CURRENT STATUS OF SPENT FUEL DISPOSAL PROGRAM IN TAIWAN, REPUBLIC OF CHINA

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ABSTRACT

In the year of 1988, Taiwan has completed a two-year preliminary study and began in late 1988 a second term for the final disposal of spent fuel program. The research conducted in the first phase was mainly concentrated on the reviews of international studies and domestic geological literatures, set-up of siting criteria, and pertinent engineering analysis of a repository. Taiwan is an area of complex and unstable geological structures, abundant ground water and high density of population. Favorable host rocks under consideration for permanent waste disposal are thick shales and mudstones, metamorphosed rocks of mesozoic basement, silicified quartzite and mesozoic granitic gneiss. The analysis of heat transfer for hypothetical case studies indicate that the temperature rises in the repository systems would be well below the proposed maximum admissible temperatures. The repository size would be less than 2 km^2 when appropriate period for surface storage of spent fuel is satisfied. A probabilistic risk analysis also demonstrates that the presence of faulting and other tectonic instabilities characterize Taiwan's disadvantages for geological disposal of nuclear waste. The on-going second phase of the disposal program facilitates a long-range planning for the spent fuel disposal and geological studies for the major offshore islets and shale and mudstone areas.

INTRODUCTION

Six reactors of three nuclear power stations, two PWRs and four BWRs, and an installed capacity of 5,144 MWe are now in operation in Taiwan. Five additional units are considered to be constructed in the future. The policy guideline of the radioactive waste management in Taiwan has been issued by the Radwaste Administration of the ROC Atomic Energy Council, in which the operation of interim storage facilities shall be started by the year of 1999, and the planning for the final disposal program of spent fuel or high-level radioactive waste shall be completed as soon as possible.

To fulfill future storage requirements, both the expansion of storage capacity for existing spent fuel pools by repacking, as a near-term measure, and long-term storage of spent fuel in the facilities with modular construction, retrievability and continuous monitoring capability will be deployed in the timely manner. As to the permanent disposal of spent fuel, the geological investigation and related research work will be undertaken to evaluate the availability of the repository site in Taiwan (1).

FIRST PHASE OF THE DISPOSAL PROGRAM

In the fiscal year (FY) of 1988, Taiwan has completed a two- year preliminary study and began in FY 1989 a second two-year term for the final disposal of spent fuel program. The first phase is regarded as a warm-up session that familiarizes the domestic research people with related subjects and provides a review of the existing geological literatures for spent fuel disposal. Siting criteria, geological and environmental features of Taiwan, as well as repository design concept and engineering analyses were the three major research categories conducted in the first phase. Table I illustrates the research contents undertaken in the first phase.

The program was sponsored by the TPC and conducted mainly by the joint efforts of the Institute of Nuclear Energy Research (INER), the Central Geological Survey (CGS), and the Energy and Mining Research/Service Organization (EMRO). Furthermore, individuals with special expertise in Taiwan's research institutions were invited.

GEOLOGICAL CONSIDERATIONS FOR THE SPENT FUEL DISPOSAL IN TAIWAN

Taiwan is an island of about 36,000 km^2. Located at the boundaries between the Eurasian plate and the Philippine Sea plate, this island is elevated to a maximal height of about 4000m as a result of compression-plus-shear. It is an arcuate island extending its shorter arm eastward to the Ryukyus and its longer arm southward to the Philippines (Fig. 1). The backbone of this mountainous island is the Central Range which is mainly Tertiary in age. It is fringed on the west by the Foothill Zone and separated on the east from the Coastal Range by the Longitudinal Valley. West of the Foothill Zone is a vast coastal plain with the very shallow Taiwan Strait farther west; east of the Coastal Range is the deep Pacific Ocean (Fig. 2). The offshore islets of Taiwan include the Penghu Group in the Strait and Lutao and Lanhsu off the southeast coast. Kinmen and Matsu are two islands close to the mainland China covered with Mesozoic granitic gneiss which may be the surface extension of the Mesozoic basement of western Taiwan. In the less tightly compressed northeastern and southwestern parts of the mountain complex of the Central Range and Foothill of Taiwan, there are the Ilan Plain and the Pintung Valley, each in the form of an intramontane trough wedging from the sea into the island.

