NEXT GENERATION OF HIGH LEVEL RADIOACTIVE WASTE REPOSITORY CONCEPT—AN OCEAN-ISLAND APPROACH

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ABSTRACT

A new strategy to dispose of high-level radioactive waste is by the use of an ocean-island approach. The approach uses several criteria that may be of interest not only nationally but also regionally. As an example, Indonesia that has more than 17000 islands can dispose its proposed High Level Radioactive Waste using one of its remote islands. The pursuance of this strategy could be conducted as early as possible parallel with the program to build nuclear power plants in future. One of the most promising aspects of this approach is the fact that ocean water can be used as dilution. Critical data of the Indonesian ocean-island approach has been categorized and analyzed and preliminary research has been implemented. Data from more detailed research is presented in this paper. One important parameter that needs to be researched further is the possibility of corrosion to the container by microbiologically induced corrosion.

INTRODUCTION

This paper presents the methodology to conduct performance assessment (PA) of a High Level Radioactive Waste (HLRW) repository particularly for spent nuclear fuels. The repository facility uses an ocean-island approach, with the case study Genting Island, Karimunjawa, Indonesia.

This paper discusses the research and continuing study that has been conducted previously by the authors.[1] Some revisions have been done since the last report. The revisions include implementing dose/risk evaluations of several radionuclides in the Accessible Environment (AE), and employing 1,000 Monte Carlo realizations to evaluate possible events based upon statistical distributions to describe each scenario. Incorporating the parameters of this research into the methodology developed in this study will lead to further evaluation and predictive modeling of the site as more site-specific geologic data become available.

THE METHODOLOGY FOR CONDUCTING THE PERFORMANCE

The waste package design includes a modified multi-purpose container (MPC) design with 1 cm of alloy 825 surrounded by 10 cm of Carbon steel.[2]

The proposed repository at Genting Island can be best designed such that the wastes are placed in the saturated zone (below the groundwater table) since the site has a relatively shallow groundwater table.

There are two thermal loading strategies being considered: high-temperature loading where the surface temperature of the container exceeds the boiling point of water (approximately 75% of the waste packages in this study), and ambient-temperature loading where the container surface temperature is maintained below the boiling point of water (approximately 25% of the waste packages in this study). Figure 1 shows schematically the proposed design of the repository site.

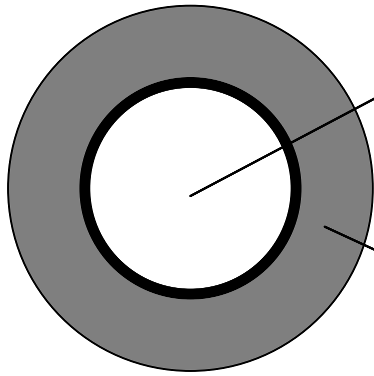

Figure 1. Schematic Cross Section Diagram

The Genting Island, Karimunjawa archipelago, is one of the islands that does not support sustainable agriculture. The geological map of Karimunjawa archipelago can be seen in Figure 2.[3] The groundwater level map can be seen in Figure 3.[3]

The lithology of the area is such that the top layer of soil is mainly alluvium consisting of pebble, gravel, clay, coral limestone and coarse grained rocks. The thickness of this layer is between 1.5 - 3.5 m. Below the layer is basalt, which consists of basaltic lava or alkaline basalts. The thickness of the layer is between 24 - 35 m. The depth to groundwater is approximately 103 m.

The basaltic rock at Genting Island is classified as a strong rock. In the area, it is found that the approximate strength is 1550.36 kg/m^2 in compression. The unconfined compression strength value is 360.86 kg/cm^2. The mean value of Poissons ratio is 0.31. The mean value of the natural density is 2.797 g/cm^3. The mean value of cohesiveness is 57.87 kg/cm^2. Table 1 shows the results of the investigation.

Table 1 Technical Classification of Intact Rocks[3]

Classification of Strength	Uniaxial Compressive Strength (Kg/cm^2)	Type of Rock
Very soft	10 – 250	Limestone, Salt rock
Soft	250 – 500	Coal, Silstone, Schist
Medium	500 – 1000	Sandstone, Slate, Shale
Strong	1000 – 2000	Marble, Granite
Very strong	> 2000	Quartz, Basalt

