Determination of Environmental Condition in Universitas Pelita Harapan Based on Radon Concentration Analysis

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Abstract. Radon Gas is the largest contributor to the annual effective dose received by humans, which is colorless, tasteless, and invisible to the eye. This gas is harmful and can cause lung cancer. Thus, we try to study the average concentration level of Radon Gas in 20 workspace rooms in two different buildings located at the same altitude that mostly made of different building materials. First are HRD workspace rooms in building A that are mostly partitioned and enclose with cemented walls and glasses. Second are FaST workspace rooms that are partitioned and enclose with gypsum. All of the rooms are equipped with air conditioner and lack air circulation. The concentration of radon gas is measured by a passive radon dosimeter equipped with a CR-39 detector. The detectors are placed in those 20 workspace rooms of Pelita Harapan University for 3 months. Radon gas levels obtained ranged from 37.95 ± 2.76Bq/m³ to 91.07 ± 6.44Bq/m³ with an average value of 58.39 ± 4.13Bq/m³. In average, concentration of Radon gas in offices at FaST is 67.54 ± 4.77 Bq/m³, which higher than average concentration of Radon gas offices at HRD that is 49.24 ± 3.74 Bq/m³. The higher concentration of Radon gas that is 91.07 ± 6.44 Bq/m³ is found in room named FaST 1, which have lack air circulation, enclose in 4 sides with gypsum, and packed with boxes. The lowest concentration of Radon gas that is 37.95 ± 2.68 Bq/m³ is found in room named FaST 7, which enclose in 4 sides with glasses and contains only several tables and chairs. Yet, the measured concentration of Radon gas is still below the threshold recommended by the International Atomic Energy Agency (IAEA), which is 1000 Bq/m³.

1. Introduction

The development of industry in Indonesia is increasing rapidly along with the increasing level of economy among the Indonesian society. Unfortunately, this increasing of development increases the negative impact of air pollution. Beside the widely known air pollution, which is carbon dioxide, there is other pollution that comes from radiation that needs to be aware of. The world's population always gets pollution from radioactive or non-radioactive radiation. Radiation derived from radioactivity is generally natural. From the total radioactive radiation that the world's population exposed by, 87% comes from natural radioactivity radiation. This natural radioactivity radiation consists of 51% Radon and isotopes, 10% cosmic rays, 12% gamma internal radiation, 14% gamma and external radiation. While the proportion or other radiations are 13% comes from artificial radioactivity radiation, 12% of medical activities and other 1% like radioactive fallout, nuclear installation activities and from radiation work[2].
The United States Radiation Protection Commission (National Commission Radiation Protection) estimates that the population of the United States receives radiation exposure, in average, 3.6mSv annually, of which 55% of the dose comes from Radon. While Protection Agency British Radiation (National Radiological Protection Board) reported that the British population receives radiation exposure, in average, 2.5mSv annually, of which 47% of the dose comes from Radon\textsuperscript{1}. This reported amounts of Radon are significant and can be the cause of serious illness such as cancer. Thus, it is necessary to study about environmental safety based on the Radon concentration.

2. Physical Properties of Radon Gases

In the table of periodic, Radon is included in the noble gas class and has the characteristics of inert gas. It is a single atom, colorless and odorless element that does not react chemically with other natural elements and soluble in water. Other Radon physical properties can be seen in table 1.

| Table 1. Physics Properties of Radon-222 |
|------------------------------------------|
| Atomic number: 86                        |
| Weight: 222                              |
| Density at 0°C, 1 atm, g 1-1: 9.73       |
| Solubility in water at 1 atm (cm$^3$Kg$^{-1}$): |
| At 0°C 510                               |
| At 20°C 230                               |
| At 30°C 169                               |
| Solubility in various liquids at 1 atm (cm$^3$Kg$^{-1}$): |
| At 18°C | At 0°C |
| Glycerine 0.21 -                         |
| Aniline 0.38 4.4                         |
| Alcohol 6.2 8.3                          |
| Aceton 6.3 8.0                           |
| Ethyl alcohol 7.4 9.4                    |
| Petroleum 9.2 12.6                       |
| Xylene 12.7 -                            |
| Benzene 12.8 -                           |
| Toluena 13.2 18.4                        |
| Chloroform 15.1 20.5                     |
| Ether 15.1 20.1                          |
| Hexane 16.6 23.4                         |
| Carbon disulfide 23.1 33.4               |
| Olive oil 29.1 -                          |
| Viscosity at 1 atm (Microiose): |
| At 20°C 229.0                            |
| At 25°C 233.2                            |
| Critical properties: |
| Pressure (atm) 62                        |
| Temperature (°C) 105                     |
| Other properties: |
| Boiling point at 1 atm (°C) -62          |
| Density (G cm$^{-3}$) at boiling point 4.4|
| Ratio volume gas/liquid 452              |
| Triple point, solid-liquid-gas (°C) -71   |
| Pressure at triple point (mmHg) 500      |
| Diffusion coefficient in free air (cm$^3$sec$^{-1}$) 0.1 |
2.1. Radon Resources

