Analysis of external radiation exposure from building materials using resrad-build (case study: perumnas bumi guwosari)

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Abstract. One of the natural radiation that is not realized by humans comes from radionuclides in building materials. So, it becomes necessary to study the natural radioactivity in various building materials to calculate the annual effective dose of the public in Perumnas Bumi Guwosari room model. In this paper, activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K in 5 cement, 5 sand, 5 red brick, and 5 ceramic samples were bought directly from the local hardware store in Yogyakarta were determined by gamma-ray spectrometry with HPGe detector. The activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K ranged from $23.87 \pm 20.88$ to $49.31 \pm 31.04$ Bq.kg$^{-1}$, $11.56 \pm 12.41$ to $36.62 \pm 14.34$ Bq.kg$^{-1}$ and $0.1443 \pm 11.2029$ to $58.82 \pm 15.01$ Bq.kg$^{-1}$, respectively in various samples. The radium equivalent activity ranged from $17.7338$ to $136.8901$ Bq.kg$^{-1}$ are lower than the limit of 370 Bq.kg$^{-1}$ set by UNSCEAR. The highest value of external and internal hazard indices was found in ceramic samples 0.3705 and 0.5317 are below the UNSCEAR recommendation ($H_{ext} \leq 1$ and $H_{in} \leq 1$). The results of calculating the annual effective dose using RESRAD-BUILD ranged 0.654 - 0.661 mSv.y$^{-1}$ is lower than the annual recommended limit of 1 mSv.y$^{-1}$. The parameters that most influence the increase in external radiation dose rate from building materials are the composition, density, and thickness of the floor and wall.

1. Introduction

Material from soil and rocks in the earth’s crust contains most of the radioactive series of uranium ($^{238}$U), thorium ($^{232}$Th), and a radioactive isotope of potassium ($^{40}$K). Some materials are made of soil and rock, which are building materials such as bricks, lightweight aerated concrete, and cement [1]. Doses of external and internal radiation from building material approximately 95.83% of the total natural radiation dose [2].

In the current era, the houses in Yogyakarta using brick, ceramic, cement and tile as the main material of the building where the materials came from the soil and rocks [3]. In addition, the sand from Mount Merapi is also widely used as a mixture of cement, concrete, or brick. The existence of natural radionuclides in building the main ingredient in Yogyakarta will contribute to external radiation exposure to residents of the house in which each person spends 80% of their time indoors. Therefore, this study was conducted in order to obtain any information in the form of radionuclides
contained in building materials, hazard index of building materials, annual effective dose received by residents in the room, especially with Perumnas Bumi Guwosari room model, located in Pajangan district, Bantul regency, and analyze any parameters that most influence on the increase in the external radiation dose rate. This room model selected as the study site because it is a Perumnas is still growing in terms of settlement expansion as well as the variation of the house from 1995 until now.

The software used to calculate radiation doses resulting from the occupancy of buildings contaminated with radioactive material is RESRAD-BUILD. By obtaining a dose of external radiation by using software RESRAD-BUILD, it can be seen whether the dose of external radiation received by residents was below the limit of effective dose for building materials suggested by the International Commission on Radiological Protection (ICRP) 1 mSv per year [1].

Research using RESRAD-BUILD software was conducted by S. Pepin. The purpose of his study was to compare external dose calculations using the CEN method and RESRAD-BUILD software. The building materials used in modeling are concrete, bricks as a building block for walls and floors in the form of concrete. Whether using RESRAD-BUILD software or the CEN method, the results of both calculations are the same regarding the exposure dose assuming that the time a person spends in a room is 7000 hours/year. In addition, the results show that the ambient dose rate will increase by 5-9 nSv/year [4].

2. Methodology

In total, 20 samples were bought from the local hardware store in Yogyakarta and were analyzed by gamma-ray spectrometry. These samples included cement (5 in number), sand (5), red brick (5), and ceramic 30 x 30 cm (5). Redbrick and ceramic samples destroyed to use a hammer before then milled using a ball mill. While direct samples of the cement and sand milled using a ball mill. Then, the results of this milling sieved with a sieve 75μm diameter to obtain a homogeneous sample. The samples were sieved poured to the size of 100 mL polyethylene tubes. When it is full, then the tube was sealed with tape and labeled as samples information and when the sample is prepared. Then, all samples are weighed using a mass balance. The sample is settled for one month, to reach radionuclides equilibrium.

