Influence analysis of natural ventilation system on radon concentration in Interim Storage for Radioactive Waste

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Abstract. The release of radioactive contaminants in nuclear facilities or facilities associated with radioactive materials could be harmful to the workers. The mechanical and natural ventilation system in the nuclear facilities can eliminate or reduce this potential risk. The purpose of this study is to analyse the correlation of natural ventilation with radon concentration in Interim Storage for Radioactive Waste in BATAN. In this study, the radon sources are not only from soil and building materials but mainly from Ra-226 radioactive waste, which was used in Brachytherapy to kill cancer cells. The simulation analysis was conducted using multi-zone airflow and contaminant transport code, CONTAM. The numerical simulation results were validated with analytical calculation and experimental measurement. The experimental measurement was performed using an electronic radon detector with real time monitoring, DURRIDGE RAD7. The results show that the change of radon concentration can be affected not only by temperature difference between indoor and outdoor but also by temperature difference between one room and the other room connected to it. The simulation- and calculation in this study are relatively consistent to the measurement results.

Keywords: Multi-zone airflow and radioactive contaminant transport analysis, radon, ventilation, Indonesia's Radioactive Waste Treatment Analysis.

1. Introduction

In nuclear facilities, the release of radioactive contaminants in indoor air is conceivable, which could be unsafe for the workers. The natural and mechanical ventilation system in the nuclear facilities can minimize this potential risk. The ventilation and air conditioning (VAC) system for nuclear facilities or facilities associated with radioactive materials depend on the type of facilities and the specific service required. This VAC system is designed to minimize radioactive contaminants in indoor air and maintain the building under negative pressure[1].

Besides ensuring safety of radioactive contaminants, the VAC system in nuclear facility also provides the appropriate temperature and humidity to ensure the optimal and safe parameters of indoor air quality (IAQ). There are a lot of studies on IAQ, however, there has not been much research on IAQ in nuclear facilities.

Several experimental and computational modelling studies on natural and mechanical ventilation in rooms with openings were conducted by Hwataik et al.[2,3].

Nicolas et al. conducted experiments and numerical analysis of wind influence on steady state[4] and transient airflows[5] inside nuclear facility buildings equipped with ventilation systems.
An analysis of radioactive contaminant concentrations in a radioactive working space equipped with ventilation and air conditioning system was made by Ciobanu et al. [6]. A calculation model of radon concentration in ventilated indoor air was proposed by Jelle [7]. Other studies on radon were the observation of the correlation between indoor radon concentration and outdoor atmospheric parameters [8], and the dispersion of radon or thoron inside dwellings [9]. The numerical and CFD modeling on radon dispersion studies were also conducted [10-16].

The purpose of this study is to investigate the correlation of natural ventilation with radon concentration at Interim Storage for Radioactive Waste in Serpong, Indonesia. The radon sources in this study is mainly generated from Ra-226 radioactive waste, which was used in Brachytherapy to kill cancer cells. The simulation analysis was performed using multi-zone airflow and contaminant transport code. The investigated radioactive contaminant was Radon 222. The numerical analysis was to be compared with measurement results.

2. Methodology
This study was conducted using numerical simulation approach and experimental measurement. The numerical analysis was performed using multi-zone airflow and contaminant transport code CONTAM. The numerical simulation results were compared and validated with the experimental measurements and analytical calculation.

It has been investigated the correlation between indoor air conditions influenced by natural ventilation and the contaminant concentration in Interim Storage for Radioactive Waste in at BATAN (National Nuclear Energy Agency of Indonesia). Some data measured in this study were concentration of radioactive contaminant and temperature. The investigated radioactive contaminant in this study was Radon. The radon concentration in this study was measured using an electronic radon detector with real time monitoring, DURRIDGE RAD7.

The Interim Storage for Radioactive Waste Building consists of 3 interim storage rooms and 1 door way. The building reserved to store radioactive waste placed in drums and concrete shells as shown in Figure 1. Recently, there are 2675 conditioned radioactive wastes from Co-60, Cs-137, Pm-147, Kr-85 and Ra-226.

