Evaluation and assessment of 7 years of radioactivity monitoring data for Th232, Ra226, K40 on surface soil and the impact of the construction of mass rapid transit stations around pasar jumat nuclear area

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Abstract. Evaluation and assessment of 232Th, 226Ra, and 40K as natural radioactivity in surface soil in Pasar Jumat Nuclear Facility (PJNA) are important and are a routine activity to monitor the impact of human activities on changes in the level of natural radioactivity in soils. The monitoring data over 7 years period (2012 – 2018) was evaluated to show the time trends, the ratio concentration, and correlation between the outside of PJNA of natural radioactivity level on surface soils. The average radioactivity trend over 7 years monitoring of 232Th, 226Ra, and 40K concentration have varied data. While the mean ratio of 40K/232Th is range from 0.732 to 2.178. The average level of radioactivity concentration at surface soil during the pre-construction, construction, and operation of the MRT project for 232Th, 226Ra, and 40K are 23.34, 21.64, 21.56 bq/kg, then 19.30, 16.73, 18.93 bq/kg, and 27.47, 26.05, 22.26 bq/kg, respectively. The evaluation result state during the MRT project that only the concentration of 232Th on before construction period has a significantly different the mean. There was no influence of MRT construction on surface soil concentration.

1. Introduction
A terrestrial radionuclide has a long-lived half-life and related to the estimated age of the earth. Most daughter terrestrial radionuclides are alpha transmitters, so if they enter the human body through the food chain process it will have a negative impact on health (internal exposure). In addition, radiation exposure emitted by radionuclides becomes a source of background radiation which provides external exposure to the human body which impacts absorbed doses. Radioactivity level monitoring facility is really needed to all activities that produced, managed, developed, and utilized nuclear power with a purpose to know is there a change of the environmental radioactivity quality as an impact from the activities around the facility. One of the environmental parameters that can change its radioactivity level is surface soil. A number of the radioactive particles can be on surface soil because of the precipitation process. The natural background radiation in soil comes from 226Ra, 232Th, and 40K. UNSCEAR publication stated that approximately 85% of annual human radiation receipts come from natural radiation exposure and 18 percent come from soil [1]. Many studies about the radiation health effect have been reported, even in the low dose category. The UNSCEAR reported that many studies about...
low-dose-rate exposure from environmental sources have the potential to make a contribution to understanding radiation-induced cancer risk [2].

Pasar Jumat Nuclear Area (PJNA) is one of four nuclear facilities owned by Indonesia. In this facility, research and development activities about nuclear technique and its application for human welfare has conducted since 1966. Environmental radioactivity monitoring is a routine program that conducted in PJNA by Occupational And Environmental Department, one of a part in the Center For Isotope and Radiation Application - National Nuclear Energy Agency (CIRA - NNEA). Surface soil is one of the environmental samples that are monitored once a year in PJNA. The level of radioactivity of surface soil can change rapidly because of the addition of radioactive material resulting from the activities near or long distance from the monitoring area. The activities not only from using radioactive source but also can from non-radioactive source activity (e.g. construction, coal fly ash, and mineral industry)

Construction activities around PJNA have been developing rapidly since 2012 both inside and outside area, the outside is Mass Rapid Transit (MRT) started in 2014 to 2017, while on the inside is the development of Rare Earth Element (REE) reactor from 2017 to 2018. Building materials from both activities can make changes in the level of radioactivity on surface soil, but in this study, the long project (2012 – 2018) impact of MRT development is the main focus to be an evaluation and assessment to the level of surface soil radioactivity. Building materials could be classified into natural materials (e.g. sand, clay mineral and lime) and artificial products (e.g. cement, concrete and brick) [3,4]. Generally, the natural materials are formed during complex geochemical process, decided by the local geological conditions, geographical conditions and the phys-chemical properties of those materials [3], while the artificial products are mainly derived from both waste products (e.g. coal fly ash, oil shale ash and coal gangue) and industry by-products (e.g. power plants and phosphate fertilizer) [5]. Both of them contain some natural radionuclides (–Ra, –Th and -K).

Many studies from other countries on natural radioactivity on surface soil have been carried out (6–9), but evaluations and assessments of long-term monitoring related to trends in the level of radioactivity and the correlation effects of construction activities on environmental radioactivity around Nuclear Facilities in Indonesia are still scarce. The main objectives of the present study are to (1) investigate the activity concentration of natural radionuclides in 7 years monitoring; (2) evaluation and assessment of the impact of MRT construction on the level of natural radioactivity concentration; (3) provide basic information for radioactivity inventory.

