocks. This classification is not a reliable index of rock strength. Therefore, it is conservatively assumed that all rocks assigned to the w-2 through w-5 category have undergone at least a small amount of degradation (other than staining) and hence are unsuitable as a foundation for Lungmen NPS category I structures. Their suitability as a foundation for category II structures shall be assessed on a case-by-case basis during excavation and construction phase.

Figure 2.5-17 is a contour map of the base of the weathered rock. This map, as well as the isopach map (Figure 2.5-14) has been compiled primarily from the weathering codes listed on the geologic logs and essentially delineates the division between w-1 and w-2 rocks. The primary purpose of these maps, along with similar maps of the overburden, is to aid the planning of excavation procedures and requirements. In addition, the maps clearly indicate that weathering in the hills to the west of the Lungmen NPS power block is deeper and more intense than within the Lungmen NPS power block itself. The reason for this condition is attributed to the postulation that the lower elevations were submerged or partially submerged beneath the sea for a substantially longer period of time than were the higher elevations, thus allowing a longer time span for weathering processes to work in the higher elevations.

The significance of the deeper weathering in the hill area is that slope stability may be affected and precautions will be taken in planning the cut slopes.

Two geologic formations underlie the Lungmen NPS power block area. They are the Tatungshan formation of Oligo-Miocene age and the Wuchishan Formation of Miocene age (reference Subsection 2.5.4.2.2). The structure of these geologic units correspond to regional structures, which is characterized by a series of tilted sedimentary units that strike to the northeast and dip to the southeast. The contact between the two formations is situated between the two Units of Lungmen NPS (see Figure 2.5-24). This contact is conformable although there is evidence of bedding-plane shearing along it. The investigations have revealed no evidence of major structural features such as faulting or folding, but bedding plane shearing is commonplace.

The tilting of the two sedimentary units at Lungmen NPS site is of tectonic origin, generally accepted to be the result of compressive forces associated with the last major orogeny which occurred in late Pliocene - early Pleistocene time.

The dip of the rock formations at Lungmen NPS ranges between 30 and 35 degrees. The field data also suggests that there is a change in strike of the upper two-thirds of the stratigraphic section exposed at the site. The strike change is attributed to apparent rotational movement that occurred contemporaneously with the paroxysms that produced regional structure. The direction of rotation of the upper zones is counterclockwise with respect to the lower zone. The change in strike accounts for the illusory change in dip direction of the beds from Unit 1 to Unit 2, as shown on Section B-B' and C-C' (Figure 2.5-18). The two east-west sections are drawn along lines that approach perpendicularly to dip direction. Thus, the more northerly striking beds at Unit 1 show a mild dip to the east, while the more easterly striking beds at Unit 2 appear to be mildly dipping to the west. True dip of all the beds is, however, to the southeast.

Filled and unfilled joints are commonplace in the rocks throughout the Lungmen NPS site area. The strike of most joints trends to the northwest and dips are generally steep (60° to 80°) with respect to bedding planes. A substantial portion of joints are filled with clay, calcite, or quartz. Iron-oxide stains and pyrite are frequently found on joint faces. Conjugate joint sets were also detected in the core samples and in the containment shafts. Joint faces are dominantly planar, but uneven, rough, and arcuate forms were also encountered during the investigation. A feature sometimes referred to as “healed” joints was also detected in a few locations. This feature is characterized by a line demarking the contact of a joint or parting that has later fused or re-cemented, leaving a suture-like scar in place of the original contact. Joints parallel to bedding are also fairly common. These features may be joints but a portion are probably stress-induced cleavage fractures that occurred during the uplifting episodes that developed the existing structural patterns.

The Lungmen NPS power block area is underlain by two geologic formations. The younger of the two, the Miocene-Wuchishan formation, provides the bearing strata for Unit 1, while the older Oligo-Miocene Tatungshan formation provides the bearing strata for Unit 2. The surface contact between the two formations is obscured by soil and vegetation, but an inferred surface contact has been mapped and is shown on Figure 2.5-24.

The subsurface contact between the Wuchishan and Tatungshan formations is also not clearly defined, mainly because of the similarities in lithology. For descriptive purposes it may be assumed that the contact is the top of siltstone layer near the south wall of the Diesel Generator Building as shown on section A-A’ (Figure 2.5-18). On this basis, the stratigraphic thickness of the Wuchishan formation in the Lungmen NPS Power Block areas is up to 100 m while the thickness of the Tatungshan formation extends to depths well below the deepest core hole, and hence is not measurable. On a regional basis, the combined stratigraphic thickness of the two geologic units is several thousand meters, hence the Lungmen NPS site represents only a small fraction of the total.

