Analysis of radon concentration and gamma dose rate in residential houses of Ambon and Seram Islands, Maluku

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Abstract. Radon concentration analysis in the residential houses in Ambon and Seram Island - Maluku through the passive method using the CR-39 nuclear track detector has been studied. The CR-39 nuclear track detector was installed inside the residential houses for 3 months. After that time, the detector was taken and etched using 6.25 N NaOH solution. The nuclear track of radon in the CR-39 was read under a microscope with 400 times magnification. From the results of reading the track of radon concentration in the houses was calculated. The results of the analysis showed that radon concentrations in the residential houses of Ambon and Seram Islands, Maluku was at the low level with the range of 2.56 ± 0.18 Bq/m$^3$ to 59.65 ± 4.22 Bq/m$^3$ and an average of 28.42 ± 1.98 Bq/m$^3$. The average concentration of radon is still below the average value radon concentration recommended by UNSCEAR was 300 Bq/m$^3$. The value of dose received by the population due to exposure of radon and gamma radiation in the range of 0.90-1.44 mSv/year. The data shows that radon concentration value is proportional to total radiation doses received by the population for a year. This data can be used in the study of radiation safety for the Ministry of Health and as a contribution to Indonesia in the international community about monitoring environmental radiation from radon concentrations in residential houses.

Keywords: radon concentration, dose rate, CR-39, Ambon, Seram

INTRODUCTION

Research of radiation and environmental radioactivity measurement has been extensively studied along with the contour map. The research particularly discusses about measuring the dose rate of environmental gamma radiation exposure and determining the radionuclide concentration of Ra-226, Th-232, and K-40 on the soil surface. But, most of the research has a lack of study about natural radiation exposure from radon and thoron. Based on the UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) report, radon radiation exposure in houses is the largest contributor to natural radiation exposure which reaches 50% [1]. Therefore, the measurement of radon-thoron concentrations in the dwellings must be measured to elaborate on the sources of natural radiation in Indonesia to characterize the existing natural radiation sources.

The average world wide indoor radon concentration is 50 Bq/m$^3$ and the average for outdoor concentration is about 10 Bq/m$^3$ although there is a wide variation in some places [2]. Radon (Rn-222) and thoron (Rn-220) are natural radioactive gas that can cause significant radiological problems. Radon is a short-lived radionuclide that releases alpha particles and can stick to mild particles in the air that can be inhaled and irradiated lung tissue then potentially increase the risk of lung cancer. Another radon isotope, Rn-220 (thoron) has identical properties with Rn-222 but with a minor chance of radiation exposure in the lungs. Lung cancer due to radon exposure can be caused by inhalation of short-lived radon particulate particles such as Po-218, Pb-214, Bi-214, or Po-214 [3].

The accuracy of measuring radon concentration through the passive method has been done by the previous study from comparing radon concentration measurements using the Lucas Cell method and the passive method with the CR-39. The study shows similarity results from
those two methods, therefore the passive method for determining radon concentration using a CR-39 detector can be used respectively [6].

Radon exposure has the potential danger that it is necessary to map the level of radon concentration in the Maluku region which is part of the radon thoron mapping plan in Indonesia. Research on the concentration of radon at home residents needs to be done because according to UNSCEAR state that more than 85% of the world's population dose reception comes from exposure to natural radiation [4]. Advantage of this research is the data can be used as an international contribution through UNSCEAR, IAEA, and WHO regarding radon concentration data at residential houses. For local governments, the data can be considered in regional development and planning related to radiation problems.

The islands of Ambon and Seram are geographically located in the Maluku Islands with the provincial capital in Ambon City. In general, Ambon and Seram Islands have the geological structure of the Mount Ambon formation and a small portion including ambon granite, alluvium, ultra ma fix, and coral rocks [5]. The residential houses in western Ambon and Seram Island are generally modest houses using cement-sand brick or red brick walls and the floors have mostly coated with cement-sand or ceramics. An example of a modest house in western Ambon Island and Seram is shown in Figure 1.

