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Radiation Hazard Index in Around NPP Candidate Site in West Kalimantan, Indonesia

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ABSTRACT

Before the construction of nuclear power plant (NPP), several documents must be prepared, including environmental and site permit documents. Environmental radiation monitoring is also necessary to ensure public safety and security. The purpose of this research is to obtain data on ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K which will be used for the preparation of site permit documents and environmental documents for NPP in West Kalimantan. In addition, it also determines the radiation hazard index (considering that there are 3 coal thermal power plants in the vicinity) by calculating the Radium equivalent index (**Ra_{eq}**), Representative Level Index (I_γ), Absorbed Dose rate (D), and Annual effective Dose Rate (D_{eff}) to estimate the potential radiological health risk. Based on this, the measurement of environmental radioactivity around the prospective site of NPP at West Kalimantan was carried out. Measurement of radionuclides using a Gamma Spectrometer an ORTEC P-type coaxial high-purity germanium (HPGe) detector for 24 hours, and for spectrum analysis it was used Personal Computer-based 4096-channel analyzer and processed using Maestro software gamma. The activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K in the soil were 23.18 ± 11.97; 24.03 ± 15.95; 12.18 ± 13.81; 113.80 ± 122.45 and 0.19 ± 0.18 respectively, lower than the world average and levels reported by several other countries (Malaysia, Thailand, China, and Japan). The hazard index values as Radium Equivalent Activity (**Ra_{eq}**), Representative Level Index (I_γ), Absorbed Dose Rate (D), and Annual Effective Dose Rate (**D_{eff}**) were 68.51 ± 41.43 $Bq.kg^{-1}$, 0.49 ± 0.30; 124.14 ± 66.16 $nGy.h^{-1}$ and 0.93 ± 0.50 $mSv.y^{-1}$ respectively. These values are below the permissible limits and in the safe zone category.

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Introduction

Humans are potentially exposed to radiation from various sources including nature, so the level of radioactivity and risk assessment is one of the main problems faced in radioecological research. Some researchers report that residents may be exposed to background radiation from terrestrial natural radionuclides at levels several times higher than the world average and this may pose health risks [1].

Regarding the Indonesian government's plan to build NPP, it is important to obtain data on the level of terrestrial radioactivity at the NPP site candidates in West Kalimantan. This is related to the preparation of several documents required by the IAEA, Indonesian Nuclear Energy Supervisory Agency, and the Regional and Central (Provincial) Environmental Agency [2]. As part of the NPP development plan, several important documents that need to be prepared are site permit documents and environmental permit documents.

According to the Regulation of the Minister of the Environment No. 05/2012, the plan for the construction and operation of NPP is an activity that requires Environmental Impact Analysis (EIA) Documents. According to the Regulation of the Minister of the Environment No. 08/2013, this is a strategic plan that needs to be assessed by the Central EIA Assessment Commission [3].

In general, the initial environmental conditions prior to the physical pre-construction activities of an NPP are referred to as the initial environmental baseline. Data on this condition, especially for radioactivity, is needed as a basis for environmental management and monitoring efforts, as well as to minimize impacts. Previous research has stated that West Kalimantan has the potential site for the construction of NPP because the location is free from earthquake risks, has a fairly wide coastline, and has a large number of uranium fuel reserves [3].

Methodology

Soil sampling was carried out in March and August 2021, the radius of 10-30 km from the NPP site candidates (Gosong Beach, Sungai Raya Village, Sungai Raya Islands District, Bengkayang Regency, West Kalimantan), which is geographically located between the GPS coordinates 108.8743 east longitude and 0.7156 south latitude. Soil samples were then taken at an area of 10 x 20 cm^2 and a depth of 5-20 cm as much as ± 2 kg in accordance with the IAEA recommendations [4].

The samples were then cleaned of organic residues and rock fragments, then packed and put in plastic to be brought to the laboratory. Before measuring the sample, the sample was dried in an oven for ± 24 hours at a temperature of 105°C to a constant weight. Furthermore, the dry matter is ground so that all particles pass through a 2 mm sieve, and put into a Marinelli container as much as ± 1 kg, closed sealed, and left for ± 30 days to achieve a secular balance of the decay product (radon gas) [5].

Soil sample preparation, measurements, and analysis of ^{238}U, ^{226}Ra, ^{232}Th, ^{40}K were carried out using Procedure of Center Research of Safety Technology, Radiation Metrology - Nuclear Quality, National Research and Innovation Agency that accredited with ISO/IEC 17025: 2017 (SOP 005.003/KN 05 02/KMR 2.1; SOP 014.003/KN 05 02/KMR 2.1; SOP 003.003/KN 05 02/KMR 2.1).