The range of static and dynamic properties of the rocks are listed in Table 2.5-10. Modulus of Elasticity and Poisson’s ratio variation are shown in Table 2.5-12 for one of the sample core. Preliminary estimation of Elastic Modulus (E) from P-wave velocity (V_p) are shown in Table 2.5-13. Seismic refraction survey plots at Lungmen NPS site are shown in Reference 2.5-58.

2.5.4.2.4 Engineering Properties of Foundation Materials

Investigative results of engineering properties are included in various reports referenced in this section. References 2.5-5, 2.5-7 Appendix F, and 2.5-6 Volume III, list various engineering properties. The basic foundation criterion for Lungmen NPS plant is that all critical structures shall be founded on sound rock. The following values are used for design:

	Class A & B Back fill	Unit 1 Weathered Rock Material
Poisson's Ratio	0.40	0.32
Cohesion	0.00	5-12 kg/cm^2
Angle Internal Friction	40°	40°
Dry Unit Weight	2.0 t/m^3	2.19 t/m^3
Moist Unit Weight	2.08 t/m^3	2.32 t/m^3
Saturated Unit Weight	2.24 t/m^3	2.40 t/m^3
Buoyant Unit Weight	1.25 t/m^3	1.41 t/m^3
Static Young's Modulus	15,000 t/m^2	280,000 t/m^2
S-Wave Velocity	---	1040 m/s
P-Wave Velocity	---	2590 m/s

	Unit 1 Intact Rock	Unit 2 Intact Rock
Poisson's Ratio	0.39	0.38
Angle Internal Friction	58°	64°
Cohesion	17 kg/cm^2	36 kg/cm^2
Permeability	0.00002 cm/s	0.00002 cm/s
Static Young's Modulus	350,000 t/m^2	703,000 t/m^2
Dry Unit Weight	2.38 t/m^3	2.45 t/m^3
Moist Unit Weight	2.48 t/m^3	2.55 t/m^3
Saturated Unit Weight	2.56 t/m^3	2.63 t/m^3
Buoyant Unit Weight	1.57 t/m^3	1.63 t/m^3
S-Wave Vel. (low strain)	1220 m/s	1370 m/s
P-Wave Vel. (low strain)	2900 m/s	2900 m/s

The allowable bearing capacity for foundation design is indicated in Subsection 2.5.4.10.

2.5.4.3 Exploration

The field and laboratory work performed is listed in Tables 2.5-1 and 2.5-2 and provides the detailed information from which specific foundation design parameters have been developed (reference Figure 2.5-8). This is documented in Reference 2.5-57.

The drilled bore holes provided core sample for laboratory testing, geophysical seismic receiving holes and the installation of groundwater measurement. The log of a typical bore hole results is shown in Table 2.5-11.

The in-situ plate load tests were performed in the exploratory shafts (reference Figure 2.5-9). The bedrock portion of each shaft was logged.

Laboratory tests included checking of index properties, unit weight, moisture content, degree of saturation, static and dynamic elastic properties, confined and unconfined compressive strength, triaxial shear and sonic velocity. The test results are summarized in Table 2.5-10. Petrographic analysis results of the rocks are shown in Table 2.5-14.

The detailed discussion of testing procedures, and summaries of test results are included in the Report of Foundation Condition (Reference 2.5-6).

2.5.4.4 Geophysical Survey

Seismic surveys, including cross-hole, uphole, and surface refraction techniques for measuring P and S wave velocities, were conducted through containment building foundation area. A complete report of this seismic survey entitled, "Report on Seismic Refraction Survey Conducted at the Yenliao Site," by HCK Geophysical Company (Reference 2.5-60), is included as Appendix E in the "Report of Foundation Conditions for Yenliao Nuclear Unit 1 and 2, June 1983" (Reference 2.5-6).

2.5.4.5 Excavation and Backfill

Excavation at Lungmen NPS Unit 1 and 2 will involve both soil and bedrock removal in the power block area and the cutting and laying back of slopes in the hills along the western and southern perimeters of the power block. Backfill may be required in some area of overexcavation and topographic low spots.

Figure 2.5-10 shows the excavation plan for Nuclear Island of Lungmen NPS. The vertical cuts around buildings shall be supported by soldier piles and rock anchors as shown on Figure 2.5-10. Support of vertical face of rock is discussed in Subsection 2.5.4.5.1.2. The blasting of the rock shall be stopped within 2 m of the final finished cut surface to prevent damage to it. Blasting method shall be such that the peak material particle velocity shall not exceed 50 mm/s at any adjacent structure, or 125 mm/s at soldier piles location.