2. Materials and Method

2.1. Study area Overview

PJNA is in Cilandak Sub-district, Jakarta Selatan Municipality. This Area consists of five work units; they are CIRA, Center for Nuclear Minerals Technology (CNMT), Center for Dissemination and Partnership (CDP), Center for Education and Training (CET), and Center for Radiation Safety Technology and Metrology (CRSTM), shown in Fig. 1, the most facilities in PJNA owned by CIRA. The average rainfall in 2012 to 2018 is 200.25 mm. The average climate parameter in a year is 60 to 80% humidity, 28°C temperature, 23.15 m/s wind speed, respectively.

Figure 2 shown the eleven soil sampling point is in three radius categories (200, 500, and 1000 meter) from the Gamma Irradiator building as a center point. In figure 2 also shown the sampling point is reduced to two locations started from 2014 (T11, T12) and two locations (T10, T13) in the year 2017 to 2018, all four of the locations on the outside of PJNA. Meanwhile, there was an addition of one sampling location (T7) in 2014; this is because a rare earth metal reactor will be built from 2016 to 2017. Reduction occurs because the location is changed to houses and roads. MRT construction is divided into three stages, they are pre-construction (2014 to 2015), construction (2016 to 2017) and operation (2018).
2.2. Sampling and sample preparation

61 soil samples were collected from ten sites from 2012 to 2013, nine from 2014 to 2016 and seven sampling points from 2017 to 2018, respectively. Sampling is carried out every summer (August to September) of the current year. Samples sampled at a depth of 5 cm from the soil surface. The Sample from each location is put into a plastic bag and was transferred for analysis in the laboratory after they are labeled accordingly to the location taken. Each raw sample was 1 kg, was confirmed clean from their impurity before dried in an oven at around 80°C along 24 hours to ensure that the moisture is completely removed. Samples were crushed, pulverized, homogenized and sieved with 200 mesh pore size. 160 grams of each weighted samples were placed in a polyethylene cylindrical container and were totally

**Figure 1.** Five Research Center at PJNA Facilities

**Figure 2.** Reduction of 11 PJNA sampling points in 7 years monitoring.
fixed for 30 days to reach secular equilibrium. This progression is important to be sure that radon gas confined within the volume and the decay chain will not break off. Radon (\(^{222}\)Rn) can achieve radioactive secular equilibrium with its parent radium (\(^{226}\)Rn) after a proximately 7 half-lives \[10\] .

2.3. Measurement and Radioactivity Analysis

The activity of \(^{232}\)Th, \(^{226}\)Ra and \(^{40}\)K in Bq.K\(^{-1}\) were measured by gamma-ray spectrometry based on a highly pure germanium coaxial detector (HPGe) with a relative efficiency of 13.264 \% at 1.33 MeV of \(^{60}\)Co line. The detector was manufactured by Canberra and hosts a high purity germanium crystal with an active diameter of 70 mm, 769.3 cm\(^3\) of volume, operated 2000 V with range energy from 5 to 2100 keV, 1.816 of gauss ratio, 41.551 of the peak to Compton ratio and a resolution of 1.98 keV. Genie 2000 software program from Canberra analyzed each gamma-ray spectrum. The HPGe detector is in a housing made of lead with of thickness of 10 cm which functions to reduce background radiation

A soil standard reference material with multi-nuclide gamma-ray energy was used to obtain the energy to an efficiency calibration curve that using equation \[1\]. The reference material contain gamma energy of \(^{210}\)Pb (10.8 keV), \(^{133}\)Ba (80.10, 276.40, 302.84, and 356.01 keV) 383.85, \(^{241}\)Am (59.54 keV), \(^{137}\)Cs (661.65 keV), and \(^{60}\)Co (1173.23 and 1332.49 keV) radionuclides.

\[
\mathcal{E} = \frac{R_{ST} - R_{B}}{A \times T_s}
\]  

Where \(\mathcal{E}\) is the efficiency, \(R\), is net peak area of reference material (count), \(R_b\) is background net peak area (count), \(A\), is the activity of nuclide reference material (Becquerel), and \(T_s\) is the time of counting in 24 hours. The efficiency from the specific energy of standard material resulted in a fitting function that used for calculating the absolute efficiency at any gamma-ray energy from the soil sample \[11\] . The efficiency curve of soil standard material that measured in 2018 was shown in figure 3 resulting in the exponential fitting function \(Y = 0.035e^{-0.003x}\). Figure 3 also showed the energy of \(^{210}\)Pb (10.8 keV) is not included in line equation function because of the capability of the detector which cannot measure low energy gamma.

