Indoor Radon measurements in Madura dwellings

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Abstract. Indoor radon concentration in Madura Island region, East Java Province, has been mapped and determined. The obtained data is useful for health policies of radon in Indonesia and can be used as internationally baseline data through UNSCEAR, IAEA, and WHO. The mapping process has been done using a grid system of 20 km x 20 km, where on each grid there are 5 - 10 passive radon detectors using CR-39 installed in the houses for 3 to 4 months. After the exposure time, the detector CR-39 is etched using a 6.25 N NaOH solution at 70 °C in the oven for 7 hours to grow traces of alpha particles from radon. The imprints are read using a microscope with 400x magnification. The number of trace amounts of alpha particles in CR-39 shows the amount of radon concentration in the house. It was found that radon concentrations on Madura Island were in the range of 15.11 ± 1.07 Bq m⁻³ to 126.93 ± 8.98 Bq m⁻³ with an average of 58.74 ± 4.15 Bq m⁻³. Radon concentration data in the house and GPS location were then entered into MapInfo Software v.10.5 for a radon distribution map. This research obtains the Regional Map of radon in Madura Island as a part of the indoor radon map in Indonesia.

1. Introduction
Activities related to the field of natural resources and environment and radiation protection through nuclear science and technology for environmental monitoring and the effects of ionizing radiation on the human body and environment have been studied. Besides the environmental samples, the samples from indoor dwellings also need to be analyzed. Radon gas concentrations in the house can be higher than radon in the environment due to the penetration of radon gas originating from the soil inside the house, fracture foundations, water pipes, and fractures on walls and the floors [1]. Radon (Rn-222) is an odorless and colorless radioactive gas that formed from radium decay (Ra-226) derived from uranium (U-238) and naturally present in rocks, water and soil [2]. Radon is formed in the soil constantly due to the decay of uranium in the earth's crust. Radon can be dissolved into surface water, but with a very low concentration because when radon reaches the surface it will be released into the atmosphere in the gas form [3].

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported that the estimated average per capita dose of natural radiation sources was 2.4 mS year⁻¹ and 47% of them came from radon [4]. World Health Organization (WHO) in the Handbook on Radon Indoor: a public health perspective: World Health Organization (2010) sets a minimum limit on indoor radon exposure of 100 Bq m⁻³ and or not exceeding 300 Bq m⁻³ [5]. Radon gas that inhaled and accumulated in the lungs can increase the risk of lung cancer. Therefore, the measurement of indoor radon gas concentration can potentially provide the distribution of radionuclides radon inside the dwellings.
Active and passive techniques have been developed to observe indoor radon gas. While active methods are usually used for short-time measurement, the passive methods are used for long-time measurement in large scale sampling. In this study, indoor radon measurement was carried out through a passive method using CR-39 nuclear trace detectors. CR-39 is a detector with the trade name Baryotrak made by Fukui Co. of Japan, in the form of a transparent sheet or thin plastic film and made from an organic polymeric material (allyldiglicol carbonate with its chemical formula: $\text{C}_{12}\text{H}_{18}\text{O}_{7}$). The interaction between alpha particles emitted by radon and its decay with CR-39 detectors can lead to latent nuclear traces [6].

This study aims to observe and measure the level of radon gas concentration in the dwellings of Madura Island, East Java. The result of this study will provide radon concentration baseline data that may be useful for guiding information in regards to the possibility of a health-hazardous problem. In addition, the coordinates of points for mapping radon were recorded using GPS. The indoor radon concentration data will be integrated into a radon distribution map in the dwellings of Madura Island, East Java. This study will give contribute toward radon distribution in the dwellings map of Indonesia which has been projected since 2012. This radon map is a contribution of Indonesia in the international world through UNSCEAR. Moreover this study can be used to estimate the average indoor radon concentration on Madura Island, East Java Province to asses any health risk from indoor radon gas in this area.

2. Materials and Methods

2.1. Study Area

Madura Island is a part of Indonesia, located off the northeast coast of Java Island and administered as part of East Java Province. It is consists of four districts: Bangkalan, Sampang, Pamekasan and Sumenep as shown in Fig. 1. In addition, Madura has some small outer islands, named Kangean. The island comprises an area of approximately 4,078.67 km² (administratively 5,168 km² including various smaller islands to the east and north). The administered area has a density of 702 people per km², while that of the island itself (3,630,000 people in 2012 count) is higher at 817 km². The climate is tropical, exhibiting defined wet (September to February) and dry (March to August) seasons, with an average annual rainfall of 1,500–2,000 mm [7]. The sampling point was determined using a grid system of 20 km x 20 km where on each grid there are 5-10 passive radon detectors installed in the houses for 3 to 4 months. A passive radon detector is installed with a total of 95 units of detectors in 13 locations of Madura Island.