The following subsections will discuss both soil and rock excavation and the requirements of backfill.

2.5.4.5.1 Excavation and Protection of Construction Slopes

2.5.4.5.1.1 Soil

Soil at the Lungmen NPS site consists mainly of organic and inorganic unconsolidated clay, silt, and sand with minor amounts of gravel, cobbles, and boulders. Boulder sizes encountered were all less than 1 meter in diameter. Due to the high ground water table, the soil at Lungmen NPS site is in a saturated condition, especially in the flat-lying areas. The Lungmen NPS site has been filled within the recent past bringing the grade up to a uniform elevation of 12 m. The soil used to bring the site to grade was class B backfill material discussed in Subsection 2.5.4.5.2.

All temporary slopes in the overburden material at Lungmen NPS will eventually be supported by structural walls or backfill.

Permanent slopes are defined as those which will exist with or without support for the life of the plant and are discussed in Subsection 2.5.5.

The overburden material at the Lungmen NPS site are rarely more than a few meters thick, hence slope protection is not expected to pose a major problem. Several options are available for stabilizing both temporary and permanent slopes. The actual option selected will depend on several factors, such as costs, availability of materials, or a more detailed evaluation of conditions after slopes are exposed. Based on existing data, any conventional slope stability method for soils should be suitable for the Lungmen NPS site. However, some judgment and adjustments may have to be made accordingly in the event of unexpected conditions encountered during excavation.

The fundamental practices and precautions that apply to all slopes, regardless of their simplicity, are briefly reviewed here. In general, construction slopes in the overburden at Lungmen NPS site shall be cut at an angle of 1.5:1 (1.5 horizontal to 1 vertical). A qualified geotechnical specialist will monitor the cut slopes on a regular basis as they are being constructed and implement changes wherever the 1.5:1cut appears to be inadequate. In the severest of cases, laboratory testing of the soils and computation of a factor of safety will be required, especially for permanent slopes.

The exposed faces of cut slopes in the overburden will be protected against rainfall erosion by one of several conventional means. These include watershed vegetation, gunite, rip rap, asphalt, or any similar materials that are relatively impermeable and resistant to deterioration by the elements.

The important standard practices and precautions required for all temporary and permanent slopes are listed below:

(1) Seepage Control: The overburden material at Lungmen NPS site is saturated for the most part, and seepage of ground water from slope faces is expected and will be controlled. This control will include both the prevention of excessive erosion of the cut face from seepage and also the diversion of the seep water to sumps or drains that will minimize undesirable accumulations of water in excavations and work areas. Toe drains, weep holes, selective grading of bedrock, and other standard methods will be implemented as required.

(2) Toe Protection: One of the most common types of slope failure in soil materials is due to “toe failure” which occurs along the base of the cut faces resulting in a rotational movement of soil masses. The cause of this type of failure is the absence of lateral support, hence some form of support is necessary. For temporary slopes, sandbags are frequently used and generally are adequate for slopes of limited height. Permanent slopes usually require a reinforced vertical wall, the height and strength of which will depend on soil type, height of the slope, and other factors which will be assessed during excavation.

Measures shall be taken to assure that the cut face of a soil slope and the cut face of underlying bedrock will not be along the same plane. The soil slope will be set back from the crest of rock slopes, leaving a berm of sufficient width to provide some form of lateral support for the soil slope and prevent its failure.

2.5.4.5.1.2 Rock

Bedrock at the Lungmen NPS site consists of interbedded and interlaminated fine-grained clastic sediments that are generally hard, well-indurated and strong. several of the stratigraphic horizons contain interconnecting networks of joints, bedding cleavages, and shear-related fractures which will facilitate excavation. Other horizons consist of extremely dense, hard, well-cemented materials which will be more difficult to remove. Qualitative indications of rippability were gained from the containment area shafts that were excavated for the purpose of performing plate load tests. For the unit 1 plate load test, the bedrock was excavated from an elevation of 8 m to 1 m above sea level almost entirely by backhoe. For the unit 2 plate load test, bedrock was excavated from elevations of 11 m to 3.2 m, but initial breakage of the rock by backhoe-mounted percussion chisel was required before mucking could proceed. Substantial portions of the bedrock at Lungmen NPS will not yield to conventional soil-site excavation equipment (bulldozers, scrapers, loaders, etc.). However, dynamite blasting will not be permitted to occur within 2 m of final foundation grade or 2 m of any finished cut face, except if test blasting is performed to verify that the procedure will not affect the finished cut surfaces within 2 m. This is because of known presence of the interconnected fracture networks described in the preceding paragraph. Ground accelerations resulting from repeated dynamite charges have the effect of further opening existing joints and other discontinuities. This not only weakens the rock mass from a structural standpoint, but also enhances the flow of ground water, which is known to exist in the fracture network.