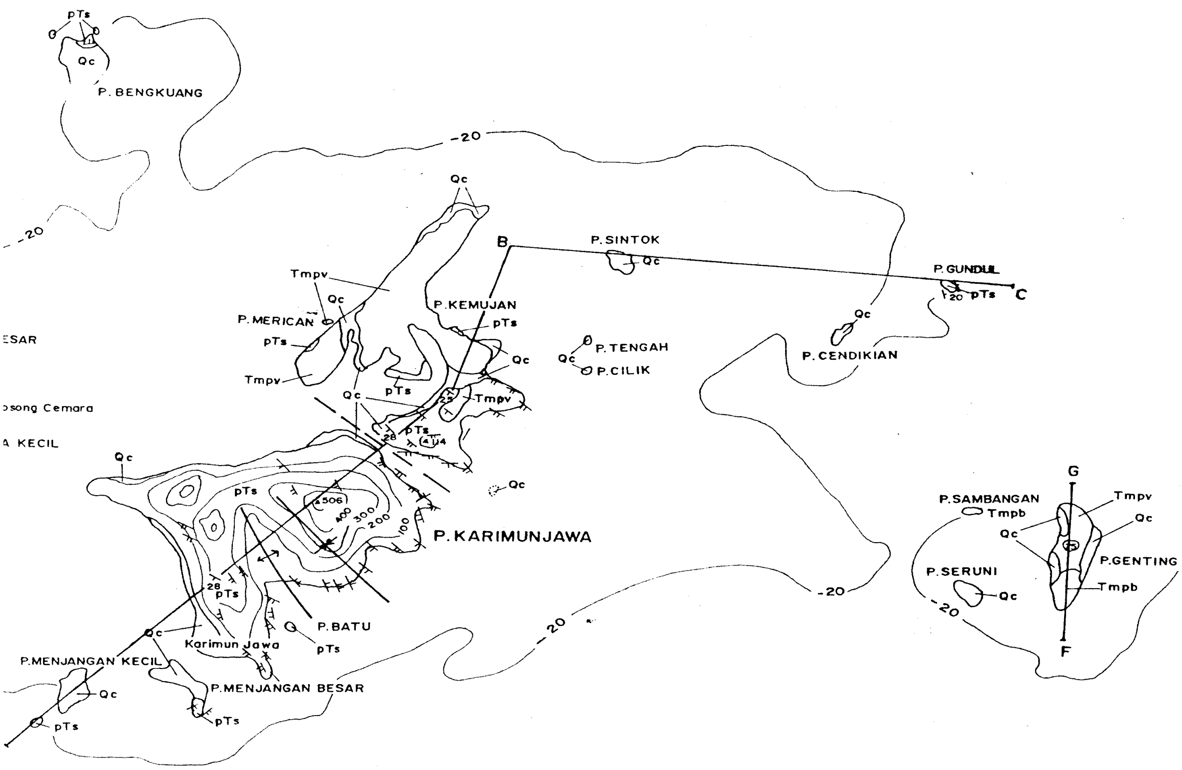

Figure 2. The Geological Map of Karimunjawa Archipelago

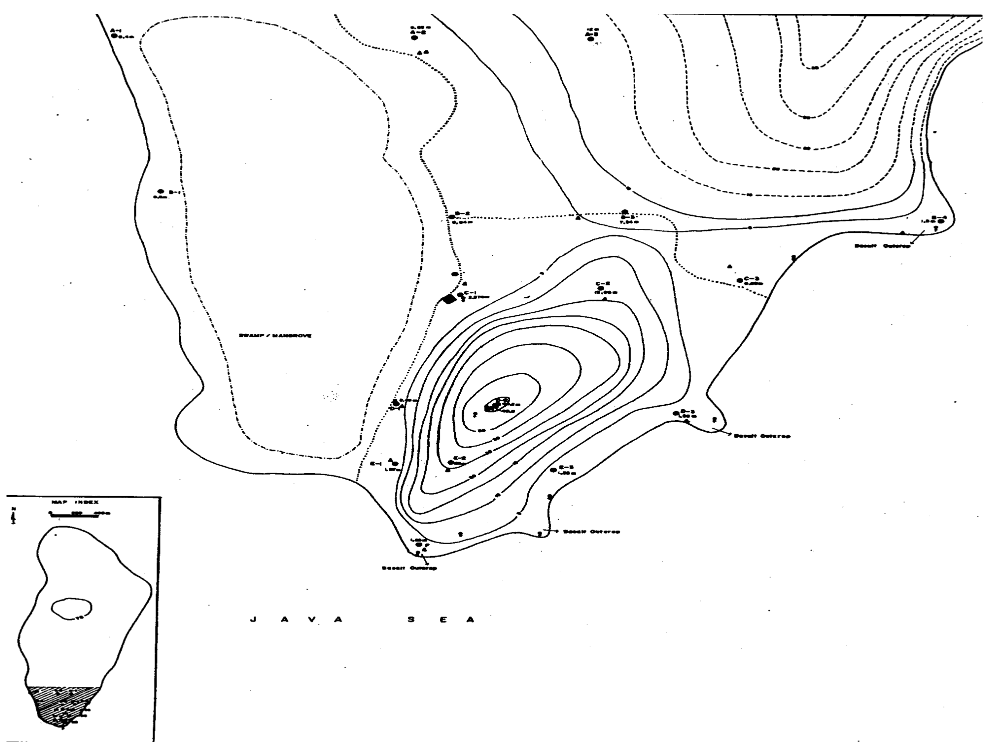

Figure 3 The Groundwater Level Map of the Genting Island

Having minimal permeability in the geologic medium is very important. The coefficient of permeability determines the ability of a material to let a liquid pass through its cross-sectional area. The permeability measurements from Genting Island are summarized in Table 2.