![Figure 1. Location of the study area.](image)

2.2. Experimental Details

This study was performed with a nuclear alpha track detector using CR-39 as detector material that places in a plastic container as shown in Fig.2 developed at the Center for Technology of Radiation
Safety and Metrology, National Nuclear Energy Agency based on the solid-state nuclear track detectors (SSNTDs). Detectors were numbered and placed in the selected dwellings according to the grid system method, for 3-4 months which is set at least above 1.5 m above the floor, more than 0.5 m at a distance from the window and at a minimum of 20 cm from any other object [8].

![Figure 2. Schematic image of radon passive detector.](image)

After the exposure time, detector films CR-39 were removed from the plastic container of radon passive detector. The detector was wrapped with plastic and aluminum foils then delivered to the environmental laboratory, Center for Technology of Radiation Safety and Metrology, National Nuclear Energy Agency. In the environmental laboratory, detector films etched in 6.25 N NaOH solution at 70 °C in the oven for 7 hours to grow traces of alpha particles from radon. After removing them from the etching solution, the detectors were washed with distilled water and dried overnight. Detectors were then read using a microscope with 400x magnification.

### 2.3. Measurement of Indoor Radon Concentration

The number of the nuclear track on the detector as shown in Fig.3, was calculated and the amount is equivalent to the radon concentrations. The track density was changed to radon concentration in Bq m⁻³ using the calibration factor. Afterward, the radon concentrations are determined by using these following relations:

\[
C_{Rn} \left( \text{Bq/m}^3 \right) = \frac{N_T - N_B}{E \times T} \tag{1}
\]

Where, \( C_{Rn} \) = radon concentration in Bq m⁻³; \( N_T \) = radon track density; \( N_B \) = radon track density background; \( E \) = efficiency (track/5.0625 mm²/Bq m⁻³ day); and \( T \) = time (day).

![Figure 3. Image of the alpha track with 400x magnification from radon on CR-39.](image)

### 3. Result and Discussion

The results of measurements of the dose rate of gamma radiation inside and outside the house on Madura Island obtained the average data rate of the dose inside the house is higher than the dose rate outside. This is likely due to the building material components used to build houses that have a higher
level of radioactivity compared to radioactivity from the soil or local geology. In general, buildings on Madura Island are made using limestone or white limestone which is cut into bricks (white bricks). The complete measurement of the gamma radiation dose in Madura Island is presented in Table 1.

Table 1. The Rate of Gamma Radiation Doses Inside and Outside the Houses on Madura Island.

| Area Code | Gamma Dose Rate (μSv hour⁻¹) |
|-----------|-------------------------------|
|           | Indoor                        | Outdoor                      |
| M-1       | 0.098 ± 0.005                 | 0.088 ± 0.004                |
| M-2       | 0.069 ± 0.006                 | 0.055 ± 0.005                |
| M-3       | 0.078 ± 0.005                 | 0.074 ± 0.005                |
| M-4       | 0.079 ± 0.004                 | 0.073 ± 0.005                |
| M-5       | 0.070 ± 0.003                 | 0.068 ± 0.003                |
| M-6       | 0.094 ± 0.005                 | 0.085 ± 0.005                |
| M-7       | 0.065 ± 0.003                 | 0.057 ± 0.004                |
| M-8       | 0.112 ± 0.005                 | 0.108 ± 0.005                |
| M-9       | 0.066 ± 0.006                 | 0.062 ± 0.004                |
| M-10      | 0.082 ± 0.007                 | 0.075 ± 0.005                |
| M-11      | 0.063 ± 0.005                 | 0.057 ± 0.005                |
| M-12      | 0.057 ± 0.004                 | 0.056 ± 0.005                |
| M-13      | 0.093 ± 0.005                 | 0.084 ± 0.10                 |

The building materials also caused the indoor radon distribution into the house because the uranium and radium are uniformly distributed in these materials from the time of origination of earth [9]. Houses with brick building materials are relatively higher in radon concentration than those made of boards. The simple house made of wood or woven bamboo and do not use ceilings has the best ventilation system, because even though the doors and windows are closed, the air circulation remains optimal. This is likely to cause the concentration of radon in permanent houses is relatively high.

Variations in weather conditions, humidity, wind speed, pressure and temperature that always changes will affect the measured concentration of radon gas. Research by Miles (2001) shows that the radon concentration level measured for 1 week produces very fluctuating data. Indoor radon monitoring should not be done in a short period of time because it cannot be used as an appropriate database [10]. Therefore, monitoring of indoor radon concentration on Madura Island, East Java Province in this study was carried out for 3-4 months to generate more accurate and representative research data. Passive radon detectors were installed with a total 95 unit of detectors in 13 locations and all of the detectors can be taken back or 100% return. Table 2 presents the radon concentrations in some houses in the 13 locations of the Madura Island region.