![Figure 1. The modest house of western Ambon Island.](image1)

**METHODOLOGY**

**Materials and Methods**

The device that used to determines the location is GPS, and for monitoring passive radon in the house residents using Solid State Nuclear Track Detector CR-39. CR-39 detector is made of polycarbonate which has an active layer that can detect alpha particles emitted by radon and can be stable for a long time. Laboratory analysis of CR-39 detector requires staining jar, oven, ultrasonic vibrator, relic desiccator, and microscope. Materials used are strings, small nails, NaOH (6.25 N), acetone, glass objects, and containers. In addition, supporting materials to supplement the radon distribution map are leaflets and maps of Ambon Island. The determination of the sampling point location is using a grid system to distributed the sampling data evenly. The grid is 10 km x 10 km for Ambon Island and 40 km x 40 km for Seram Island as presented in Figure 2.

A passive radon monitor with a CR-39 detector was installed in the resident house in which each grid installed with 6-10 detectors. Each location where the detector is installed is marked with a longitude and latitude position with GPS. A passive radon monitor is installed by hanging on the ceiling for 3 months. The building materials of houses, type of houses, and the ventilation system are also be noted to observe further factors that might influence the indoor radon concentration level.

![Figure 2. The grid map of Ambon and Seram Island as location of study area.](image2)

To find out the correlation between gamma radiation exposure and radon concentrations in the house, gamma radiation exposure measurements were taken inside and outside the house. Measurement of the dose rate of environmental gamma radiation exposure inside the house was carried out using an Exploranium Model GR-135 Plus surveillance made in Canada. Measurement of the dose rate is measured for at least 10 minutes at each measurement location at a height of ± 1 m from the floor surface. Measurement data stored in device memory was transferred to a laptop for data processing using the Speck View program. The coordinates of the measurement location are marked on the positioning device, GPS (Global Positioning System). Obtaining data of the rate gamma radiation dose and the coordinate location is used as supporting data in the determination of radon in the residential houses.

After being installed for 3 months, passive radon monitors were needed to be analyzed at the laboratory by etching. The etching process was done by soaking the CR-39 in a staining jar
containing a 6.25 N NaOH solution, then heated in an oven at 70 °C for 7 hours. Then, CR-39 was washed 3-4 times using distillate water to wash the NaOH solution and then proceed with using an ultrasonic vibrator washer for 5 minutes. After washed, the CR-39 detector was dried at room temperature in an electric desiccator for 2 days. Then the CR-39 was moved to an object-glass with the exposed surface facing up. Detector CR-39 was tracked using a microscope with 25 times viewing angle at 400 times magnification. The number of traces can be used to determine the value of the radon concentration in the house. Radon tract have a unique characteristic that is shaped like drops of water with a smooth shape on the outer circle. Figure 3 shows the trace of radon trail that has a direction and is perpendicular to form a black circle.

**Figure 3.** Image of radon track on CR-39 using microscope with 400x magnification.

### Measurement of Radon Concentration and Exposure Dose

In the passive method, the radon concentration in the house depends on the number of traces in CR-39, calibration factor, and the length of time of exposure. The amount of radon concentration in the house by the passive method calculated using the following equation [7]:

\[ C_{\text{Rn}} = \frac{N_T - N_B}{E \times T} \]  

(1)

The amount of radon concentration in the house (CRn) is the number of total sample traces (NT) minus the background traces (NB) for 25 times viewing angle (trace/5.0625 mm²), then divided by the detector efficiency (E) [(trace/5.0625 mm²)/Bq/m³·day] or radon calibration factor of 0.00241 and exposure time (T, day). The amount of 5.0625 are 25 times the number of views on a reading traces under a microscope at magnification 400 times.