After a month of settling, the samples were counted using a gamma spectrometer that had been carried out with energy calibration using standard sources 241Am (59.5 keV) and 60Co (1173.2 keV and 1332.5 keV). In addition to counting samples, a standard sample of IAEA Soil 6 which was inserted in a polyethylene tube was also carried out for 12 hours counting. Each sample was counted in the detector for a minimum of 12 hours, i.e. 43,200 seconds.

All twenty samples of building materials counted using gamma spectrometer and analyzed the gamma spectrum peak using Genie 2000. In the information data displayed by Genie 2000, there was energy, net peak area, radionuclide types at the net peak area, hal-life, and so on. Then the results of this analysis can be used to calculate for the specific activity.

Before looking for a specific activity of the sample, especially first to determine the efficiency calibration of absolute efficiency. The efficiency calibration performed using a standard material of known IAEA Soil 6 fabricated on January 30, 1983 and counting on April 25, 2019. The equation that will be obtained are:

\[ y = ax + b \]

In this case:
- \( y \): natural logarithm (ln) the efficiency of the detector
- \( a, b \): constants
- \( x \): natural logarithm (ln) of energy (keV)
The data from the detector efficiency on the sample at a particular energy, it is used to calculate the specific activity of radionuclides contained in the sample. To find activity in the sample, use the following equation [5]:

\[ A = \frac{N}{\varepsilon_{(E)} \cdot m \cdot P_y \cdot t} \]  

(2)

In this case:
- \( A \): radionuclide activity (Bq/kg)
- \( \varepsilon_{(E)} \): absolute efficiency in certain energy
- \( N \): net peak area (cps)
- \( m \): sample mass (kg)
- \( P_y \): the absolute intensity of gamma-ray (yield)
- \( t \): counting time (second)

In measuring activity, measurements of activity uncertainty are also carried out which have the following equation [6]:

\[ u(A) = \frac{1}{t \cdot P} \sqrt{\left(\frac{1}{\varepsilon}\right)^2 \cdot u^2(\eta_\eta) + \left(\frac{u(\varepsilon)}{\varepsilon}\right)^2 \cdot u^2(\varepsilon)} \]  

(3)

In this case:
- \( u(A) \): uncertainty of the activity (Bq)
- \( t \): counting time (second)
- \( P \): the absolute intensity of gamma-ray (yield)
- \( \varepsilon \): detector efficiency
- \( u^2(\eta_\eta) \): uncertainty of count (cps²)
- \( u^2(\varepsilon) \): uncertainty of detector efficiency

However, there is no data uncertainty efficiency, the efficiency uncertainty variable is treated as zero, so \( \left(\frac{u(\varepsilon)}{\varepsilon}\right)^2 \cdot u^2(\varepsilon) \) can be ignored.

Activity (Bq/kg) is the value of the specific activity of radionuclides then be input on RESRAD-BUILD software and used to calculate the hazard index. In addition, the data size of the house of each type of housing in Perumnas Bumi Guwosari also is input on RESRAD-BUILD. In this analyzing is used geometry 1-Room Warehouse where the size of the room is approached by the size of the bedroom. Bedroom selected as the analyzing room, due to people spending more time in the bedroom when they are at home. Size of the bedroom in the house of each house type is shown in Table 1.

**Table 1.** Bedroom size of various types of houses in Perumnas Bumi Guwosari.

| No | Home Type | Size Bedroom (m) |
|----|-----------|------------------|
| 1  | 21        | 2.5 x 2.5        |
| 2  | 27        | 3 x 2.4          |
| 3  | 29        | 3 x 2.5          |
| 4  | 36        | 3 x 3            |
| 5  | 45        | 3 x 3            |
Based on the 1982 UNSCEAR and 1999 EC, there are three indices which can be calculated based on activity concentration. The three indices are equivalent radium equivalent ($R_{eq}$), external hazard index ($H_{ext}$), and internal hazard index ($H_{in}$) [7, 8].