Table 2. Levels of indoor radon in the Madura Island dwellings.

| Area code | Indoor Radon Concentration (Bq m⁻³) |
|-----------|-----------------------------------|
|           | Range                             | Average               |
| M-1       | 27.44 ± 1.94 to 51.84 ± 3.67       | 42.55 ± 3.01          |
| M-2       | 30.49 ± 2.16 to 57.94 ± 4.10       | 43.54 ± 3.08          |
| M-3       | 27.44 ± 1.94 to 36.59 ± 2.59       | 32.62 ± 2.31          |
Based on the number of traces on the radon passive detector, the level of radon gas in the houses can be determined using (1). Related to the data as seen in Table 2, generally the radon concentration is still below 100 Bq m⁻³. The lowest indoor radon concentration in the M-12 area with an average concentration of 31.39 ± 2.22 Bq m⁻³, while the highest average indoor radon concentration reached 86.40 ± 6.41 Bq m⁻³ for M-8 Area. From Table 1, the lowest gamma dose rate inside the houses is also in the M-12 area and the highest gamma dose rate inside the houses in the M-8 area. This result indicates a correlation between the values of the gamma dose rate inside the house with indoor radon gas concentrations. The value of radon concentration in the dwellings is influenced by the geological conditions of the measurement area, the type of house, the ventilation system of the house and the building materials used to make the house. The low measured radon concentration value on Madura Island related to a good ventilation system in the houses in this region. This result is similar to the study by Fahiminia et al, which states that the average radon concentration in a house with good air ventilation will be lower than a house with poor air ventilation [11]. Overall the range of indoor radon concentrations in the Madura Island region, East Java Province is 15.11 ± 1.07 to 126.93 ± 8.98 Bq m⁻³ and the average concentration is 58.74 ± 4.15 Bq m⁻³. The value of indoor radon concentrations on Madura Island are relatively higher than indoor radon concentrations in South Sulawesi (3.43 ± 0.24 to 69.38 ± 4.91 Bq m⁻³) [12], in Bali (9 ± 1 to 48 ± 3 Bq m⁻³) [13], and Aceh (3.32 ± 0.23 Bq m⁻³ to 68.30 ± 4.83 Bq m⁻³) [14]. Also to the results of radon concentrations in other countries such as in Delhi, India (4.4 ± 1.6 to 29.8 ± 3.8 Bq m⁻³) [15], in Turkey (30 to 39 Bq m⁻³) [1], in Qom, Iran (40.69 Bq m⁻³) [11].

In this study, the radon distribution map was prepared using the Map Info program by integrating the radon concentration values in the houses with the coordinates of the measurement locations. The map as seen in Fig. 4 shows the domination of blue color in all regions of Madura Island indicated that the average indoor radon concentration at various measurement locations relatively has the same value. The average value is less than the lower limit of the range of the action level recommended by the ICRP, UNSCEAR, and WHO which is 100 Bq m⁻³ or not more than 300 Bq m⁻³ [4], [5], [16]. However, the values of radon concentrations in Madura Island are more than the average values reported for the worldwide dwellings (40 Bq m⁻³) [4].

| Area   | Minimum to Maximum | Average ± Standard Deviation |
|--------|--------------------|-------------------------------|
| M-4    | 45.74 ± 3.23 to 70.13 ± 4.96 | 60.35 ± 4.27 |
| M-5    | 18.13 ± 1.28 to 96.71 ± 6.84 | 79.95 ± 5.65 |
| M-6    | 29.96 ± 2.12 to 80.88 ± 5.72 | 55.61 ± 4.00 |
| M-7    | 29.96 ± 2.12 to 65.91 ± 4.66 | 48.70 ± 3.20 |
| M-8    | 35.95 ± 2.54 to 110.84 ± 7.84 | 86.40 ± 6.41 |
| M-9    | 15.11 ± 1.07 to 63.47 ± 4.49 | 42.81 ± 3.03 |
| M-10   | 23.97 ± 1.69 to 104.85 ± 7.41 | 62.14 ± 4.39 |
| M-11   | 24.18 ± 1.71 to 126.93 ± 8.98 | 63.73 ± 4.51 |
| M-12   | 21.34 ± 1.51 to 39.64 ± 2.80 | 31.39 ± 2.22 |
| M-13   | 24.39 ± 1.72 to 48.79 ± 3.45 | 36.13 ± 2.55 |
| Madura Island | 15.11 ± 1.07 to 126.93 ± 8.98 | 58.74 ± 4.15 |
4. Conclusions
The indoor radon concentration measurement in the dwellings of Madura Island has been studied using a radon passive detector. The range of indoor radon concentrations in the Madura Island region, East Java Province is $15.11 \pm 1.07$ to $126.93 \pm 8.98$ Bq m$^{-3}$ and the average concentration is $58.74 \pm 4.15$ Bq m$^{-3}$. The average values of radon concentrations in this study area were found to be higher than the global average values, but less than the lower limit of the range of the action level recommended by the ICRP, UNSCEAR, and WHO. The measured values of concentrations of radon in 95 houses in 13 locations of Madura Island were used for making radon distribution maps as part of the radon concentration map in the dwellings all around Indonesia.

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