![Figure 1. Interim Storage for Radioactive Waste in Serpong](image)
2.1. Numerical Simulation

The radioactive contaminant dispersion analysis in this study was performed using CONTAM software, a multi-zone airflow and contaminant transport code. The modelling of Interim Storage for Radioactive Waste with CONTAM software is shown in Figure 2. The zones in the model are 3 interim storage rooms and 1 doorway. There are 20 openings or flow paths. The openings are ventilation windows, open doors and leakages from closed doorway.

![Figure 2. CONTAM-Modelling of Interim Storage for Radioactive Waste](image)

The mathematical equation, which can be applied to correlate the airflow and pressure difference, is the power law model [17]. The power law model is expressed in volumetric flow form and mass flow form. In volumetric form, the general form of power law is determined as follows:

\[ Q = C (\Delta P)^n \]  

(1)

While mass flow form is:

\[ F = C (\Delta P)^n \]  

(2)

where \( Q \) is volumetric flow in m\(^3\)/s, \( F \) is mass flow in kg/s, \( C \) is flow coefficient in (m\(^3\)/s)/Pan for volumetric flow form and in (kg/s)/Pan for mass flow form, \( n \) is flow exponent and \( \Delta P \) is pressure difference in Pa.

The other model that can be applied is one way flow using quadratic models (G. N. a. W. S. D. Walton, 2005). The equations in volumetric- and mass flow form are:

\[ \Delta P = aQ + bQ^2 \]  

(3)

\[ \Delta P = aF + bF^2 \]  

(4)

where the coefficient \( a \) is in Pa.s/m\(^3\), \( b \) is in Pa.(s/m\(^3\))\(^2\).

The natural airflow without mechanical ventilation system could happen due to the temperature difference between indoor and outdoor and elevation difference of flow paths (orifices). Some equations that can be applied are as follows:

The change of air density due to temperature difference is shown below.

\[ \rho(T) = \rho(T_0) [1 - \beta (T - T_0)], \text{ with } \beta = 1/273 \]  

(5)

CONTAM uses the following equation to calculate \( \rho \) (G. N. Walton & Dols, 2005)

\[ \rho(T) = \rho_r/(287.055 T) \]  

(6)

the general form of power law is determined as follows:
\[ P_t = P_0 - \rho g z_t \]  \hspace{1cm} (7)

where \( \rho(T) \) is density in kg/m\(^3\) at temperature \( T \) in Kelvin, \( T_0 \) is the reference temperature.

2.2. Experimental Measurement

The measurement of radon concentration was carried out using DURRIDGE RAD7, an electronic radon detector with real time monitoring and spectral analysis as shown in Figure 3.

![Figure 3. DURRIDGE RAD7 Radon Detector](image)

The RAD7 is a multipurpose radon measuring instrument that may be used in many different modes for different purposes. The RAD7 is equipped with a built-in air pump, rechargeable batteries and a wireless infrared printer. The RAD 7 is a Sniffer that uses the 3-minute alpha decay of radon daughter, without interference from other radiations, and the instantaneous alpha decay of a thoron daughter. The measurement accuracy according to manufacturer is +/-5% absolute accuracy. The radon concentration ranges from 4 – 750,000 Bq/m\(^3\) [18].

The radon concentration measurement using RAD7 was performed in several rooms in Radioactive Waste Treatment Installation and in Interim Storage for Radioactive Waste. The measurement cycle per one measurement data is set for 60 minutes each. The measurement was performed for several hours.

3. Results and Discussion

The radon concentration measurement in Interim Storage for Radioactive Waste (Figure 2) was performed in Storage 1. As mentioned above, one of radioactive wastes stored in this building is radium Ra-226. In the past, Ra-226 was used in Brachytherapy, a cancer treatment therapy using radioactive sources to kill the cancer cells. The decay product of Ra-226 is radon. This clarifies that the radon concentration in this building is significantly higher than that of in Radioactive Waste...
Treatment Installation building, as shown in Figure 4. The radon sources in this building are not only from soil and building materials but also from stored radioactive waste.

Figure 4 shows that the radon concentration decreased quite significantly from 258 Bq/m$^3$ at 18:41 to 24.2 Bq/m$^3$ at 21:41. The decrease in radon concentration in this building is not affected by VAC system, since the building is not equipped with VAC system.