The activity of \(^{40}\)K in surface soil was determined in 1460 keV line energy, while \(^{226}\)Ra and \(^{232}\)Th were determined by their nuclide decay product. The \(^{226}\)Ra was obtained from the average of \(^{214}\)Pb (351.9 keV) and \(^{214}\)Bi (609.3 and 1764.5 keV), \(^{232}\)Th from the average of \(^{212}\)Pb (238.6 keV) and \(^{228}\)Ac (911.1 and 338.42 keV) decay products. The activity concentration Bq/kg \((A)\) in the soil sample was obtained as follows:

\[
A = \frac{R_{SP} - R_{Bq}}{P \times m \times T_s}
\]
Where \( R_{sp} \) is the net peak area of the sample, \( p \) is the abundance of the gamma-peak in a radionuclide, \( E \) is measured efficiency for each gamma-ray peak using the fitting function equation, and \( m \) is sample mass in kilograms.

3. Result and Discussion

3.1 Annual Activity Concentration of radionuclides

The average and its standard error, standard deviation, median, minimum and maximum activity concentration each radionuclide in the year of measurement is presented in Table 1. The average concentration of naturally radionuclide in seven years monitoring were found to vary from 16.763 ± 1.544 in 2015 to 32.650 ± 2.271 in 2013 for \( ^{232} \text{Th} \), from 14.184 ± 3.312 in 2016 to 20.010 ± 9.509 in 2017 for \( ^{226} \text{Ra} \), while \( ^{238} \text{K} \) from 19.820 ± 3.031 in 2017 to 30.888 ± 5.969 Bq/Kg in 2016. It was observed that the average activity concentration in each year is dominated by \( ^{238} \text{K} \) than both \( ^{226} \text{Ra} \) and \( ^{232} \text{Th} \). Also, it was shown in Table 1 the specific radioactivity ratio for \( ^{238} \text{K}/^{232} \text{Th} \) and \( ^{238} \text{K}/^{226} \text{Ra} \). The lower radioactivity ratio indicating the concentration is dominated both \( ^{232} \text{Th} \) and \( ^{226} \text{Ra} \) that was possible from geochemical composition and the origin of soils type. The result for \( ^{238} \text{K}/^{232} \text{Th} \) ratio range is from a minimum of 0.732 in 2013 to 1.751 in 2015. While the ratio for \( ^{238} \text{K}/^{226} \text{Ra} \) varies from 0.991 in 2017 to 2.178 in the year 2016. The ratio results in this study are lower than the study was conducted in Kuwait, Iraq [10]. Most of the reported mean for \( ^{232} \text{Th} \) and \( ^{226} \text{Ra} \) are in the determined ranges in this study, while reported \( ^{238} \text{K} \) mean are higher than our results, but the maximum activity of \( ^{238} \text{K} \) in 2015 and 2016 are in range from the reported results of UNSCEAR 2008 [12] which state that the average activity concentrations of radionuclides in soils of Indonesia in West Java are 0.5 – 66, 2.4 – 242, and 48 – 252 Bq/kg for \( ^{232} \text{Th} \), \( ^{226} \text{Ra} \), and \( ^{238} \text{K} \), respectively. It seems the result of this study is lower than the reported from Lampung – Sumatra land, which state that the observed surface soil are in 35.5 ± 0.26 to 65.32 ± 0.63, 2.50 ± 0.67 to 65.12 ± 1.67, and 185.15 ± 2.80 to 424.68 ± 4.68 for \( ^{232} \text{Th} \), \( ^{226} \text{Ra} \), and \( ^{238} \text{K} \), respectively [13]. The highest mean of this study if compared with other countries that have a result higher for \( ^{232} \text{Th} \) that was 12.70 ± 0.17 Bq/kg, higher of \( ^{226} \text{Ra} \) that was 16.99 ± 0.21 Bq/kg, and lower of \( ^{238} \text{K} \) for 333.20 ± 7.59, respectively [10]. The result radioactivity is compared by Georgia soil that was higher of \( ^{232} \text{Th} \) for 26.9 Bq/kg, lower of \( ^{226} \text{Ra} \) for 25.4 Bq/kg, and lower of \( ^{238} \text{K} \) for 464 Bq/kg [14].