Permanent slopes will be required in the foothill area to the west and southwest of Lungmen NPS power block. In some areas, those slopes will extend to heights of 30 to 35 m above plant grade level and will require stabilization to preclude failure. Further discussion can be found in Subsection 2.5.5.

Temporary construction retaining slopes in bedrock at Lungmen NPS site are expected to consist of the walls of excavations which are constructed to reach foundation grade levels.

Experience gained in excavating the plate load test shaft at Unit 1 shows that rocks that have been weakened by shearing, extensive joints or fractures will not stand without support for any appreciable length of time.

It is proposed to support the vertical faces of the excavations using soldier piles and rock anchors grouted into the intact rock beyond the assumed seam line. The soldier piles define the vertical face of the cut. The excavated vertical surface will be covered with shotcrete reinforced with welded wire fabric. The soldier piles will be placed at about 2 to 3 m horizontal spacing around the excavation sites and will be supported by rock anchors at approximately 1.5 to 3 m spacing vertically (Figure 2.5.10).

As mentioned in Subsection 2.5.1.2, there is a potential for encountering shear zones or shear-related weak zones in the rocks at Lungmen NPS site. In addition, the core samples indicate that some of the rocks in the foothill are intensely weathered to considerable depths. These zones will require special measures for stabilization when they are encountered during the slope excavation. A conservative slope design will be developed and provided with the FSAR. During slope excavation an engineering geologist will supervise excavation methods and will designate areas which require special treatment. The cut slope will be mapped in detail prior to application of slope protection. A slope stability analysis for both static and dynamic conditions is discussed in Subsection 2.5.5.

2.5.4.5.2 Backfill Requirements

The Lungmen NPS site is primarily a bedrock site and it is planned that all foundations of Category I and Category II structures will rest directly on firm, unweathered rock. It is possible, however, that some exceptions will occur due to : (1) overexcavation to remove excessively weathered rock, (2) overexcavation to remove rocks weathered by shearing, or (3) as yet unmapped topographic low spots on top of the bedrock surface. In the event that some portions of the Category I and Category II base mats do not extend to competent bedrock, it is planned that these areas will be backfield with lean concrete. The basis for this is that the compressibility of the lean concrete and bedrock are relatively close.

Backfill will be required at the Lungmen NPS as described below.

2.5.4.5.2.1 Class A Backfill

Class A backfill is that which is acceptable for use beneath Category II structures and adjacent to both Category I and Category II structures. It shall consist of crushed rock or gravel in size from 3 inches to No. 8 U.S. Standard Sieve size, or sand passing ¾ inch sieve to No. 200 size. Rock or gravel backfill shall be compacted to 85% relative density determined in accordance with ASTM D4254. Sand shall be compacted to no less than 95% of maximum dry density determined in accordance with ASTM D1557.

2.5.4.5.2.2 Class B Backfill

Class B backfill is that which is used to bring the yard area up to grade as well as for miscellaneous backfill requirements not covered by class A backfill. The class B type is frequently referred to as “general backfill.”

The class B backfill will consist of free-draining granular material such as crushed rock or gravel or sand as indicated in Subsection 2.5.4.5.2.1. Crushed rock backfill against seismic category II structures will be compacted to 80% of maximum dry density in accordance with ASTM D 4254. Sand backfill will be compacted to 90% of maximum dry density determined in accordance with ASTM D1557. In areas which will provide foundation for warehouses, administrative buildings, non-safety related tanks, pavement, and other miscellaneous structures and equipment, class B backfill compaction will be increased to 95% of maximum dry density in accordance with ASTM D 1557.

Class B backfill was recently used to bring the site up to 12.0 m finished grade.

2.5.4.5.2.3 Lean Concrete Backfill

Lean concrete is acceptable as a substitute for class A or class B backfill. The strength of lean concrete shall be13.8 MPa at 28 days. The properties of lean concrete making materials for Seismic Category I structures shall be similar to those described in Subsection 3.8.1.6.1.

2.5.4.5.2.4 Backfill Source Parameters

The sources of backfill material are not determined and defined yet. However, some generalizations can be made with regard to the suitability of materials excavated for power block as a source of fill. These generalizations are strictly qualitative judgments that are based on observations in the field. The process of formally siting the borrow source will require the collection and evaluation of quantitative data.