Energy produced due to the movement and collision between two plates inside the earth causes magma and hot springs that then diffuse through the soil releasing with it Radon gas toward the air. Radon gas concentration in soil is influenced by the depth, the temperature and the humidity of the soil. Radon gas concentration increases in the deeper part of the soil and as the temperature of the soil drops, the gas in the soil will experience shrinkage thus the concentration of Radon gas will rise. This relation between temperature and concentration of gas is following the Boyle-Charles law, which states that gas will increase by 1/273 of its volume for every 10°C increment in temperature. Water also provides a significant contribution to the concentration of Radon gas in the air. As groundwater pierces through rocks and soil, which contain Radon gas, it dissolves the Radon gas and evaporates it into the atmosphere. Concentration of Radon gas dissolved in groundwater is depend on the characteristics of the rock. Figure 1 shows the content of Ra-226 and Ra-228 of several rock types.

![Figure 1. The Content of Ra-226 and Ra-228 of Several Rock Types](image)

The source of Radon gas is not only outdoors or from environment, it also can be found indoors, which generally comes from the building materials such as cement, brick, sand, gypsum, and granite flooring.

2.2. CR-39 Detector

CR-39, or allyl diglycol carbonate (ADC), is a plastic polymer commonly used in the manufacture of eyeglass lenses. The abbreviation stands for "Columbia Resin #39", which was the 39th formula of a thermosetting plastic developed by the Columbia Resins project in 1940. An alternative use includes a purified version that is used to measure neutron radiation, a type of ionizing radiation, in neutron dosimetry.

Although CR-39 is a type of polycarbonate, it should not be confused with the general term polycarbonate, a tough homopolymer usually made from bisphenol A. CR-39 is transparent in the visible spectrum and is almost completely opaque in the ultraviolet range. It has high abrasion resistance, in fact the highest abrasion/scratch resistance of any uncoated optical plastic. CR-39 is about half the weight of glass with an index of refraction only slightly lower than that of crown glass, and its high Abbe number yields low chromatic aberration, altogether making it an advantageous material for eyeglasses and sunglasses. A wide range of colors can be achieved by dyeing of the surface or the bulk of the material. CR-39 is also resistant to most solvents and other chemicals, gamma radiation, aging, and to material fatigue. It can withstand the small hot sparks from welding, something glass cannot do. It can be used continuously in temperatures up to 100 °C and up to one hour at 130 °C."

In the radiation detection application, CR-39 is used as a Solid-State Nuclear Track Detector to detect the presence of ionising radiation. Energetic particles colliding with the polymer structure leave a trail of broken chemical bonds within the CR-39. When immersed in a concentrated alkali solution (typically sodium hydroxide) hydroxide ions attack and break the polymer structure, etching away the bulk of the plastic at a nominally fixed rate. However, along the paths of damage left by charged particle interaction the concentration of radiation damage allows the chemical agent to attack the polymer more rapidly than it does in the bulk, revealing the paths of the charged particle ion tracks. The resulting etched plastic therefore contains a permanent record of not only the location of the radiation on the plastic but also gives spectroscopic information about the source. Principally used for the detection of alpha radiation emitting radionuclides (especially radon gas), the radiation-
sensitivity properties of CR39 are also used for proton and neutron dosimetry and historically cosmic ray investigations.

The ability of CR-39 to record the location of a radiation source, even at extremely low concentrations is exploited in autoradiography studies with alpha particles,[5] and for (comparatively cheap) detection of alpha-emitters like uranium.[5] Typically, a thin section of a biological material is fixed against CR-39 and kept frozen for a timescale of months to years in an environment that is shielded as much as possible from possible radiological contaminants. Before etching, photographs are taken of the biological sample with the affixed CR-39 detector, with care taken to ensure that prescribed location marks on the detector are noted. After the etching process, automated or manual 'scanning' of the CR-39 is used to physically locate the ionising radiation recorded, which can then be mapped to the position of the radionuclide within the biological sample. There is no other non-destructive method for accurately identifying the location of trace quantities of radionuclides in biological samples at such low emission levels.

CR-39 is used in some photographic filters, such as the Cokin filter system. A direct equivalent is produced by Acomon AG with the brand name RAV, and another one by Danyang Yuedo FineChemichal Co. Ltd in China.[5] A highly purified CR-39, manufactured under the name of TASTRAK, is available specifically for radio-dosimetry.