3.2. The impact of MRT development on soil surface quality

The quality of radioactivity on soil in terms of before construction (2012-2013) pre-construction (2014 to 2015), construction (2016 to 2017), and operation (2018) for \( ^{232} \text{Th} \), \( ^{226} \text{Ra} \), and \( ^{238} \text{K} \) are showed in figure 4, 5, and 6. The hypothesis there was a difference average of \( ^{232} \text{Th} \), \( ^{226} \text{Ra} \), and \( ^{238} \text{K} \) for four-period constructions. It seems that the average of \( ^{226} \text{Ra} \) and \( ^{238} \text{K} \) not far for each other period (figure 5 and 6), while for \( ^{232} \text{Th} \) there was differences average between before construction than the three other periods (figure 4). In figure 4 showed the mean of before construction was higher than the three other, its causes can from many things such as; public construction houses near from sampling location, sample preparation was not clean from the residual, or the background of counting was lower than the three other periods. Accordingly, the result of \( ^{232} \text{Th} \) before construction MRT cannot determine the specific cause of this study.

Figure 5 showed the boxplot graph for the distribution of \( ^{226} \text{Ra} \) radioactivity. On that graph, there was two outliers on construction period that have a higher concentration 76.33 and 39.02 Bq/kg which both locations were near from REE laboratory and also on that period the pre-construction of REE reactor was started. There have been no reports of previous studies on the concentration of building materials in Indonesia so that the best approach is used from other countries. Comparison of all surface soil radioactivity in a four-period construction with radioactivity of building materials gives results that are not much different for \( ^{232} \text{Th} \) and \( ^{226} \text{Ra} \), while \( ^{238} \text{K} \) is lower. The previous study was stated that sand material in China has an average concentration of \( ^{232} \text{Th} \), \( ^{226} \text{Ra} \), and \( ^{238} \text{K} \) was 47.77 ± 12.1, 32.57 ± 21.6, and 249.67 ± 22.8 Bq/kg, respectively [5]. Meanwhile, the result of this study is lower than the cement material that was reported in the previous study.
Table 1. Descriptive of $^{232}$Th, $^{226}$Ra, and $^{40}$K in seven years monitoring

| Variable      | N  | Range   | Min    | Max    | Median  | Mean     | Std. Err. of Mean | Ratio $^{40}$K/$^{232}$Th and $^{40}$K/$^{226}$Ra | Std. Dev |
|---------------|----|---------|--------|--------|---------|----------|------------------|-----------------------------------------------|----------|
| Th232_2012    | 10 | 16.91   | 21.963 | 38.874 | 32.605  | 31.998   | 1.561            | 0.879                                         | 4.936    |
| Th232_2013    | 10 | 23.49   | 19.780 | 43.266 | 33.061  | 32.650   | 2.271            | 0.732                                         | 7.181    |
| Th232_2014    | 9  | 23.73   | 20.990 | 44.716 | 27.12   | 29.922   | 0.855            | 0.732                                         | 7.881    |
| Th232_2015    | 9  | 15.133  | 10.310 | 25.443 | 15.757  | 16.763   | 1.544            | 1.751                                         | 4.633    |
| Th232_2016    | 9  | 15.787  | 16.776 | 32.563 | 18.795  | 19.971   | 1.547            | 1.547                                         | 4.807    |
| Th232_2017    | 7  | 7.67    | 18.876 | 26.551 | 24.281  | 23.791   | 0.953            | 0.833                                         | 2.521    |
| Th232_2018    | 7  | 12.94   | 15.914 | 32.563 | 18.795  | 19.971   | 1.547            | 1.547                                         | 4.807    |
| Ra226_2012    | 10 | 17.56   | 12.054 | 29.612 | 19.053  | 19.267   | 1.635            | 1.460                                         | 5.172    |
| Ra226_2013    | 10 | 20.9    | 6.384  | 38.806 | 24.378  | 21.053   | 1.916            | 1.394                                         | 6.060    |
| Ra226_2014    | 9  | 23.49   | 6.300  | 39.016 | 11.05   | 14.184   | 2.578            | 1.458                                         | 7.734    |
| Ra226_2015    | 9  | 37.46   | 1.341  | 38.806 | 17.853  | 17.547   | 2.578            | 1.394                                         | 12.051   |
| Ra226_2016    | 9  | 32.72   | 6.300  | 39.016 | 11.05   | 14.184   | 2.578            | 1.458                                         | 7.734    |
| Ra226_2017    | 7  | 7.018   | 6.363  | 76.330 | 11.816  | 20.010   | 9.509            | 0.991                                         | 25.158   |
| Ra226_2018    | 7  | 13.91   | 13.136 | 27.050 | 18.138  | 18.929   | 2.035            | 1.176                                         | 5.385    |
| K40_2012      | 10 | 32.1    | 12.608 | 44.706 | 27.242  | 28.121   | 3.353            | *                                            | 10.602   |
| K40_2013      | 10 | 44.542  | 1.777  | 46.319 | 22.269  | 23.885   | 4.910            | *                                            | 15.527   |
| K40_2014      | 9  | 31.746  | 7.010  | 38.756 | 23.473  | 25.587   | 3.578            | *                                            | 10.734   |
| K40_2015      | 9  | 62.41   | 2.004  | 64.415 | 32.239  | 29.355   | 5.947            | *                                            | 17.841   |
| K40_2016      | 9  | 6.07    | 10.818 | 72.889 | 26.271  | 30.888   | 5.969            | *                                            | 17.906   |
| K40_2017      | 7  | 19.312  | 11.547 | 30.859 | 17.147  | 19.820   | 3.031            | *                                            | 8.019    |
| K40_2018      | 7  | 27.270  | 10.305 | 37.575 | 19.29   | 22.257   | 3.644            | *                                            | 9.642    |