From the measurement of radon concentration in the house it can be estimated that the effective dose received by the population using the following equation:

\[ D_{\text{Rn}} = F_{\text{kRn}} F_{\text{Rn}} T \cdot C_{\text{Rn}} \text{ (mSv/year)} \]  

(2)

with:
- \( F_{\text{kRn}} \): radion equilibrium factor with its deceased child (0.4)
- \( F_{\text{Rn}} \): radon dose conversion factor (9 nSv/Bq.hour/m²)
- \( T \): length of stay in the house (hours/year)
- \( C_{\text{Rn}} \): concentration of radon gas in the house (Bq/m³)
- \( D_{\text{Rn}} \): Effective dose due to inhalation of short-lived radon (mSv/year).

By integrating radon concentration data and coordinate sampling location from GPS data, a radon concentration contour map was prepared using Surfer and MapInfo software. In order to easily see the difference in radon concentration levels in the house, color degradation is made on the digital map. The darker color on the map shows the level of radon concentration in the house is higher and vice versa.

Public dose from radon calculated by using equation 2 according to the radon concentration and gamma dose rates determined by direct measurement gamma exposure rates one meter above the ground by using Exploranium GR-135. From both data can determined total annual dose rate in Ambon and Seram islands.

### RESULTS AND DISCUSSION

The data results of the radon concentration analysis in the residential houses on Ambon and Seram Islands in this study was obtained from 130 detectors installed in various locations in which GPS position of the sampling point location can be seen in Table 1. The sampling point is based on a grid that has been created. In addition, the sampling point also depending on the presence of the population, so the dose obtained is the radiation dose received by the population. For the area of Ambon Island, sampling was carried out evenly, while for Seram Island it was only done in the West Seram area this was due to the difficulties of the location to reach.

To determine the effect of the environmental gamma dose rate, a dose rate measurement was carried out inside and outside the residential houses using the Exploranium GR-135 Plus survey. The measurement results can be seen in Figure 4, which shows the dose rate inside the house is slightly higher than the dose rate outside the house. This might be caused by the influence of the concentration of the radionuclides in building materials.
Table 1. GPS Position of sampling point location of Ambon and Seram Islands.

| Area Code | GPS Position             | Indoor Radon Concentration (Bq/m³) |
|-----------|--------------------------|-----------------------------------|
| Ambon-1   | 3°46’39”N 28°07’18”E    | 34.65 ± 2.45                      |
| Ambon-2   | 3°39’03”N 28°13’55”E    | 37.77 ± 2.41                      |
| Ambon-3   | 3°45’05”N 28°01’25”E    | 25.83 ± 1.83                      |
| Ambon-4   | 3°40’53”N 27°55’38”E    | 29.67 ± 2.10                      |
| Ambon-5   | 3°35’23”N 28°03’31”E    | 23.03 ± 1.64                      |
| Ambon-6   | 3°40’37”N 28°13’22”E    | 32.12 ± 2.27                      |
| Ambon-7   | 3°30’50”N 28°20’32”E    | 9.90 ± 0.70                       |
| Ambon-8   | 3°33’05”N 28°11’43”E    | 5.15 ± 0.36                       |
| Seram-1   | 3°00’22”N 28°07’06”E    | 32.48 ± 1.90                      |
| Seram-2   | 3°25’11”N 28°41’17”E    | 34.87 ± 2.26                      |
| Seram-3   | 3°13’05”N 28°59’24”E    | 36.44 ± 2.58                      |
| Seram-4   | 3°23’17”N 28°12’02”E    | 46.08 ± 3.26                      |
| Seram-5   | 3°11’54”N 28°52’40”E    | 50.65 ± 4.22                      |
| Seram-6   | 3°20’35”N 28°21’17”E    | 23.03 ± 1.64                      |

The amount of radon concentration in the residential houses is influenced by the conditions of the measurement area, including the type of house, the ventilation system, and the building materials of the house. Houses with building materials made of bricks are relatively higher in radon concentration than those made of boards. Modest house type has brick walls, cement floors, and ceiling from plywood. While the very modest house type made from wooden walls and even woven bamboo, slurry floors and do not use ceilings. Very modest house type has the best ventilation system since the air circulation still going well even though the doors and windows are closed. In contrast to the house with ceiling and cement floor which unable to manage the air circulation inside the house. This is likely to cause radon concentrations in modest house type is higher than in a very modest one.