The overburden materials at Lungmen NPS site consist of three discrete layers which soil scientists refer to as “A”, “B”, and “C” horizons (refer to Subsubsection 2.5.4.2.3). The A horizon is considered to be an organic zone and contains significant amounts of floral matter in various stages of development if living, and in varying degrees of decomposition if dead. Under no condition will this material be used as backfill or as a foundation material for any permanent structure. All of the “A” horizon will be removed and disposed of in a manner and in a location that is consistent with good environmental practices. The thickness of the organic zone varies, but for estimating purposes, an average thickness of 1 m is assumed.

Directly underlying the “A” horizon, the “B” horizon consists of unconsolidated inorganic sediments, mainly clay, silt and sand, with minor amounts of gravel, cobbles, and boulders. No quantitative testing was performed on this material, but field observations indicate that a large portion of the B horizon can be used as class B general backfill provided the material is selectively excavated and suitably moisture conditioned such that the ASTM D1557 compaction requirements will be attained. Almost all of the B horizon is presently saturated by ground water, hence the principal upgrading task will be to drain the materials to reduce the moisture content. In addition, an indeterminate amount of selective sorting will be required to remove cobbles and boulders, excessive clay, and any organic debris that may have been missed during the process of removing the A horizon. Detailed procedures and specifications for upgrading will be written and will be followed during the cut and fill planning stages. Such procedures will require a certain amount of quantitative data. The investigation program will include a representative number of samples from the Lungmen NPS power block area. The sampling procedure will employ the widely-accepted Standard Penetration Testing (SPT) method. Blow counts will be accurately recorded and selected spoon samples will be tested by a qualified soils testing laboratory to determine index and engineering properties. The quantitative data thus developed will be used to: (1) identify the most promising areas and horizons, (2) accurately estimate the total quantity of usable material, and (3) accurately assess the extent of upgrading needed to meet compaction requirements.

A third layer of overburden material, the “C” horizon, underlies the “B” horizon and consists of weathered bedrock materials. The weathering processes are described in paragraph 5.2 of the Report of Foundation Conditions, June 1983 (Reference 2.5-6). The principal feature of weathering at Lungmen NPS site consists of a fairly wide variety of weathering intensity. The intensity varies from slight iron-oxide staining to complete alteration from bedrock materials to soil materials. Whether or not any of the weathered material can be used as a class B backfill is, at present, not known. The determination, if the material will meet the compaction requirements, either in its present state or through some upgrading process will be done. As in the case of B horizon, representative samples of the weathered zone will be taken during the backfill investigation program and tested for index and their use will depend to a large extent on the results of the tests. The results of these tests and investigations will be provided with the FSAR.

Consideration has been given to erecting a high capacity crushing plant to process the firm, unweathered bedrock into class A and class B grade backfill. Such an operation has distinct possibilities and would partially resolve the problems of disposing of excavated materials.

2.5.4.6 Groundwater Conditions

Investigation of groundwater quality at Lungmen NPS site was started in 1980 to determine if potential existed to encounter corrosive water at plant foundation levels. A total of 23 exploratory wells was used for investigation (Reference 2.5-57). Water samples were collected over a period of time from these wells. The water was tested for the presence of chemicals. The chloride and sulfate salts were found to be less than 250 mg/l, the tap water quality standard in Taiwan. Some wells, within a radius of 5 km of Lungmen NPS, had higher alkalinity, acidity, total hardness or turbidity or presence of iron. However, not all wells were similarly affected. Some wells in the northern zone had higher pH value, turbidity, alkalinity or hardness while those in the south had a higher biological oxygen demand, and coliform count. Table 2.5-10 shows the results for one of the typical drill holes.

The water table height at Lungmen NPS site is found very close to the grade elevation as discussed in Section 2.4.12. Thus, the rocks are saturated. However, that does not affect the stability or the loading capacity of the rocks. It is planned to dewater the site during construction. The dewatering will remain active during Lungmen NPS operating life. It is estimated that for Unit 1 Reactor and Control Buildings area approximately 55 m^3/day spring water will need to be pumped out during excavation and 52 m^3/day during plant operation. Rock strata under Unit 1 has higher permeability and thus, these numbers are conservative. Planned Drainage ditches and sumps around the excavation area will keep the area dry during construction. Suitable pumping arrangement is planned to keep the plant site water table under control throughout the life of the plant.