3. Research Scheme

As a precaution to maintain the health of employees in Pelita Harapan University, a research was carried out to study the average concentration level of Radon Gas in Pelita Harapan University. This research was conducted in two places, Pelita Harapan University and National Nuclear Power Agency (BATAN). Sample and data was collected from several offices at Pelita Harapan University, which are offices of Faculty of Science and Technology (FaST) that located at the 5th floor of Building B and offices of HRD that located at the 5th floor of Building A. Collected data then processed at the Center for Radiation Safety and Metrology Technology (PTKMR BATAN).

The concentration of Radon gas is detected with passive radon dosimeters, which each of it was equipped with a CR-39 detector.

On figure 2 each detector consists of two parts, each detector is filled with a CR-39 detector and then closed by black rubber to hold the film, after that the dosimeter is closed and becomes one part. Each dosimeter was marked with number to indicate its location thus the result of the detected concentration of Radon gas can be linked and analyzed based on the characteristics of its location. Marked dosimeter then attached to the ceiling with rope at a certain length because the dosimeters must be, at least, 2 meters from the floor and 1 meter from ceiling, walls and windows.

After attached for 3 months, all the dosimeters were collected with each one of it was inserted into a tightly sealed plastic bag. Then, all the sealed dosimeter were taken to BATAN to be
analyzed. CR-39 detector etching by NAOH 6 N at 70°C for 6 hours in incubator. CR-39 is washed by distilled water and dried. BATAN uses optical microscope with 400x magnification to read the concentration of Radon gas captured by CR-39 detector as shown in figure 3 and 4.

The reading result then calculated with following equation:

\[
C = \frac{(N_T - N_B) \pm Sd}{E \times t} \quad [4]
\]

\( C \) = Indoor Radon levels (Bq/m³)
\( N_T \) = Total nuclear footprint (trace/cm²)
\( N_B \) = Number of background traces (trace/cm²)
\( Sd \) = Standard deviation (trace/cm²), calculated with equation (2)
\( E \) = Efficiency of trace (trace/cm²/Bq day or %), calculated with equation (3)
\( t \) = Time of radiation exposure (length of CR-39 detector installation) in days

With 95% confidence intervals (2Sd), standard deviation is calculated with the following equation:

\[
Sd = \sqrt{\frac{(N_T - N_B)E}{E \times t}} \quad [4]
\]

Efficiency of trace is calculated with the following equation:

\[
E = \frac{N_T - N_B}{A_t} \times 100\% \quad [4]
\]

\( A_t \) = Standard activity of Radon Gas

4. Research Results
From the research, the measurement result of the Radon gas concentration at several offices in Pelita Harapan University is shown in Figure 5.
In terms of building materials, most office rooms at FaST are partitioned and enclose with gypsum while office rooms at HRD are mostly partitioned and enclose with cemented walls and glasses. In average, concentration of Radon gas in offices at FaST is 67.543±4.775Bq/m$^3$, which higher than average concentration of Radon gas offices at HRD that is 49.244±3.741Bq/m$^3$. Thus, it shows the relation between building materials and concentration of Radon gas. Besides building materials, items in the rooms are also potential sources of Radon gas. More items stored and stacked in boxes at office rooms at FaST than at HRD contributes to higher concentration of Radon gas in offices at FaST than at HRD.

The fact that office room named FaST 1, which has highest concentration of Radon gas, is a room that enclose in 4 sides with gypsum and packed with boxes, while the lowest concentration of Radon gas that is 37.95±2.68Bq/m$^3$ is found in room named FaST 7, which enclose in 4 sides with glasses and contains only several tables and chairs, it corroborates relation between all mentioned causes with the concentration of Radon gas.

Fortunately, the measurement data for the concentration of Radon gas in some offices at Pelita Harapan University is still below the threshold recommended by the International Atomic Energy Agency (IAEA), which is 1000Bq/m$^3$ for the concentration of radon gas in the resident area and 200Bq/m$^3$ in the working places.

5. Conclusions
Measured concentration of Radon gas in some offices at Pelita Harapan University are ranged from 37.95 ± 2.68Bq/m$^3$ to 91.07 ± 6.44Bq/m$^3$, with an average value of 58.39 ± 4.13Bq/m$^3$. Office rooms at FaST have higher concentration of Radon gas than office rooms at HRD due to higher amount of gypsum used to partition the office rooms and more boxes packed in the rooms. In average, concentration of Radon gas in offices at FaST is 67.543±4.775Bq/m$^3$, which higher than average concentration of Radon gas offices at HRD that is 49.244±3.741Bq/m$^3$. The higher concentration of Radon gas that is 91.07 ± 6.44Bq/m$^3$ is found in room named FaST 1, which enclose in 4 sides with gypsum and packed with boxes. The lowest concentration of Radon gas that is 37.95±2.68Bq/m$^3$ is found in room named FaST 7, which enclose in 4 sides with glasses and contains only several tables and chairs. Yet, the measured concentration of Radon gas is still below the threshold recommended by the International Atomic Energy Agency (IAEA), which is 1000Bq/m$^3$.

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