For comparing is there a difference of average for four-period MRT construction, we used Analysis of Variance (ANOVA) test that has used before in Iran, the t-test is an inferential statistical test that determines whether there is a statistically significant difference between the averages of two independent groups [15]. The hypothesis was there average differences between four-period constructions with the significance level was 0.05. Table 2 showed the result of ANOVA, from the table below can be known the F count of $^{232}$Th, $^{226}$Ra, and $^{40}$K was 10.298, 0.159, and 0.241, respectively. Meanwhile, table F with significance, numerator, and de-numerator were 0.05, 3 and 57, respectively, which were 2.7743. The average difference expressed by F is lower than the F table. Thus, only $^{232}$Th has the average difference as evidenced by the highest average value of before construction period than to the others. Accordingly, can be determined that the impact of MRT construction did not influence the radioactivity concentration in surface soil during seven years of monitoring.
Figure 4. Radioactivity of $^{232}$Th on the period of construction

Figure 5. Radioactivity of $^{226}$Th on the period of construction
Figure 6. Radioactivity of 40K on the period of construction

Table 2. ANOVA Table

|     | Sum of Squares | df  | Mean Square | F     |
|-----|----------------|-----|-------------|-------|
| **Th232** |                |     |             |       |
| Between Groups (Combined) | 1360.824 | 3   | 453.608     | 10.298 |
| Linear Term | Unweighted | 623.320 | 1 | 623.320 | 14.151 |
|           | Weighted     | 1040.567 | 1 | 1040.567 | 23.624 |
|           | Deviation    | 320.256 | 2 | 160.128 | 3.635 |
| Within Groups |               |     |             |       |
| Total     | 2510.660      | 57  | 44.047      |       |
| **Ra226** |                |     |             |       |
| Between Groups (Combined) | 60.214 | 3   | 20.071      | .159  |
| Linear Term | Unweighted | .470 | 1 | .470 | .004  |
|           | Weighted     | 5.079 | 1  | 5.079 | .040  |
|           | Deviation    | 55.135 | 2 | 27.568 | .219  |
| Within Groups |               |     |             |       |
| Total     | 7177.204      | 57  | 125.916     |       |
| **K40**   |                |     |             |       |
| Between Groups (Combined) | 137.003 | 3   | 45.668      | .241  |
| Linear Term | Unweighted | 86.480 | 1 | 86.480 | .457  |
|           | Weighted     | 43.188 | 1 | 43.188 | .228  |
|           | Deviation    | 93.815 | 2 | 46.908 | .248  |
| Within Groups |               |     |             |       |
| Total     | 10794.062     | 57  | 189.370     |       |
|           | 10931.065     | 60  |             |       |
4. Conclusion
Seven years of monitoring made the concentration of radioactivity at surface soil change over time. Human activities are thought to cause changes in the quality of environmental radioactivity on the surface soil. By the ANOVA test, this study concluded that MRT development activities do not influence the concentration of surface soil radioactivity. The surface soil radioactivity in this study is mostly for $^{232}$Th and $^{226}$Ra still within the measurement range from other countries, while for $^{40}$K it is below.

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