Equivalent radium activity describes gamma radiation emissions from a combination of uranium (in this case turned away radon), thorium, and potassium. $R_{eq}$ calculated using the following equation [7]:

$$R_{eq} = A_{Ra} + 1.43 A_{Th} + 0.077 A_{K}$$

with $A_{Ra}$ is the specific activity of radium, $A_{Th}$ is a specific activity of thorium, and $A_{K}$ is the specific activity of potassium. The maximum value is 370 Bq/kg for the purposes of security and maintaining the external dose values were below 1.5 mSv/year [7].

External hazard index estimating potential radiological hazards. This parameter has no units and is a radiation safety criteria for building materials to the value $H_{ext} \leq 1$ [7]. $H_{ext}$ caused by gamma radiation on building materials is calculated using the following equation [7]:

$$H_{ext} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{159} + \frac{A_{K}}{4810} \leq 1$$

with $A_{Ra}$ is the specific activity of radium, $A_{Th}$ is a specific activity of thorium, and $A_{K}$ is the specific activity of potassium.

Internal radiation exposure from radon and its decay radionuclide can be measured by calculating the internal hazard index value ($H_{in}$) using the following equation [7]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{209} + \frac{A_{K}}{4810} \leq 1$$

with $A_{Ra}$ is the specific activity of radium, $A_{Th}$ is a specific activity of thorium, and $A_{K}$ is the specific activity of potassium. The value of the safety limit is $H_{in} \leq 1$ [7].

3. Results and Discussion

3.1. Radionuclide Identification in Building Materials Sample

In the twenty samples of building materials, there is a count of the energies of the radionuclides are read by the gamma spectrometry system. Of these energies, can be identified types of radionuclides contained in twenty samples of building materials. In one radionuclide can have some energy to the value of different yields. Yield is a fraction of the radiation energy emitted during the decay process [9]. The higher the yield, the more likely the energy of these radionuclides read by the counting system.

Based on the counting using gamma-ray spectrometry, radionuclides contained in twenty samples of building materials are $^{212}$Pb, $^{214}$Pb, $^{228}$Ac, $^{214}$Bi, dan $^{40}$K as shown in Table 2. No fission radionuclides were counted in all samples of building materials. Information on radionuclide count obtained from basic spectrum analysis is represented by the net peak area.

| Sample name | $^{214}$Pb | $^{214}$Bi | $^{212}$Pb | $^{228}$Ac | $^{40}$K |
|-------------|------------|------------|------------|------------|--------|
| sm-01       | 3275       | 3167       | 3070       | 1037       | 4716   |
| sm-02       | 2416       | 2649       | 1712       | 806        | 5063   |
| sm-03       | 3159       | 2978       | 3012       | 1014       | 5672   |
| sm-04       | 3349       | 2099       | 3251       | 1117       | 5099   |
| sm-05       | 2352       | 2486       | 1825       | 936        | 5254   |
| pa-01       | 2262       | 3167       | 2446       | 860        | 5984   |
3.2. Radionuclide Activity Calculation

Before calculating radionuclide activity in building material samples, detection limit calculations were carried out. Then, detector efficiency is calibrated using the standard IAEA Soil 6 standard.

Based on Figure 1, the efficiency calibration equation is \( \ln \epsilon = -1.2669 \ln E + 3.2851 \) with the \( R^2 = 0.9618 \). Before counted and analyzed, all samples of building materials in this study first settling for less than 1 month to reach secular radionuclide equilibrium between parent radionuclide and radionuclide children reached. Samples were allowed to stand in a closed state to ensure that no \(^{222}\)Rn is released from the system [10].