2.5.4.7 Response of Soil and Rock to Dynamic Loading

This section provides geotechnical information for the Lungmen NPS site-specific soil and rock profiles and their response to dynamic loading from earthquakes. The stability of all soils and rocks which may affect the safety of Seismic Category I structures under dynamic loading conditions, using Soil Structure Interaction (SSI) technique, shall be evaluated and the results shall be provided in Appendix 3A in the FSAR.

The project site principal rock strata include (Subsections 2.5.1 and 2.5.2) Tatungshan Stratum, Makang Stratum, Wuchihshan Stratum, Fangchueh Stratum, Mushan Stratum, Taliao Stratum, Shihti Stratum, Quaternary sediments and igneous rocks. The remaining area is covered with the quaternary sediments thin unsolidified layer which consists of platform deposits, alluvium, sand hills, colluvium, laterite, volcaniclastic gravel and shore sand.

The most important faults within 8 km radius from the plant site are Chuchih Fault, Aoti-Shuanghsi Fault, Kungliao Fault, Fangchiao Fault and YentzukÕeng Faults. There is no evidence of major faulting within 1 km of the plant site. There is also no evidence of other geological hazards such as landslides, or subsidence which could adversely affect the safety of the plant. The data produced by the Kungliao Area Fault study (Reference 2.5-5) demonstrates with a high level of confidence that there are no capable faults, using US NRC siting criteria, in the vicinity of the Lungmen NPS plant site.

Derivation of the design Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE) is outlined in Subsection 2.5.2. Design spectra are presented in Subsection 3.7.1 and SSI analyses is discussed in Subsection 3.7.2.4.

2.5.4.7.1 Response of Rock to Dynamic Loading

The foundation rock is encountered at the relatively shallow depth of between 0 and 10 m. Therefore all Seismic Category I structures shall be founded on rock. The data from core drilling demonstrates that the foundation rock (Reference 2.5-7) at the plant site consists of dark gray siltstone and medium gray fine-grained sandstone belonging to the tatungshan formation of oligocene age. This rock will provide excellent foundation for the Lungmen NPS.

The depth of rock weathering in the plant area is not regular and the thickness of the weathering rock layer is about 5 to 12 m. The change of seismic wave velocity shows that the rock has structural characteristics of joints and cleavages. The results of seismic measurements indicate that there is a crushed belt in the rock wall in the plant area. The crushed rock belt was evaluated and shown to have no detrimental effects (Reference 2.5-7).

The seismic records available at Chenliao and the earthquakes in years 1832 and 1916 in Ilan are taken into consideration. The earthquakes having the most effect at Aoti were the Great Western Earthquakes in 1810 and 1832, and the Great Chilung Earthquake in December 1866 that had an intensity of 7.0 magnitude on the modified Mercalli scale and an acceleration of 0.35g. The accelerations for the Lungmen NPS site has been increased to 0.4g for SSE and 0.2g for OBE (Subsection 2.5.2) dynamic loading.

Shear modulus and damping are the two dynamic engineering properties important for evaluation of the site response under earthquake loading.

The results of the in-situ dynamic testing for evaluation of the strain dependent shear modulus and damping ratios are presented on Figure 2.5-23, Tables 2.5-16, and 2.5-17. These strain dependent properties have been used in determining the site specific OBE and SSE ground motions.

2.5.4.7.2 Response of Soil to Dynamic Loading

The plant area is covered by alluvium, ranging from 0 to 10 m in thickness, except for the ground outcrop of rock. Most of the area is used for agriculture and the soil layer is mainly composed of clayey silt and sand mixed with some gravel and pebbles. Most of the surface soil belongs to sandy loam which has good permeability. The results of the response of soil to dynamic loading will be provided in the FSAR.

2.5.4.8 Liquefaction Potential

All safety-related structures are founded on rock. Therefore, liquefaction during OBE and SSE and ground subsidence due to nonseismic activities such as mining, erosion, floods, and fluid withdrawal, are not a factor needing consideration at the Lungmen NPS site (Reference 2.5.2).

2.5.4.9 Earthquake Design Basis

The maximum vibratory motion expected at the Lungmen NPS site is 0.4g from the SSE and 0.2 g from OBE for both horizontal and vertical directions. The design bases for the SSE and OBE dynamic loading are discussed in Subsection 2.5.2. The design spectra for these earthquakes are presented in Subsection 3.7.1.

2.5.4.10 Foundation Stability

Seismic category I structures are likely to have crushed stone backfill. The foundation rock at the Lungmen NPS site consists of hard, well cemented, fine grained sandstone, siltstone, and shale of oligocene age. The rocks have acceptable bearing capacities.