Figure 4. Indoor and outdoor dose rate of Ambon and Seram Island.

The measurement of radon concentration in the residential houses using equation (1) obtained results in the range values of 2.56 ± 0.18 Bq/m³ to 59.65 ± 4.22 Bq/m³ with an average of 28.42 ± 1.98 Bq/m³ (Table 2). This concentration is still below the radon reference level set by the International Commission on Radiological Protection (ICRP) [4] and the International Atomic Energy Agency (IAEA) of 300 Bq/m³ [1]. Data on Table 2 shows that the highest indoor radon concentration was in the Ambon-2 area with a value of 37.77 ± 2.41 Bq/m³.

These results are slightly similar with the results of radon measurements at residential houses in Halmahera Island (2.47 ± 0.1 to 47.02 ± 2.95 Bq/m³) [8]. South Sulawesi (3.43 ± 0.24 to 69.38 ± 4.91 Bq/m³) [9], Bali (9 ± 1) to (48 ± 3) [10]. Aceh (3.32 ± 0.23 to 68.30 ± 4.83 Bq/m³) [11], West Kalimantan (3.13 to 69.57 Bq/m³) [12] and South Kalimantan (3.10 ± 0.20 to 94 ± 6.70 Bq/m³) [13]. But, relatively lower than recent study of indoor radon concentrations in Madura Island (15.11 ± 1.07 to 126.93 ± 8.98) Bq/m³ [14].

Table 2. Indoor radon levels in dwelling of Ambon and Seram Island.

| Area Code | Indoor Radon Concentration (Bq/m³) | Average | Range |
|-----------|-----------------------------------|---------|-------|
| Ambon-1   | 34.65 ± 2.45                      | 5.11 ± 0.36 to 43.47 ± 3.07 |
| Ambon-2   | 37.77 ± 2.41                      | 12.80 ± 0.90 to 40.95 ± 2.90 |
| Ambon-3   | 25.83 ± 1.83                      | 7.67 ± 0.54 to 46.00 ± 3.25 |
| Ambon-4   | 29.67 ± 2.10                      | 12.79 ± 0.90 to 43.50 ± 3.08 |
| Ambon-5   | 28.47 ± 1.90                      | 10.24 ± 0.71 to 46.08 ± 3.26 |
| Ambon-6   | 36.44 ± 2.58                      | 15.56 ± 1.10 to 59.65 ± 4.22 |
| Ambon-7   | 29.60 ± 2.09                      | 17.90 ± 1.55 to 43.48 ± 3.07 |
| Ambon-8   | 9.90 ± 0.70                       | 2.66 ± 0.19 to 15.94 ± 1.13 |
| Seram-1   | 32.12 ± 2.27                      | 5.16 ± 0.36 to 54.13 ± 3.83 |
| Seram-2   | 26.55 ± 1.88                      | 5.15 ± 0.36 to 46.13 ± 3.28 |
| Seram-3   | 19.75 ± 1.40                      | 2.58 ± 0.18 to 30.92 ± 2.19 |
| Seram-4   | 14.70 ± 1.04                      | 2.58 ± 0.18 to 23.21 ± 1.64 |
| Seram-5   | 19.43 ± 1.37                      | 7.72 ± 0.55 to 33.47 ± 2.37 |
| Seram-6   | 19.64 ± 1.39                      | 2.56 ± 0.18 to 23.03 ± 1.63 |
| Ambon and Seram Island | 28.42 ± 1.98 | 2.56 ± 0.18 to 59.65 ± 4.22 |
In contrast, indoor radon concentrations on Ambon and Seram Island are higher than radon concentration in other countries, such as in the city of Qom, Iran (40.69 Bq/m³) [15], Turkey (30 to 39 Bq/m³) [16] and Delhi, India (4.4 ± 1.6 to 29.8 ± 3.8 Bq/m³) [17]. However, the average values of radon concentrations in Ambon and Seram Island are lower than the average values reported for the worldwide dwellings of 50 Bq/m³ [2]. Radon concentration data in the residential houses from this study can be used as baseline data of radon concentrations in the dwellings and can be integrated to create radon concentration distribution maps of Ambon and Seram Island, Maluku as shown in Figure 5, which is part of the radon concentration map in Indonesian residential houses. The domination of blue color in all regions of Ambon and Seram Island indicated that the average indoor radon concentration at various measurement locations relatively has the same range of value. However, the area with a brighter blue color shows a higher level of radon concentration than the darker blue area.