Particular earth sciences considerations for the site selection in Taiwan should be paid to the following topics (2).

(1) The most demonstrated and tested crystalline rocks, tuffs and salt deposits in other countries are not likely to be found favorable for this purpose on this island. Some less tested rock formations, such as shale and mudstone, gneiss, etc., are to be considered.

(2) Situated right on the Circum-Pacific seismic zone, the island of Taiwan has strong and frequent earthquakes. Tectonic obility is high. Upheaval and erosional rate, both have an annual average of about 5 mm, are among the highest in the world.

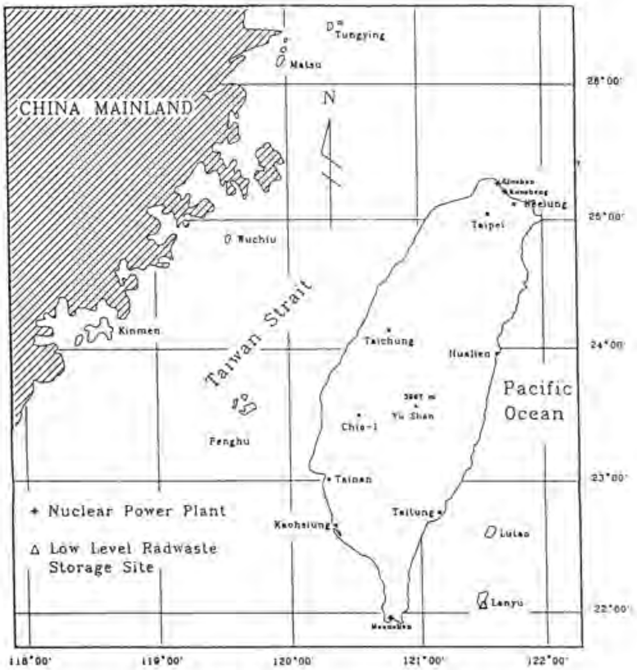

Fig. 1. Map of Taiwan and its Offshore Islands.

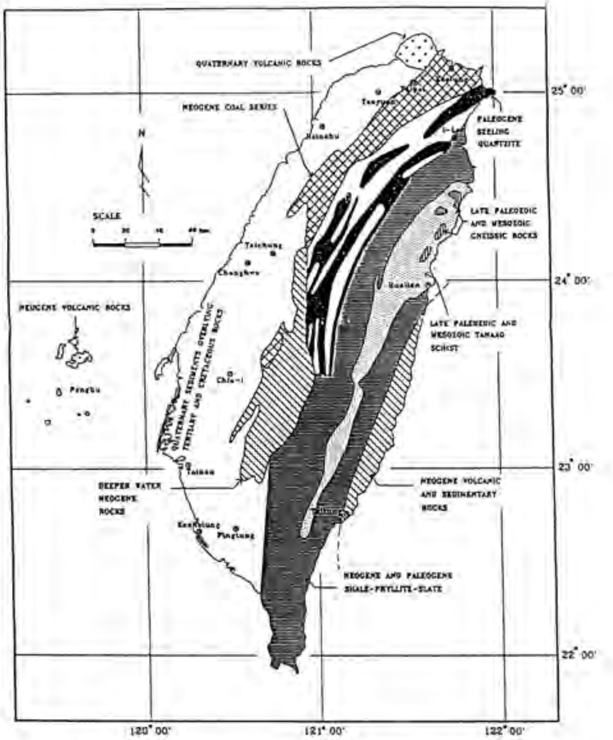

Fig. 2. Geological Sketch Map of Taiwan.

(3) Geothermal gradient is normally high and hot springs are widespread. The changes in the level of ground water are also high in some part of Taiwan due to prominent dry and wet seasons. Ground water hydrology is not well studied and understood.

(4) Orogenic activity is strong. Faulting and folding structures are rather closely spaced. Rock consolidation and induration processes are comparatively rapid.