Table 2 The Coefficient of Permeability [3]

Coefficient of Permeability (m/s)	Type of Rocks
1.82×10^{-6}	Soil and Basalt
1.75×10^{-6}	Basalt
1.26×10^{-7}	Basalt
5.55×10^{-6}	Basalt
4.79×10^{-6}	Basalt

The water chemistry of Genting Island shows that the concentrations of Mg^{2+}, Na^{+}, and Cl^{-} are rather high at the coastal area. The content of HCO_3^- tends to increase on the southern side of the Island. The existence of HCO_3^- in the groundwater is due to the influence of decomposed plants and swamp materials.

The southern side of the Genting Island is primarily a volcanic cone region. The highest point of this area is 40.5 m above mean sea level, while the lowest point is about 5.0 m above mean sea level.

Near-field conditions

Near-field conditions refer to environmental factors, such as pH, water contact mode, temperature, etc. In the model, pH, water contact mode, and temperature are included. Regarding pH, along the 50 m depth of an experimental borehole, the pH varies from 7.7 to 6.8. The average pH is 7.25. For the saturated zone, the water contact mode can be divided into two categories: zero velocity-leading to diffusive transport, and high velocity-leading to advective transport. The water contact mode will lead to primarily diffusive transport.

This study employs the groundwater pathway as the most dominant pathway. No biotic transport mechanisms are available in this design except for transport of radionuclide by bioaccumulation in marine life.

Waste Package Selection

The waste package technology currently proposed for the Genting Island site employs the Universal Container System (UC System). The proposed UC system can employ two types of waste package designs: the Multi-Purpose Container (MPC) design and the Multi-Element Sealed Canister (MESC) design. Both designs have advantages such as:

1. High capacity for spent fuel in a single transportable package
2. Criticality control with burnup credit
3. Sufficient heat transfer capability to keep cladding temperatures within regulatory limits

4. The number of required handling steps and procedures are significantly reduced.

The container failure mode is assumed to be general corrosion for the carbon steel and pitting corrosion for the corrosion resistant materials. The cladding failure mode is assumed to be creep rupture.

Dose/Risk Evaluation

Dose/risk evaluation is the calculation of drinking-water doses. The calculation is relatively straightforward, that the release rate calculation is multiplied by the dose-conversion factors provided. The conversion factors are extracted from the table of the study conducted by INTERA Inc., SANDIA Report for the Yucca Mountain project, and the use of GENII computer code.[5,6,7] These dose-conversion factors are based on the ICRP 30 (International Council on Radiation Protection) standards. Note, source of drinking water only comes from groundwater.

The concentration of the radionuclides are based on the mean release rates of these isotopes to the AE (Ci/yr.). The average volumetric flow rate of the groundwater (L/yr.) is given as 315.58 m^3/yr. Therefore, the concentration of each isotope in the AE can be determined.

Disruptive Event Scenario

The disruptive events scenarios for the island are assumed to be flooding of the repository and disruption of the repository by earthquakes. There is no volcanic activity in the area. Since the area is remote, if either disruptive event occurs, the resulting radionuclide release from the site will be limited by the significant dilution effects of the ocean. This dilution will prevent significant radiological impacts. The ocean will mitigate the impact of any radionuclide leakage from repository due to geohydrological factors.[2] The primary benefit that is derived from an ocean island repository is the protective mechanism resulting from the great dilution of any release of radionuclides from the repository into the surrounding seawater.

PERFORMANCE ASSESSMENT ANALYSES

In this study, the Repository Integration Program (RIP)[4] computer code is used to conduct the PA analyses of the Genting Island repository facility. The code employs “top-down” approach. This approach relies on the expert interpretation of the available data about the repository facility. It integrates the entire system and utilizes relatively high-level descriptive models and parameters. In this study, the RIP code employs 1,000 Monte Carlo realizations to evaluate possible events based upon statistical distribution to describe each scenario. The time histories recorded for this study are up to 100000 years following initial emplacement of the waste containers.