![Figure 5. Radon distribution map of Ambon and Seram Island.](image)

The amount of annual dose of gamma radiation exposure and radon gas exposure in the house can be seen in Table 3. The dose of radon concentration in the house is in the range of 0.18 to 0.81 mSv/year, from gamma radiation in the range of 0.32 to 0.95 mSv/year and total radiation doses in the value range of 0.77 to 1.76 mSv/year. The highest total dose was in the Ambon-2 area. This is likely in the area stockpiled by using sand which has relatively higher radioactivity concentrations of Ra-226 compared to other locations.

### Table 3. Annual dose of radon and gamma exposure.

| Area Code | \(D_{\text{Radon}}\) (mSv/yr) | \(D_{\text{Gamma}}\) (mSv/yr) | \(D_{\text{Total}}\) (mSv/yr) |
|-----------|-------------------------------|-------------------------------|------------------------------|
| Ambon-1   | 0.63                          | 0.35                          | 0.98                         |
| Ambon-2   | 0.81                          | 0.95                          | 1.76                         |
| Ambon-3   | 0.50                          | 0.53                          | 1.03                         |
| Ambon-4   | 0.65                          | 0.46                          | 1.11                         |
| Ambon-5   | 0.54                          | 0.64                          | 1.18                         |
| Ambon-6   | 0.76                          | 0.67                          | 1.43                         |
| Ambon-7   | 0.68                          | 0.32                          | 1.00                         |
| Ambon-8   | 0.18                          | 0.59                          | 0.77                         |
| Seram-1   | 0.68                          | 0.47                          | 1.15                         |
| Seram-2   | 0.47                          | 0.51                          | 0.98                         |
| Seram-3   | 0.35                          | 0.67                          | 1.02                         |
| Seram-4   | 0.28                          | 0.63                          | 0.91                         |
| Seram-5   | 0.40                          | 0.62                          | 1.02                         |
| Seram-6   | 0.41                          | 0.49                          | 0.90                         |

### CONCLUSION

Analysis of radon concentrations in the residential houses on Ambon and Seram Island is in the range of values from 2.56 ± 0.18 to 59.65 ± 4.22 Bq/m³ with an average of 28.42 ± 1.98 Bq/m³. The radon concentration in residential houses is influenced by the condition of the air circulation in the house. The highest indoor radon concentration average and total dose exposure was in Ambon-2 area. The obtained radon concentration data from this study is still below the recommended value by UNSCEAR of 300 Bq/m³. The dose received by the population due to exposure of radon and gamma radiation values obtained in the range of 0.90-1.44 mSv/year. This study found that outdoor radon dose rate proportional to indoor radon dose rate, and indoor radon concentration level proportional to total radiation doses received by the population for one year.

### ACKNOWLEDGMENT

Our gratitude goes to homeowners who have agreed to be respondents and to all personnel of the Environmental Safety Sub-Division and the Terrestrial Radioecology Group. We would also like to thank the Head of the Centre for Technology of Radiation Safety and Metrology, the National Nuclear Energy Agency for Indonesian who has funded this research project in 2017.