(5) Active volcanoes have not been found. However, there are Pleistocene volcanoes with post-volcanic activities.

(6) Oil and natural gas evidences are common in the Neogene sediments. Many prospecting and producing wells have been drilled.

(7) High CO^2 activity in the west Foothills and the Central Range indicates that the assemblage, the reaction temperature, kinetics, diffusion and transport process of rock minerals would be affected.

In view of the above statements, the following rocks on the island of Taiwan and its offshore islets including Kinmen and Matsu are considered as favorable candidates for further studies.

1. The plastic, impermeable and thick shale and mudstone formations;
2. the most stable and shallow stratigraphic high of Mesozoic basement close to the western coast;
3. the quartz porphyry islet in the Pescadores of Taiwan Strait; 4. the highly silicified and impermeable Eocene quartzite formations in the northeastern Taiwan;
5. the Mesozoic granitic gneiss of Kinmen Island.

PROPOSED SITING CRITERIA

Deep geological disposal and multibarrier concepts are adopted in the set-up of the siting criteria. Thirty-five qualitative and descriptive criteria entitled in twelve categories as shown in Table I are proposed with due considerations to the current international practices and regional features. These criteria provide guidelines of the basic technical, environmental and socioeconomic requirements that shall be met by the candidate sites.

Comparisons of the criteria with those of IAEA, United States, Canada and Germany have been made. The high density of population, complex geological structure, rugged topography, warm and humid climate of Taiwan require special attention be paid to the drafting of the criteria, in addition to those global factors which are universally applicable.

The final report of siting criteria has a content of introduction, a discussion of the legal position of the criteria in the nuclear energy related regulations, principles and important factors for the set-up of the criteria, and procedures It is hoped that these siting criteria can serve the following purposes:

1. to provide basic technical requirements and framework for the disposal program;
2. to provide information with due considerations for both of the international practices and the local conditions; and
3. to provide communicative references and channels for those environmentalists.

ENGINEERING ASPECTS OF SPENT FUEL DISPOSAL IN TAIWAN

An assessment has been made for the effects on temperature rises associated with the disposal of spent fuel in a conceptual repository constructed within granite and clay host rocks respectively (3). It is due to the fact that, as depicted in the geological features of Taiwan, the major prospective rock types under consideration for a repository are the thick shales and mudstones, or granitic rock bodies. The heat source as function of time is generated by ORIGEN-2 code of typical burn- up of 25,000 and 33,000 MWd/tU for BWR and PWR spent fuels, respectively. Four scenario cases with different host rocks, number of spent fuel bundle, the geometry of fuel bundle arrangement and their pitches are analyzed. The service life and the associated period of spent fuel generation in a reactor are assumed to be 30 years in the analysis.

A computer simulation is carried out using three-dimensional transient heat transfer computer code HEATING-5. It is assumed that the heat transport by the water flow is negligible and the influence of latent heat for vaporization is ignored. It is assumed that there is no gap between waste container and the host rock. The thermal property of the material is independent of the temperature. Thermal loading effects on the geological disposal in literatures have been reviewed and the safety criteria associated with temperature rise in engineered barriers have been proposed.

The temperature profiles for various cases are enumerated, and conclusions are drawn as follows:

(1) Significant temperature drop (about 20 ^{0}C) occurred between the surface of waste container and the host rock.

(2) The temperature rises in different components of the repository systems are well below the proposed temperature limits.

(3) The peak temperature will occur after 1 to 2 years of spent fuel emplacement after a 50-year surface storage.

(4) After 1000 years of fuel emplacement, the temperature will drop to the background level.

The occurrence of criticality of the spent fuels emplaced in the canisters is beyond the realm of reasonable possibility. If it is nevertheless assumed that a critical mass may arise, the effects will also be localized to a limited extent, since the reactions cease when the water boils away and the chain reactions stop.