The determination of \(^{226}\)Ra activity uses a direct gamma energy spectrometry system 186.211 keV. However, because the energy yield is very small is 3.64% and there is a contribution of \(^{235}\)U to 185.7 keV, the measurement is not reliable. Therefore, a more sensitive and accurate measurement method is

|   | pa-02 | pa-03 | pa-04 | pa-05 | bm-01 | bm-02 | bm-03 | bm-04 | bm-05 | km-01 | km-02 | km-03 | km-04 | km-05 |
|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| pa-02 | 3513 | 3548 | 3107 | 1039 | 6568 |       |       |       |       |       |       |       |       |       |
| pa-03 | 3719 | 3471 | 3008 | 1041 | 6414 |       |       |       |       |       |       |       |       |       |
| pa-04 | 3038 | 3124 | 3076 | 1027 | 6294 |       |       |       |       |       |       |       |       |       |
| pa-05 | 3328 | 2837 | 2800 | 953 | 6470 |       |       |       |       |       |       |       |       |       |
| bm-01 | 2357 | 2533 | 2299 | 836 | 5612 |       |       |       |       |       |       |       |       |       |
| bm-02 | 2157 | 2457 | 2335 | 893 | 5461 |       |       |       |       |       |       |       |       |       |
| bm-03 | 2008 | 2225 | 2134 | 822 | 5487 |       |       |       |       |       |       |       |       |       |
| bm-04 | 2673 | 2896 | 2862 | 982 | 6217 |       |       |       |       |       |       |       |       |       |
| bm-05 | 1257 | 1426 | 1353 | 425 | 3218 |       |       |       |       |       |       |       |       |       |
| km-01 | 1534 | 1632 | 1595 | 656 | 3460 |       |       |       |       |       |       |       |       |       |
| km-02 | 1998 | 2017 | 3114 | 768 | 4514 |       |       |       |       |       |       |       |       |       |
| km-03 | 1700 | 1726 | 1576 | 546 | 3566 |       |       |       |       |       |       |       |       |       |
| km-04 | 1912 | 1789 | 2475 | 766 | 3656 |       |       |       |       |       |       |       |       |       |
| km-05 | 1669 | 1508 | 2132 | 744 | 3427 |       |       |       |       |       |       |       |       |       |

Sm code for cement; pa for sand; bm for red brick, and km for ceramic.
used using gamma energy from $^{214}\text{Pb}$ and $^{214}\text{Bi}$ by waiting until secular equilibrium occurs between $^{226}\text{Ra}$ and $^{222}\text{Rn}$ [11].

Determination of activity $^{232}\text{Th}$ using several radionuclides of progeny may be carried out under certain conditions. The long half-life thorium decays to $^{228}\text{Ra}$ which has a half-life of 6.7 years, the half-life of $^{228}\text{Ra}$ is the longest half-life of other progeny radionuclides. Therefore, in $^{232}\text{Th}$ pure samples, if there are no physical processes and chemical processes that occur, it will not interfere with equilibrium $^{232}\text{Th}$ and $^{228}\text{Ra}$. It takes around 35 years for $^{228}\text{Ra}$ to reach the same activity as $^{232}\text{Th}$. $^{228}\text{Ra}$ only produces very low yield low energy gamma rays which cannot be relied upon for $^{232}\text{Th}$ activity calculation. The decay product of $^{228}\text{Ra}$ is $^{228}\text{Ac}$. Actinium-$^{228}$ has a half-life of 6.17 hours, so the activity of $^{228}\text{Ac}$ will increase quite quickly and reach equilibrium with activities $^{228}\text{Ra}$ and $^{232}\text{Th}$. Both are solids under normal conditions. Therefore, if it is assumed that no process occurs that disrupts its equilibrium, then $^{228}\text{Ac}$ can be used to determine activity $^{232}\text{Th}$ [12]. In addition, the activity of $^{232}\text{Th}$ can also be approached with radionuclide $^{212}\text{Pb}$. $^{212}\text{Pb}$ has a half-life of 10.64 hours, so that $^{212}\text{Pb}$ activity will increase rapidly and reach equilibrium with $^{228}\text{Ra}$ and $^{232}\text{Th}$ activities. In addition, the yield value of $^{212}\text{Pb}$ is quite large at 43.3%.

While the determination of $^{40}\text{K}$ activity can be done easily, because this radionuclide has only one peak of the gamma spectrum and its half-life is quite long, which is $1.28 \times 10^{9}$ years.