### REFERENCE

[1] IAEA. 2005 Radiation, People and the Environment Viena: IAEA.
[2] UNEP. 2016 Radiation: Effects and
Analysis of radon concentration and gamma dose rate in residential houses of Ambon and Seram Islands…
(Wahyudi, Ilma Winarni, Maji Wiyono, Kusdiana)

Sources.

[3] Ting, D. S. 2010. WHO Handbook on Indoor Radon: A Public Health Perspective. Int. J. Environ. Study. 67 100–102.

[4] UNSCEAR. 2015. UNSCEAR report to the general assembly with scientific annexes: United Nations.

[5] Pusat Penelitian Pengembangan Geologi. 1995. Peta Geologi Pulau Ambon (Bandung: Pusat Penelitian Pengembangan Geologi).

[6] Minarni, A.; Iskandar, D.; Bunawas. 1996. Radon di Kompleks Perumahan BATAN. Pros. Present. Ilm. Keselam. Radiasi dan Lingkung. 262–265.

[7] Sutarman; Nirwani, L.; Emlinarti; Warsona, A. 2005. Penentuan konsentrasi gas radon dan thoron menggunakan detektor film LR-115 di DKI Jakarta dan sekitarnya. Pros. PPI–P3TM-BATAN 212–221.

[8] Wahyudi; Winarni, I. D.; Kusdiana; Widyaningsih, O. D. 2019. Konsentrasi Radon di Maluku Utara. Pros. Semin. Nas. Teknol. Energi Nuklir. 131–138.

[9] Wahyudi; Kusdiana; Iskandar, D. 2016. Mapping of Indoor Radon Concentration in Houses Located in South Sulawesi Province. Proceeding 2nd Int. Conf. SERIR2&14th Bienn. Conf. SPERA. 35–38.

[10] Kusdiana; Wiyono, M.; Syarbaini. 2016. Assessment of Natural Radioactivity Levels in Soil of Bali Island, Indonesia. 2nd Int. Conf. Sources, Eff. Risks Ioniz. Radiat. 14th Bienn. Conf. South Pacific Environ. Radioact. Assoc. 180–185.

[11] Wahyudi; Iskandar, D.; Safitri, R.; Kusdiana. 2017. Determination of Radon Concentrations in Dwelling in Aceh. J. Nat. 17 96.

[12] Wahyudi; Kusdiana; Wiyono, M.; Iskandar, D. 2019. Analisis Dosis RADIASI Alam Radon dan Sinar Gamma di Rumah Penduduk Kalimantan Barat. Maj. IPTEK Nukl. 22 63–72.

[13] Nugraha, E. D.; Kusdiana; Wahyudi; Iskandar, D. 2019. Radon Concentrations in Dwelling of South Kalimantan, Indonesia. Radiat. Prot. Dosimetry. 184 463–465.

[14] Wahyudi; Winarni, I. D.; Wiyono, M. 2020. Indoor Radon measurements in Madura dwellings. J. Phys. Conf. Ser. 1436 012012.

[15] Fahiminia, M.; Fouladi, F. R.; Ardani, R.; Mohammadbeigi, A.; Naddafi, K.; Hassanvand, M. S. 2016. Indoor radon measurements in residential dwellings in Qom, Iran. International J. Radiat. Res. 14 331–339.

[16] Celebi, N.; Ataksor, B.; Taskin, H.; Albayrak, B. N. 2015. Indoor radon measurements in Turkey dwellings. Radiat. Prot. Dosimetry. 167 626–632.

[17] Sharma, A.; Mahur, A. K.; Sonkawade, R. G.; Sharma, A. C. 2015. Measurement of Indoor Radon, Thoron in Dwelling of Delhi, India Using Double Dosimeter Cups with SSNTD S. Phys. Procedia. 80 125–127.