The repository size is estimated for host rock areas required to accommodate the heat loading capacity. Disposal areas for the granite and shale are assumed to be 150 and 400 m^2 /kW, respectively. According to the analysis made for the heat dissipation from the spent fuels and the heat loading capacities of geological media, an underground area of approximately 1.4 km^2 is required for shale after a 60-year period of interim storage, and 0.7 km^2 is

TABLE I

Contents of teh First Phase for the Final Disposal of Spent Fuel in Taiwan

A. Repository Siting Criteria	
1. Site Geometry	7. Natural Resources
2. Site Geology	8. Surface Features
3. Hydrogeology	9. Climatology
4. Radionuclide Migration	10. Transportation
5. Tectonics and Seismology	11. Environmental Impacts
6. Human Intrusion	12. Socioeconomic Factors
B. Geological Literatures Review	
1. Geography	
2. Climatology	
3. Cultural Aspect	
4. Stratigraphic and Geologic Structures	
5. Hydrology	
6. Engineering Geology	
7. Geological Evolution	
C. Disposal Systems and Engineering Analysis	
1. International Experiences	7. Systems Utility
2. Heat Transfer and Criticality	8. Decontamination
3. Radionuclide Migration	9. Corrosion and Containment
4. Interaction Between Radionuclide and Host Rocks	10. Repository Decommissioning
5. Radiation Effects on Repository	11. Radiological Assessment
6. Repository concept	12. Repository Operation

required for granite subsequent to a 30-year period of interim storage, respectively.

RISK ANALYSIS

A probabilistic risk analysis is performed primarily due to the concerns of adverse environmental conditions in Taiwan (4). The project was sponsored by the INER, and in cooperation with the Institute of Statistical Science, Academia Sinica. This study utilizes the fault tree model (FTM) as the tool for risk analysis, in which the logic gates and basic events leading to the failure of a system construct the framework of this model. This study, for the time being, facilitates a generic model to analyze the scenarios developed for Taiwan's environment. The gates of OR, AND, and CONDITION are applied to delineate the radionuclide release to the ground water above and below the repository, to the land surface, and to the atmosphere. *Four periods of time*, i.e., 2,000, 25,000, 100,000 and 250,000 years posterior to the repository closure, are chosen to evaluate the influences of the failure events on the timing basis. 25 basic events initiating the possible failure of the system are identified. The movement of radionuclides to ground water in the FTM mainly consists of the failure of engineered barriers, faulting, diapirism, drilling activity, land subsidence, etc. Radionuclide transported upward to the land surface are primarily due to the severe faulting, extrusive magmatic activity, pumping of contaminated ground water, human interference, denudation, stream and glacial erosion, ground water dispersion, etc. As regards the radionuclide dispersed directly into the atmosphere, only most severe meteoritic impact and explosive volcanic activity are taken into account.

In order to evaluate the probabilities of various pathways bringing about system failure, 58 minimal cut sets of serial events are constructed. Minimal cut set is the set in which no event may be removed such that the top event still occurs. Furthermore, the analysis of weighted risks are used to compare the relative significance of basic events and associated minimal cut set resulting in the system failure. "Weighted risk" stands for the occurrence probability of a certain minimal cut set of serial events, leading to a system failure caused by an initiating basic event, in comparison with the overall failure probability of a system. In brief, weighted risk analysis may be regarded as a priority setting technique in managing the inherent risks. The results of weighted risk analysis reveal that the existence of faults play a dominant role in assessing the radio- nuclide migration into the ground water; the denudation and stream erosion may exert significant effects on radionuclide release to the land surface; and the explosive magmatic activity is important for the atmospheric dispersion of radionuclides escaped from the repository.

The results of this analysis illustrate that the presence of faulting and potential magmatic activity characterize Taiwan's disadvantages for the permanent disposal of spent fuel.

A conceptual configuration of a repository is thus proposed to reduce the possible damage that would be caused by earth- quake. The underground layouts of repository tunnels, exhibiting a crossed "Z" shape and extending the waste allocation arrays into various depth of a repository, is illustrated in Fig. 3. It is anticipated that this arrangement would lead to foreseeable advantages in order to avoid the major seismic hazard. The effect of tunnel breakage and associated nuclide migration would be localized to a limited zone. Furthermore, this design concept would facilitate more flexible repository layouts. The small units of tunnels can be constructed in desired positions and sizes as long as displacement areas are found suitable for engineering work.