After secular equilibrium is reached, measurements can be made on $^{226}\text{Ra}$, $^{232}\text{Th}$, and $^{40}\text{K}$ activities using the gamma spectrometry system. In secular equilibrium, the parent radionuclide activity is the same as the child radionuclide activity. Determination of $^{226}\text{Ra}$ activity using $^{214}\text{Pb}$ at 295.22 keV with a yield of 18.15% and energy 351.93 keV with yields of 35.1% and $^{214}\text{Bi}$ on energy 609.31 keV with yields of 44.6%. Activity determination $^{232}\text{Th}$ used $^{228}\text{Ac}$ children's radionuclides at 911.2 keV with yields of 25.8% and $^{212}\text{Pb}$ on 238.6 keV with yields of 43.3%. Determination of $^{40}\text{K}$ activity at 1460 keV with a yield of 10.67%. By using Equation (2), the data obtained for radionuclide activity in the sample of building materials as in Table 3.

| Samples name | Activity (Bq / kg) | $^{226}\text{Ra}$ | $^{232}\text{Th}$ | $^{40}\text{K}$ |
|--------------|------------------|------------------|------------------|------------------|
| sm-01        | 54.98 ± 26.87    | 22.15 ± 16.19    | -                | -                |
| sm-02        | 20.64 ± 22.27    | 1.12 ± 5.54      | -                | -                |
| sm-03        | 47.81 ± 26.72    | 22.46 ± 15.45    | 56.01 ± 0.72     | -                |
| sm-04        | 31.04 ± 19.75    | 26.53 ± 14.80    | -                | -                |
| sm-05        | 17.44 ± 22.33    | 12.08 ± 7.14     | -                | -                |
| pa-01        | 33.31 ± 35.52    | 12.39 ± 8.96     | 59.72 ± 1.48     | -                |
| pa-02        | 58.43 ± 24.26    | 22.03 ± 6.44     | 73.13 ± 1.68     | -                |
| pa-03        | 63.44 ± 29.30    | 19.06 ± 14.77    | 54.28 ± 68.61    | -                |
| pa-04        | 41.45 ± 25.55    | 18.90 ± 14.97    | 45.35 ± 1.66     | -                |
| pa-05        | 49.92 ± 40.57    | 14.84 ± 13.72    | 61.62 ± 1.63     | -                |
| bm-01        | 23.81 ± 21.64    | 12.32 ± 8.66     | -                | -                |
| bm-02        | 17.04 ± 21.02    | 11.67 ± 4.77     | -                | -                |
| bm-03        | 18.97 ± 8.95     | 11.35 ± 6.14     | -                | -                |
| bm-04        | 40.63 ± 23.78    | 20.70 ± 13.94    | 52.94 ± 1.48     | -                |
| bm-05        | 28.92 ± 18.98    | 10.65 ± 19.69    | 64.26 ± 0.75     | -                |
| km-01        | 42.99 ± 23.75    | 32.37 ± 14.53    | 58.88 ± 1.46     | -                |
| km-02        | 48.43 ± 30.47    | 43.32 ± 8.95     | 97.45 ± 75.40    | -                |
Sm code for cement; pa for sand; bm for red brick, and km for ceramic.

Sm-01, sm-02, sm-04, sm-05 cement samples and red brick samples bm-01, bm-02, bm-03 did not have $^{40}$K due to the size of the net peak area of the sample rather than the net peak area of the background.

From Table 3, measuring the activity of $^{226}$Ra, $^{232}$Th, and $^{40}$K is still in the average range of the world according to data from UNSCEAR is 50 Bq/kg for $^{226}$Ra, 50 Bq/kg for $^{232}$Th, and 400 Bq/kg for $^{40}$K [13]. The highest $^{226}$Ra activity found in the sample sand pa-03 in $(63.44 \pm 29.30)$ Bq/kg. The highest $^{232}$Th activity found in the ceramic sample km-04 for $(50.76 \pm 18.33)$ Bq/kg. The highest $^{40}$K activity found in the ceramic sample km-02 for $(97.45 \pm 75.40)$ Bq/kg.