In this case, based on the results of simulation and calculation analysis, the difference in air temperature between indoor and outdoor might be the cause of the radon concentration reduction.

Figure 5. Comparison of Radon concentration measurement and simulation in Interim Storage of Radioactive Waste
Table 1. Comparison of Radon concentration measurement and simulation in Interim Storage of Radioactive Waste

| Time  | Outdoor | Storage 1 | Doorway | Storage 2 | Storage 3 | Measurement | Simulation |
|-------|---------|-----------|---------|-----------|-----------|-------------|------------|
| 18:41 | 28.2    | 29.4      | 29.4    | 29.4      | 29.4      | 258         | 258        |
| 19:41 | 27.4    | 29.4      | 29.4    | 29.4      | 29.4      | 205         | 201        |
| 20:41 | 26.7    | 29.1      | 28.8    | 29.1      | 29.1      | 80.8        | 80.4       |
| 21:41 | 25.5    | 28.8      | 27.8    | 28.8      | 28.8      | 24.2        | 25.3       |
| 22:41 | 25.2    | 27.9      | 27.7    | 27.9      | 27.9      | 43          | 43.9       |

At the beginning of the measurement (at 18:41) the temperature difference between indoor and outdoor was not so high. A few moments later, as shown in Table 1, the decrease in the outdoor temperature was more rapid than that of in the indoor temperature that the temperature difference between the indoor and the outdoor became larger. With this temperature difference and the existing orifices (opening) in the building, it can be concluded that the measurement results in Figure 4 were almost the same as the simulation results CONTAM software as shown in Figure 5. The simulation result values are written in white script on the gray block, while the simulation results are in black letters.

The CONTAM modelling in this study was made as closely as possible with to real conditions. Some parameters needed to be set were the dimension of all rooms and all flow paths (orifices including door leakages), species properties of radon contaminant, the radon generation (exhalation) rate, temperature in all rooms, outdoor temperature, etc. The simulation results show that the temperature difference between indoor and outdoor generates air flow through the existing orifices in the building. This natural air flow in the building causes the reduction in radon concentration.

Using some of the equations mentioned above, the reduction in radon concentration in the building from 18.41 to 19.41 can be explained with the following calculations:

− The room (Storage 1) temperature is 29.4°C, the air density is 1.167 kg/m³
− The ambient (outdoor) temperature is 27.4°C, the air density is 1.174 kg/m³
− The elevation of each orifice 1 and orifice 13 is 3 m while orifice 2 and orifice 14 are 3.03 m.

\[ \Delta P_i = g z_i (\rho_{\text{room}} - \rho_{\text{amb}}) - X_i \] (8)
where \( X_i \) is residual pressure inside the building in Pa.

Pressure difference at orifice 2:

\[
\Delta P_2 = g \ z_2 \ (p_{amb} - p_{room}) + X_i
\]  \( (9) \)

Using mass conservation concept: \( F_1 = F_2 \) in kg/s, the \( X_i, \Delta P_1 \) and \( \Delta P_2 \) values can be obtained, i.e. 0.229 Pa, 0.001 Pa and 0.001 Pa, respectively.

Comparing simulation with CONTAM as shown in Figure 7, the above calculations have nearly the same values. The CONTAM simulation results show: The pressure difference in orifice 1 is 0.0009 Pa with flow direction from ambient to room, and the pressure difference in orifice 2 is 0.0009 Pa with the opposite direction.

![Figure 7. Airflow and pressure after running CONTAM simulation.](image)

4. Conclusion

The simulation- and calculation results on radon concentration in this study are relatively similar to the measurement results.

The natural ventilation can reduce the radon concentration. The radon concentration can increase when the rise in radon concentration caused by radon generation rate (Bq per unit of time) is greater than the decrease in radon concentration per unit of time caused by the air flow. The very slow air flow through the room can occur if the difference between the indoor and the outdoor temperature is small.

The natural air flow that can give influence on radon concentration can also be affected not only by temperature difference between indoor and outdoor but also by temperature difference between one room and the other room connected to it.

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