Radionuclide ^{238}U was determined directly from the specific activity of its decays, ^{234}Th at gamma energy of 1001.03 keV, ^{226}Ra was determined from its decays, ^{214}Bi at gamma energy of 609.31 keV or ^{212}Pb at gamma energy of 351.92 keV, while ^{232}Th was determined from its decay daughter, ^{228}Ac at gamma energy of 911.07 keV and 968.97 keV. Radionuclide ^{40}K was determined directly at gamma energy of 1460.75 keV, while ^{137}Cs was also measured directly at gamma energy of 661.66 keV [3].

The Activity concentration of radionuclides (^{226}Ra, ^{232}Th, ^{238}U, ^{40}K and ^{137}Cs) for this measurement were calculated using the equation -1 [3]:

$$A\ (Bq/kg) = \frac{Ns - Nb}{\varepsilon\gamma\ \text{p}\gamma\ W} \pm \sigma \qquad (1)$$

where A is radionuclide concentration in the sample (soil) in $Bq.kg^{-1}$, Ns is sample gamma counting rate/ counts per second (cps), Nb background gamma counting rate (counts per seconds/ cps), εγ the detector efficiency of specific γ-ray (%), pγ is the transition probability of gamma decay (yield), *W* is sample weight (kg), σ uncertainty of concentration measurement. The MDA (Minimum Detectable Activity) calculation with a 95% confidence level uses the following equation- 2 [3]:

$$\text{MDA} = 4.66\,\frac{\sqrt{\frac{NB_G}{t^2 B_G}}}{\varepsilon\gamma.\text{p}\gamma.W.Cf} \qquad (2)$$

Where MDA is the Minimum Detectable Activity ($Bq.kg^{-1}$), N_{BG} is the background gamma counting rate (counts per seconds/cps), t_{BG} is counting time of background (seconds), εγ is the detector efficiency of specific γ-ray (%), pγ is the transition probability of gamma decay (yield), W is the sample weight (kg), Cf is the self-absorption correction factor.

Radiation Hazard Indices Calculation

Several researchers have proposed radiological risk hazard assessment in the form of radiation hazard indices, such as radium equivalent activity (**Ra_{eq}**), representative level index (I_γ), absorption dose rate (D) nGy/h, annual effective dose rate/ AEDR (D_{eff}), External hazards index [**H_{ex}**] and internal hazard index [**H_{in}**] [6].

Radium equivalent activity index. Radium equivalent activity (**Ra_{eq}**) has been in practice for the assessment of radiological hazards of radioactivity in the environment. Radium equivalent activity (**Ra_{eq}**) is calculated to assess the uniformity of radiation exposure in the soil sample and can be calculated using equation-3 on the following equation [7]:

$$Ra_{eq} = C_{Ra} + 1.43\ C_{Th} + 0.077\ C_K \qquad (3)$$

Where:
Ra_{eq} is Radium equivalent = radioecology index, C_{Ra}, C_{Th} and C_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in $Bq.kg^{-1}$ respectively.

Ra_{eq} maximum in the soil must be less than 370 $Bq.kg^{-1}$, this value gives an annual dose rate of 1 $mSv.y^{-1}$. The concept of the radium equivalent is expressed as a single index which is a widely used radiation index associated with mixed gamma radiation of radium (uranium), thorium, and potassium in soil samples.

Representative Level Index. The representative level index ((I_γ) is used to estimate gamma radiation associated with the natural radionuclide in the soil. It is defined according to [8,9]:

$$I_\gamma = \frac{CRa}{150} + \frac{CTh}{100} + \frac{CK}{1500} \qquad (4)$$

Where:
C_{Ra}, C_{Th} , and C_K are the activity concentration ($Bq.kg^{-1}$) of radium, thorium and potassium in the soil samples. The safety value for I_γ(representative index) is ≤ 1. Assuming that the decay series of ^{137}Cs, ^{90}Sr and ^{235}U can be neglected because their contribution is very small to the total dose from the environmental background [10].

Absorbed Dose rates (D). The absorbed dose rate for outdoor air (D) expressed as $nGy.h^{-1}$, about 1 m above ground level, calculated according to the following guidelines [7]:

$$D\ (nGy.h^{-1}) = 4.462C_{Ra} + 0.621C_{Th} + 0.0417C_K \qquad (5)$$

Where:
C_{Ra}, C_{Th} , and C_K are the activity concentration ($Bq.kg^{-1}$) of radium, thorium and potassium in the samples.