The high activity of $^{226}$Ra in samples of sand can be influenced from the geological conditions and geography of sand mining sites, there are form Mount Merapi volcanic explosion have high levels that affect a high mineral content, especially Fe. Then, the high activity of $^{232}$Th and $^{40}$K in the sample can be influenced by the ceramics of the raw materials. Ceramics utilizing fly ash and alumina as raw materials, where this is a TENORM waste. The ceramics industry is often added to natural radionuclides uranium and thorium as a dye. Zircon sand in the form of zirconium silicate (ZrSiO$_4$) is often added as an emulsifier in the production of ceramic. Zircon sand containing 400-1000 ppm of thorium and uranium oxide [14].

3.3. Safety Criterion Calculation
In calculating the safety criterion, radium, thorium, and potassium activity were required. By entering each activity into Equation (4), (5) and (6) obtained the results shown in Figures 2, 3, and 4.

| Sample | $^{226}$Ra Activity | $^{232}$Th Activity | $^{40}$K Activity |
|--------|---------------------|---------------------|------------------|
| km-03  | 40.39 ± 23.68       | 16.08 ± 13.81       | 41.33 ± 59.81    |
| km-04  | 59.91 ± 26.04       | 50.76 ± 18.33       | 56.97 ± 1.52     |
| km-05  | 32.17 ± 23.31       | 40.55 ± 16.08       | 18.68 ± 1.51     |
| Average| 38.10 ± 25.24       | 20.20 ± 13.01       | 34.27 ± 13.65    |

Figure 2. External hazard index of each sample.
The highest value of external hazard index, internal hazard index, radium equivalent found in km-04 sample with a value of 0.370525, 0.531681, and 136.8901 Bq/kg. This indices that the entire sample has a lower value than the maximum limit set by UNSCEAR is \( H_{ext} \leq 1 \), \( H_{in} \leq 1 \), and \( Ra_{eq} \leq 370 \) Bq/kg. So it can be said that the entire sample is still safe to use as a building material for removable thoron gas and radon gas generated does not give potential radiological hazards.

The high value of the index external dangers, internal hazard index, as well as radium equivalent in ceramic samples due to the raw material of ceramic, which is made from a mixture of clay, feldspars, silica, tale, and kaolin. Zircon sand (ZrSiO₄) is added to the raw materials and the manufacture of ceramics used to make the glaze, due to the nature of the elements lanthanum series that shines [15]. Uranium is more easily penetrate and are trapped inside the zircon crystal lattice. Ceramics covered with a layer of glass called ceramic glaze to keep the characteristics of which do not absorb liquids, and make it smoother and easier to clean [16].

### 3.4. RESRAD-BUILD Simulation

In carrying out dose calculations using RESRAD-BUILD, there are two types of dose calculations performed. The calculation of the first type of dose is the calculation of the dose with the specifications of the room model in Perumnas Bumi Guwosari. While the second type of calculation is a scenario calculation. Several scenarios are determined in order to find out which parameters have more influence on the external dose rate. The first scenario is a variation in the composition of...
building materials making up walls. The second scenario is a variation in the composition of building materials that make the floor.

From the data measured in the sample, obtained specific activity $^{226}\text{Ra}$, $^{232}\text{Th}$, dan $^{40}\text{K}$ each type of building materials samples in Table 4. below:

**Table 4.** Specific activity in each type of building materials.

| Sample     | $^{226}\text{Ra}$ (Bq/kg) | $^{232}\text{Th}$ (Bq/kg) | $^{40}\text{K}$ (Bq/kg) |
|------------|-----------------------------|-----------------------------|--------------------------|
| Cement     | 34.46 ± 23.59               | 15.88 ± 12.81               | 0.144 ± 11.20            |
| Sand       | 49.31 ± 31.04               | 16.76 ± 12.46               | 58.82 ± 15.01            |
| Red brick  | 23.87 ± 20.88               | 11.56 ± 12.41               | 23.44 ± 0.45             |
| Ceramics   | 44.78 ± 25.46               | 36.62 ± 14.34               | 54.66 ± 27.94            |