Analysis of the Results

Transport of radionuclides in the saturated zone yields retardation of radionuclide migration due to sorption and dispersion. During this period of retardation, radioactive decay reduces the inventory of most radionuclides. Table 3 shows the calculated mean annual release rate of these radionuclides to the AE.

From the table, it shows that Ra-226 and U-234 have high annual release rates compared to other radionuclides. These isotopes do not retard significantly in the saturated zone. They have low retardation factors. Ra-226 is the second ingrowth product in the U-234 decay chain. That is U-234 decays to Th-230 and then Th-230 decays to Ra-226.

Table 3 The Mean Annual Release Rate (Ci/year) for Various Radionuclides

Radionuclide	AE
C-14	$7.346x10^{-5}$
Se-79	$5.666x10^{-5}$
Tc-99	$2.693x10^{-3}$
I-129	$8.023x10^{-6}$
Cs-135	$1.204x10^{-4}$
Ra-226	$4.608x10^{-1}$
U-234	1.066
Np-237	$1.030x10^{-4}$
Pu-239	$1.855x10^{-2}$
Pu-240	$3.466x10^{-3}$
Pu-242	$4.239x10^{-4}$

Dose/Risk Evaluations

The analyses of radiation hazard is very involved for several reasons: interaction of radiation and matter, and the relationships of dose and observable effects to humans. The total body dose calculation can be seen on Table 4.

Table 4 Total Body Dose Calculations (No Dilution Factor)

Isotope	**AEDE (rems)**	**CEDE (rems)**	**CCEDE (rems)**
C-14	$3.49x10^{-4}$	$3.49x10^{-4}$	$1.749x10^{-2}$
Se-79	$9.34x10^{-4}$	$1.10x10^{-3}$	$5.39x10^{-2}$
Tc-99	$1.37x10^{-2}$	$1.37x10^{-2}$	$6.91x10^{-1}$
I-129	$4.07x10^{-3}$	$4.58x10^{-3}$	$2.31x10^{-1}$
Cs-135	$1.72x10^{-3}$	$1.91x10^{-3}$	$9.54x10^{-2}$
Ra-226	$1.168x10^{+2}$	$1.022x10^{+3}$	$3.796x10^{+4}$
U-234	$4.729x10^{+1}$	$6.418x10^{+1}$	$2.973x10^{+3}$
Np-237	$3.26x10^{-2}$	1.240	$3.264x10^{+1}$
Pu-239	$7.64x10^{-1}$	2.116	$7.642x10^{+1}$
Pu-240	$1.43x10^{-1}$	$3.95x10^{-1}$	$1.428x10^{+1}$
Pu-242	$1.61x10^{-2}$	$4.57x10^{-2}$	1.6119

Using a cylindrical model to determine the seawater volume and assume that only one third of the volume is occupied by water, the calculation suggests

$$\text{Volume} = \pi \times (1{,}000)^2 \times 20 \times 0.3 = 2.09 \times 10^7 \text{ m}^3$$

Dilution factor = 315.58 m^3 / 2.09 x 10^7 m^3= 1.51 x 10^{-5}

Table 5 shows the result of calculations when the seawater dilution factor is incorporated. The existence of ocean clearly has significant impact in reducing the concentration of each radionuclide in the perimeter of the exclusion zone used in this study.

Table 5 Total Body Dose Calculations (With Dilution Factor)

Isotope	AEDE (rems)	CEDE (rems)	CCEDE (rems)
C-14	5.27×10^{-9}	5.27×10^{-9}	2.64×10^{-7}
Se-79	1.41×10^{-8}	1.66×10^{-8}	8.14×10^{-7}
Tc-99	2.07×10^{-7}	2.07×10^{-7}	1.04×10^{-5}
I-129	6.15×10^{-8}	6.92×10^{-8}	3.49×10^{-6}
Cs-135	2.60×10^{-8}	2.88×10^{-8}	1.44×10^{-6}
Ra-226	1.76×10^{-3}	1.54×10^{-2}	5.73×10^{-1}
U-234	7.14×10^{-4}	9.69×10^{-4}	4.49×10^{-2}
Np-237	4.92×10^{-7}	1.87×10^{-5}	4.93×10^{-4}
Pu-239	1.15×10^{-5}	3.20×10^{-5}	1.15×10^{-3}
Pu-240	2.16×10^{-6}	5.97×10^{-6}	2.16×10^{-4}
Pu-242	2.43×10^{-7}	6.90×10^{-7}	2.43×10^{-5}

SUMMARY

The emphasis of the analyses is the evaluation of releases of radionuclides to the AE. Two disruptive event scenarios were incorporated: earthquakes, and flooding the repository site.

The key points for selecting the sites are: the area is remote, low population density, geologically stable, large ocean dilutions, the economic growth potential is very low, and close proximity to the proposed NPP site.

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