The rock bearing pressures shall be so determined as to maintain overall moment equilibrium for each building. The applied moments are due to active soil pressure (or interaction force) and building base moment. The resisting moments are due to passive soil pressure (or interaction force) and wall skin friction. The unbalanced moment will be resisted by the underlying soil which, together with applied vertical loads, determines the bearing pressures assuming no tension in soil. The effect of bi-axial bending is considered in determining the maximum bearing pressure.

For Lungmen NPS Units 1 and 2 foundations the allowable bearing capacities are:

Location	Static Condition kg/cm^2	Dynamic Condition kg/cm^2
Bearing on top of intact rock*	15	20
Bearing at a depth of 15 m* below top of intact rock	30	40

* Bearing pressure between top of intact rock and 15 m depth will be calculated by interpolating.

The total and differential foundation settlements and maximum bearing pressure for Seismic Category I structures shall be provided with the FSAR.

2.5.4.11 Design Criteria for Safety-related Structures on Rock / Soil

The methods used in evaluating the Lungmen NPS site response characteristics and seismic design of safety-related facilities are presented in Sections 3.7 and 3.8. Reference Subsection 2.5.2 for SSE and OBE dynamic loading, respectively. The basic geotechnical design criteria for Seismic category I structures are listed in Subsections 2.5.4.1, 2.5.4.2, 2.5.4.6, 2.5.4.7 and 2.5.4.8. Discussion of the computer programs used in dynamic analysis is presented in Appendix 3C and Subsection 3.8.1.4.

2.5.4.12 Techniques to Improve Subsurface Conditions - Rock / Soil

Groundwater is present in the overburden and dewatering will be required during construction and operation of Lungmen NPS (Subsection 2.5.4.6). The Lungmen NPS plant site shall have a permanent dewatering system and therefore groundwater will pose no problem during construction and operation.

A function of this dewatering system is to eliminate the application of buoyant forces on buried structures. The dewatering system consists of stainless steel screen 200 mm drain pipes, polyvinyl chloride 50 mm perforated subdrain pipes, collector trenches and sumps. The dewatering system has been designed such that the water flows by gravity towards the sumps. A total of 6 sumps is provided to collect water under the Reactor Building and Control Building foundation mats. The water is collected in sumps and from there the pumps discharge this water to the site drainage system. The manholes facilitate inspection and cleaning of the drain pipes. The design details of the dewatering system, including size of sumps and size of the pumps, will be provided with the FSAR.

There may be local slope stability problems in deep excavations where bedding planes or joints dip out of cut faces. These problems will be adequately handled by appropriate design and construction procedures and foundation dental work will be performed where appropriate. If soft rock or friable rock is encountered and concrete mortar shotcrete protection is not possible, horizontal lagging will be utilized to protect from rock slides.

Blasting may be utilized for rock excavation (Subsection 2.5.4.5.1.2). The quantity of dynamite utilized for rock excavation shall be based on the requirement that the final grade, foundation, and finished cut surface are not damaged. The blasting work will not be permitted within 2 m from the final grade foundation and/or finished cut surface, except where test blasting has demonstrated that it will not affect the cut surface within 2 m distance.

The design details of the rock anchor system, including method of installation and construction procedures, shall be provided with the FSAR. The rock anchor strength shall be determined through the pull-out test, the strength test, and the durability tests. The results of these tests shall also be provided with the FSAR.

There are no extractable minerals or economic deposits of coal, petroleum, etc., which could create the potential for subsidence of the foundation rocks at the plant site. The subsidence potential, therefore, is zero.

The groundwater quality investigation has not produced any evidence that the plant site is underlain at depth by warm, sulfurous, or acidic ground water which would pose corrosion problems.

No other special treatment is required to improve foundation conditions beneath the Seismic Category I structures bearing on rock.

2.5.5 Stability of Slopes

Up to the present time, the site was leveled to the elevation of 12.0 m. All the permanent cut slopes (Figure 2.5-33) surrounding the site was completed in 1985. Before the construction of these cut slopes, a thorough slope stability analysis by using geometric parameters, such as stereoprojection of the discontinuities, wedge analysis, and finite element model was conducted by Pacific Engineers and Constructions, LTD, (Reference 2.5-63). Slope characteristics, design criteria and analysis, the logs of test pit for the power blocks and filling material are described below.