The building materials are samples of building materials making up the walls and floors. For building materials making up the ceiling, we use secondary data from a specific activity $^{226}\text{Ra}$, $^{232}\text{Th}$, dan contained in gypsum. Secondary data gypsum samples were taken from research conducted by Riana Anis Safitri has shown in Table 5. below [17]:

**Table 5.** Secondary data gypsum material.

| Sample | Activity (Bq/kg) |
|--------|------------------|
|        | $^{226}\text{Ra}$ | $^{232}\text{Th}$ | $^{40}\text{K}$ |
| Gypsum | 3.939            | 34.23             | 15.655          |

3.4.1. *Dose calculation with Perumnas Bumi Guwosari room model.* The results of the dose rate calculations in Table 6. seen that the dose rate received by the resident are still within safe limits, i.e in the range (0.654 to 0.661) mSv/year. The dose rate until the seventh or the hundredth is constant in number 1.0 mSv/year, so it can safely be said of building materials used in the long-term. Then, the are of the room does not any effect on the dose rate.

**Table 6.** External dose rate with Perumnas Bumi Guwosari room model.

| Type of Home | The rate of dose (mSv/year) | Output RESRAD (background correction) | Output RESRAD after 7 years (background correction) | Output RESRAD after 100 years (background correction) |
|--------------|-----------------------------|----------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
| Type 21      | 0.924                       | 0.654                                  | 1.1                                                 | 1.1                                                 |
| Type 27      | 0.927                       | 0.657                                  | 1.1                                                 | 1.1                                                 |
| Type 29      | 0.928                       | 0.658                                  | 1.1                                                 | 1.1                                                 |
| Type 36      | 0.931                       | 0.661                                  | 1.1                                                 | 1.1                                                 |
| Type 45      | 0.931                       | 0.661                                  | 1.1                                                 | 1.1                                                 |
3.4.2. Dose calculation with the variation of wall composition. The results of the dose rate calculations in Figure 5, seen that the dose rate received by residents in the bare wall higher than the plastered wall. The result of this calculation in accordance with the reports of other researchers [18, 19]. This is because the porosity shrink, so loose radon from the air to the wall decreases. Therefore, all the walls of the building should be plastered and painted, so that the concentration of radon in the room can be reduced. In addition, the density and thickness of the raw materials components also affect the amount of external dose rate. The higher the density and thickness of building material, it will give external dose rate is higher. The area of the room did not provide a significant difference to the value of the external dose rate on the plastering wall or the bare rate.

![Figure 5. Comparison of external radiation dose rate with the variation of wall composition materials](image)

3.4.3. Dose calculation with the variation of floor composition. The results of the dose rate calculations in Figure 6, seen that the dose rate received by residents of the tiled concrete floor is higher than an ordinary concrete floor. This occurs due to differences in the composition of the raw materials of ceramic, wherein the thickness and density of the concrete floor tiled higher than an ordinary concrete floor.

![Figure 6. Comparison of external radiation dose rate with the variation of floor composition materials](image)
4. Conclusion

Radionuclides contained in the samples of building materials is $^{212}\text{Pb}$, $^{214}\text{Pb}$, $^{228}\text{Ac}$, $^{214}\text{Bi}$, and $^{40}\text{K}$ The activity concentration of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ ranged from $23.87 \pm 20.88$ to $49.31 \pm 31.04$ Bq/kg, $11.56 \pm 12.41$ to $36.62 \pm 14.34$ Bq/kg and $0.1443 \pm 11.2029$ to $58.82 \pm 15.01$ Bq/kg, respectively in various samples.

The highest radium equivalent ($\text{Ra}_{eq}$) in the ceramic samples of 136.8901 Bq/kg is lower than $\text{Ra}_{eq}$ maximum limit value is 370 Bq/kg. External and internal hazard indexes are highest in ceramic sample 0.370525 and 0.531681 lower than the maximum limit value $\leq 1$.

The results of calculating the annual effective dose using RESRAD-BUILD ranged 0.654 - 0.661 mSv.y$^{-1}$ is lower than the annual recommended limit of 1 mSv/y. The parameters that most influence on the increase in the external radiation dose rate of building materials is the composition of the raw materials of floors and walls as well as the density and thickness of building materials.

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