Annual Effective Dose Rate (AEDR). The annual effective dose (**D_{eff}**) for outdoor air is the convertion coefficient from absorbed dose rate in air to effective dose (0.7 $SvGy^{-1}$) and the outdoor occupancy factor (0.2) that proposed by UNSCEAR [11]. Therefore, the annual effective dose rate ($mSv.y^{-1}$) is calculated by the formula:

$$\text{Effective Dose Rate } (mSv.y^{-1}) = D_{eff} =$$
$$D\ (nGy.h^{-1}) \times 8760\ h.y^{-1} \times 0.7 \times (10^3 \times 10^9)\ nGy \times 0.2 \qquad (6)$$
$$\mathbf{D_{eff}} = D \times 1.2264 \times 10^{-3}$$

UNSCEAR (2000) reported that the annual effective dose of natural radiation sources in the background area under normal conditions in the world is 1 $mSv.y^{-1}$. The International Commission on Radiological Protection (ICRP) has recommended the limit of annual effective dose from the natural radiation sources in normal background area is estimated to be 1 $mSv.y^{-1}$ [11].

External hazard index (H_{ex}). External hazard index (H_{ex}) is an assessment of the external hazard of gamma radiation from natural radionuclides contained in the investigated and evaluated soil sample, using the following equation-7:

$$H_{ex} = \frac{226Ra}{370} + \frac{232Th}{259} + \frac{40K}{4810} \quad (7)$$

The maximum value of Hex must correspond to the upper limit of Raeq, which is 370 $Bq.kg^{-1}$ or < 1 , so that the annual radiation dose is below 1.5 $mGy.y^{-1}$ [12].

Internal Hazard Index (H_{in}) must also be considered because it is harmful to the respiratory organs. The internal hazard index comes from radon radiation and its short-lived products. The $\mathbf{H_{in}}$ is calculated using the equation-8:

$$H_{in} = \frac{226Ra}{185} + \frac{232Th}{259} + \frac{40K}{4810} \quad (8)$$

The value of the external hazard index (H_{ex}) and internal hazard ($\mathbf{H_{in}}$) must be less than 1 [13].

Result and Discussion

The distribution of natural radionuclides ^{232}U, ^{226}Ra, ^{232}Th, and ^{40}K in soil samples around the NPP candidate's site at the West Kalimantan is shown in Figure 1.

This measurement is intended to ascertain the possible contribution of radioactive elements in the area prior to construction. In addition, it can also predict the geological conditions of the site. The results showed that the activity concentrations of ^{232}U, ^{226}Ra, ^{232}Th, and ^{40}K varied greatly, each ranging from <MDC–36.30 $Bqkg^{-1}$; 4.71–62.30 $Bqkg^{-1}$; 8.73–45.22 $Bqkg^{-1}$; 2.14–422.30 $Bq.kg^{–1}$. The average of activity concentrations of 232U, 226Ra, 232Th, 40K were 15.76; 23.18; 24.80; and 127.99 respectively, this value is still lower than the world average (35, 35, 30 and 400 $Bq.kg^{-1}$) and several other countries (Thailand, Malaysia, Japan, China, Hong Kong, and India) [11].

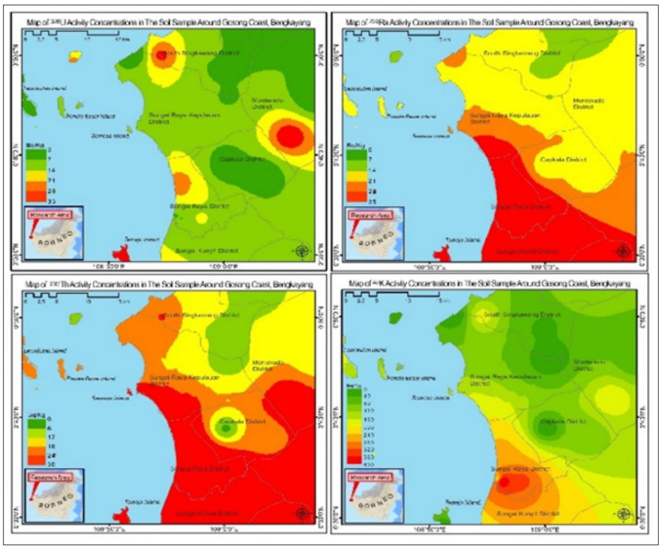

Figure 1: Concentration Activity Distribution of ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K in Site Candidate of NPP, in West Kalimantan

The mineral geological phenomena of the soil in the areas of Semesak Island, Temajo Island, Sungai Raya Village, and Sungai Kunyit Village containing ^{232}Th and ^{226}Ra higher than in other areas. This is related to the mineral potential in the Bengkayang is granite. Quartz and zircon sands are abundant in Bengkayang mostly derived from weathered granite rocks [12].

The data of radium equivalent activity ($\mathbf{Ra_{eq}}$), level index (I_g) and absorbed dose D ($nGy.y^{-1}$) and the annual effective dose rate($\mathbf{De_{ff}}$) are shown in Table 1.