2.5.5.1 Slope Characteristics

As mentioned above, the site area has been leveled to the elevation of 12.0 m. The power block area or the Category I structure will be found on the bed rock. The foundation of these structures as shown on the site geological map (Figure 2.5-24 and Figure 2.5-11) are the Tatungshan Formation of Oligocene and the Wuchishan Formation of Miocene in age. They are characterized by a series of dipping sedimentary units that strike to the northeast and dip to the southeast. The dip of the rock unit at the site ranges between 30 and 40 degrees. Filled and unfilled joints are common in the rock mass throughout the site area. The strike of most joints trends to the northwest and dips are generally steep (60 to 80°C) with respect to bedding planes. Some referred to as shears or shear zones and characterized by the present of intense fracturing of the original rock, in-place crushing of the original rock, the development of mylonite, breccia, gouge and some combination of these features are found.

The presence of the shears at the site is not expected to pose a major problem with the foundation materials. Some treatment of these shears may be required, but such treatment is well within current foundation technology, such as tie back anchoring, and is not expected to be extensive.

2.5.5.2 Design Criteria and Analysis

The previous slope stability study suggested that the standard cut slope design calls for a benched 1:1 (H:V) slope in rock, overlain by a 2:1 (H:V) slope in deeply weathered rock and overburden. Each bench has a vertical height of 7.5 m and has 4 m-wide horizontal bench. It was concluded by the wedge method that the design cut slope supplemented by a thorough drainage by horizontal drain hole will produce the factor of safety 1.67 and 1.16 under the condition of 0.2g and 0.4g seismic acceleration (modeled as a pseudostactic seismic force) and without hydrostactic forces. As mentioned before, the cut slope surrounding the site area (Figure 2.5-33) was completed in 1986. All these cut slope is proved to be stable after the construction for more than 10 years.

2.5.5.3 Logs of Borings

Two test pits for plate loading test are located approximately in the center of the proposed Unit 1 and Unit 2 reactors (Sinotech Engineering Consultants, Inc., 1983). These pits were excavated on a relatively flat farm field at the ground elevation of 12 m to a depth of 11 m at Unit 1, and 13.4 m to a depth of 10m at Unit 2 respectively. The overburden was excavated to a slope of 1:1 (H:V) from the ground surface to bed rock. The excavated slope was stabilized by three rows of sandbag in its toe. The bed rock was excavated mechanically by a breaker installed in a backhoe to 2 m above proposed excavation level which was then followed by hand digging to minimize any disturbance that may have caused to the test surface. After excavation the rock walls were lined with plunk and supported by steel beams. The space between the plunk and steel support was tightened up by inserting wooden wedges. As most of the pits are situated blow groundwater table, dewatering by using a submerged pump installed in a sump at the corner of the pit is applied. Figures 2.5-34 and 2.5-35 are geological logs of bore hole CA-1 and CA-8 performed in phase investigation program and the geological records of the test pits. For more detailed geological profile, see References 2.5-58 and 2.5-60.

The experience of the test pit excavation suggests that the general area of unit 1 is easier to excavate than the unit 2 area. However, the safest generalization that can be made is that substantial portions of bedrock at power block area will not yield to conventional soil-site excavation equipment (Bulldozers, scrapers, loaders, etc). It is recommended that dynamite blasting not be permitted within 2 m of final foundation grade or 2 m of any finished cut face. The basis for this recommendation evolves from the known presence of the interconnected fracture networks described in the preceding paragraph. Ground accelerations resulting from repeated dynamite charges have the effect of further opening existing joints and other discontinuities. This not only weakens the rock masses from a structural standpoint, but also enhances the flow of groundwater, which is known to exist in the fracture network.

2.5.5.4 Compacted Fill

The present design of the excavation for the power block will be the vertical cut slope protected by the surrounding in-place large piles in incorporation with the tie back anchoring. It is anticipated that most foundation of Category and Category structures will rest directly on firm, unweathered rock. There is no need to put compacted fill right behind the piles. In case that some portions of Category and Category base mats do not extend to competent bed rock, it is recommended that these areas be backfilled with lean concrete. The basis for this recommendation is that the compressibility of the lean concrete and bedrock are relative close, whereas sand or rockfill even if properly compacted, will be somewhat more compressible than bedrock, which introduces the possibility of differential settlement.

2.5.6 Embankments and Dams

As stated in Subsection 2.4.2, the 120,000 cu m raw water storage reservoirs located on the west hill of the power block at elevations from 100 to 135 m MSL are postulated to fail. However, because of the topographic features, which directs the flow elsewhere, no water due to reservoir failure will reach the power block area.

Based on the above consideration, no embankments will be needed to protect the safety-related structures inside the power block from the flood caused by the rupture of the raw water storage reservoirs. The site drainage plan (Figure 2.4-3) (Subsection 2.4.2) shows that no other embankments or dams will be constructed in Yenliao site causing any potential flood hazard to the safety-related facilities of Units 1 and 2.

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