It is nevertheless aware that more engineering and managerial aspects, such as geotechnical design concerns, cost evaluation, as well as operation management, are further required to validate this hypothetical configuration.

SECOND PHASE OF THE DISPOSAL PROGRAM

The second phase began in November of 1988, and the major task in the extended two-year term is to perform a long-range planning for the overall program development in the next few decades. In the meantime, the geological verification studies for offshore islets and mudstone area are also conducted to provide further information for the screening process of potential repository sites. As in many developed countries, Taiwan has encountered the environmental movement in which the "Not in My Backyard" and "Local Unwanted Land Use" symptoms are widespread in the nation. It thus may lead to lay heavy emphasis on the survey of the offshore islets with very sparse population. The international cooperation and technology transfer are eagerly required to accomplish the program goal. TPC is currently sponsoring the program and managing the participation of inter- national firms and expertise. INER, CGS, and EMRO are still the major organizations in conducting the on-going program.

The planning task is to furnish eight sets of reports for the ultimate disposal program of spent fuel, they are:

(1) Full-scale R&D and engineering tasks, as well as associated schedules. The program phases, major activities and research items are to be included in this report . The coming three to five years are termed short-range in which the methodologies, equipments and related measurements for various research items are to be identified.
(2) Program management and decision-making process.
(3) Quality assurance program.
(4) Required expertise and equipments.
(5) Social communication program.
(6) Literatures and information collection and dissemination.
(7) International cooperation.
(8) General description of spent fuel disposal program.

The geological verification studies have the following three purposes: 1. critical reviews of the presently available geological literatures with additional field studies in respect to the disposal program; 2. tests for those newly developed technologies and instruments; 3. examination of those geological data which are required for the screening process of the candidate sites.

The field and laboratory works in this phase will include remote sensing study, surface geological investigation, rock and mineral analyses, geochemical and geophysical surveys. Major efforts are directed to the geohydrological and geotechnical problems. Most of the subsurface studies will be considered in the future programs.

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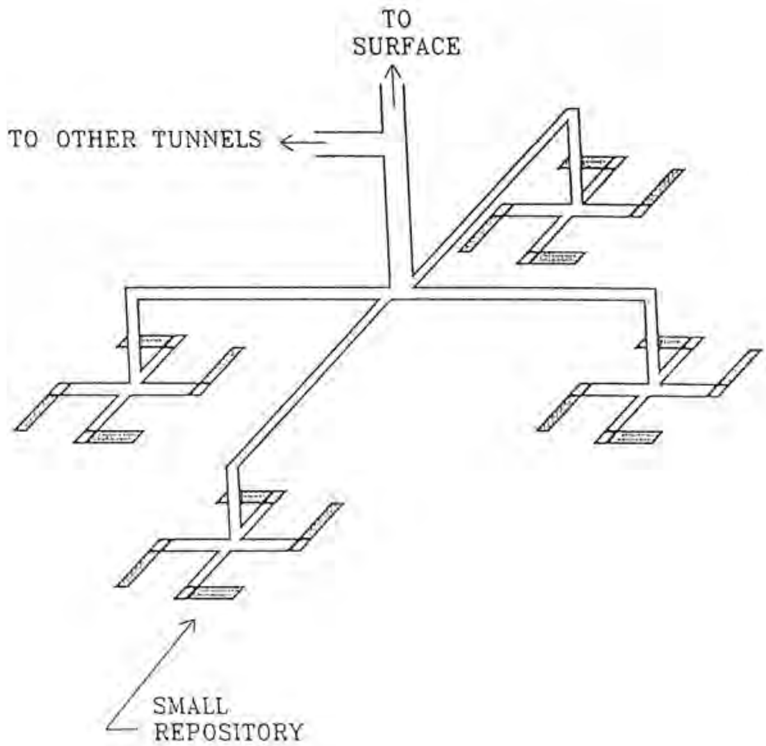

Fig. 3. Hopothetical Underground Layout of a Repository.