The mean value of **radium equivalent activity** (Ra_{eq}) was 68.51±41.43 $Bq.kg^{-1}$ (21.19-145.28 $Bq.kg^{-1}$). According to UNSCEAR (2000) this value is acceptable because it is still lower than 370 $Bq.kg^{-1}$[11].

Generally, the **gamma representative index** (Iγ) is a screening parameter applied to assess the likelihood of the level hazard of radionuclides in the human body due to exposure to a certain number of effective annual doses of gamma radiation that decays from radionuclides in the soil. These data are quite important in monitoring gamma radiation in the human body. This index is related to the activity concentrations of ^{232}Th, ^{226}Ra, and ^{40}K in the soil samples [13].

The average representative index (Iγ) of soil samples from several locations around the NPP site candidate at West Kalimantan is 0.48 ± 0.30 $Bq.kg^{-1}$ (0.15–1.20 $Bq.kg^{-1}$). There were only two sites with Iγ values higher than the UNSCEAR (2000) recommendation, 1.04 and 1.20 $Bq.kg^{-1}$. However, most locations have Iγ-values which are still smaller than the UNCEAR (2000) recommendation [11].

The data of absorption dose rate (D), annual effective dose rate (AEDR), External hazards index [$\mathbf{H_{ex}}$] and internal hazard index [$\mathbf{H_{in}}$] are shown in Table 2.

The absorbed dose rate (D) and annual effective dose rate (AEDR). In this study, the absorbed dose rate (D) was found in the range of 46.78-247.91 $nGy.h^{-1}$ with mean 124.14 $nGy.h^{-1}$, so the value is greater than the range and world average (18-93 $nGy.h^{-1}$ and 60 $nGy.h^{-1}$). However, the effective dose rate was found to be in the range of 0.35-1.90 $mSv.y^{-1}$, and a mean of 0.93 $mSv.y^{-1}$. Compared to world average (1 $mSv.y^{-1}$) recommended by ICRP, the average annual effective dose rate value is still lower (0.93 $mSv.y^{-1}$) [14].

External hazards index ($\mathbf{H_{ex}}$) and Internal hazard index [$\mathbf{H_{in}}$]. External and internal hazard indexes must be less than 1, radon and its short-lived derivatives, although they have a harmful effect on the respiratory organs, can be ignored. In the study obtained external hazard index ($\mathbf{H_{ex}}$) ranged from 0.08-0.45 $mSv.y^{-1}$ and an average of 0.18 $mSv.y^{-1}$, while the internal hazard index ($\mathbf{H_{in}}$) was 0.23-1.22 $mSv.y^{-1}$ and an average of 0.62 $mSv.y^{-1}$. The $\mathbf{H_{ex}}$ value is in accordance with the ICRP recommendation (≤ 1), but there are two locations (in Sungai Raya Village) that have a $\mathbf{H_{in}}$ value slightly higher than 1 (1.17 and 1.22 $mSv.y^{-1}$), compared to others that still meet UNSCEAR, 2000 (≤1 $mSv.y^{-1}$) [11].

Conclusion

Data on the radioactivity levels of ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K have been obtained, as well as data on the estimation of radiation hazard indexes, such as the radium equivalent index (Ra_{eq}), Representative Level index (Iγ), Absorbed dose rate (D), Annual effective dose rate (D_{eff}), also external (H_{ex}) and internal hazard (H_{in}) indices. Furthermore, this data will be used in the preparation of licensing documents as required by the Ministry of Environment and the

Nuclear Energy Supervisory Agency in Indonesia, which refers to the IAEA regarding the plan to build the first nuclear power plant in Indonesia. In general, within a radius of 10-30 km from the prospective site (Gosong coast, Sungai Raya Village, Sungai Raya Kepulauan, Bengkayang, West Kalimantan) it is still relatively natural, and no radiation-contributing industry is found, so it is categorized as safe from exposure to natural radiation.

Data on the radioactivity levels of ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K have been obtained, as well as data on the estimation of radiation hazard indexes, such as the radium equivalent index (Ra_{eq}), Representative Level index ($I\gamma$), Absorbed dose rate (D), Annual effective dose rate (D_{eff}), also external (H_{ex}) and internal hazard (H_{in}) indices. Furthermore, this data will be used in the preparation of licensing documents as required by the Ministry of Environment and the Nuclear Energy Supervisory Agency in Indonesia, which refers to the IAEA regarding the plan to build the first nuclear power plant in Indonesia. In general, within a radius of 10-30 km from the prospective nuclear power plant site (Gosong Beach, Sungai Raya Village, Sungai Raya Islands, Bengkayang, West Kalimantan) it is still relatively natural and the area within the tolerable level so categorized as low in natural radiation.

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