THE RISK OF RADON/THORON EXPOSURE TO THE PUBLIC IN GEBENG INDUSTRIAL ESTATE, KUANTAN, PAHANG

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ABSTRACT

This study aims to assess radon/thoron concentrations and the potential risks of exposure to the public from the Lynas rare-earth processing plant operation in the Gebeng Industrial Estate (GIE), Pahang. The concentrations of radon and thoron in air and water (surface and ground) have been measured within a radius of 3 km from the plant. Based on the finding in this study, it can be concluded that the mean radon and thoron equivalent equilibrium concentration (EEC) in the GIE area were low i.e., 6.5 and 2.5 Bq/m³ respectively. These values were equivalent to values measured outside the GIE area. The mean radon concentration in water in the GIE area was about 1 Bq/L which is very far below the WHO (2011) reference level for drinking water. There was no thoron detected in all sources of water around the GIE. Overall, there was no enhancement of radon/thoron concentrations in air and water in the GIE due to activities carried out by Lynas. The public only received a dose from natural background radiation sources. The effective dose received by the public from exposure to radon/thoron in air and water was 0.3 mSv/y. The results indicated that no radiological hazard to the people living in the vicinity of the Lynas rare-earth processing plants.

Keywords: Dose, Lynas, radon, rare-earth processing, thoron

INTRODUCTION

Naturally occurring radioactive material (NORM) which occurs everywhere poses radiation exposure risks to the people throughout the world. In certain areas, human activities such as mining, mineral processing, oil and gas industries have contributed to its enhancement in the environment. NORM is known to contain a certain amount of radioactivity. The important radionuclides are those from 238U and 232Th decay series. Radon (222Rn) and thoron (220Rn) are radioactive noble gases that are part of the 238U and 232Th decay series respectively. Whenever 238U and 232Th occur the inert gas radon and thoron are inevitably present. The exposure to indoor radon is the most significant contributor to natural radiation dose. Radon (including thoron) contributed about 52% of the natural radiation dose received by the public (UNSCEAR, 2000). Radon, thoron and their decay products in the air have been known as a potential health hazard as they can cause a significant inhalation radiation dose to the respiratory tract and other tissue. Besides the exposure through inhalation, peoples may also be exposed to radon/thoron through the ingestion of drinking water. In certain areas, groundwater contains significantly high radon concentration and its usage as drinking water may increase the ingestion dose. Due to the increased awareness on the risk of exposure to radon, the interest on the subject became important and studies have been conducted worldwide (Akerblom et al., 1993; Choubey et al., 2010; Cliff et al., 1992; Doi et al., 1992; Guo et al., 1992; Mjones et al., 1992; Nagaratnam, 1994; Nazaroff et al., 1988; NRC, 1999; Ramola et al., 2005; Rannou et al., 1988; Saat et al., 2010; Stranden, 1980; Stuardo, 1996; Sulaiman et al., 1994; Tso et
The Gebeng Industrial Estate (GIE), Kuantan, Pahang is the leading chemical and petrochemical hub of the region. One of the industries located in the GIE is Lynas Advanced Materials Plant (LAMP). LAMP is a rare earth processing plant. The plant processes lanthanide concentrate and produces lanthanide oxide (LnO) or lanthanide oxide basis of high purity lanthanide compounds in the form of different products. The Lynas rare earth plant also produces solid waste or residue i.e., water leach purification (WLP) which contains NORM. The WLP contains $^{226}\text{Ra}$ and $^{228}\text{Ra}$ radionuclides which are the parent nuclides for radioactive gases radon ($^{222}\text{Rn}$) and thoron ($^{220}\text{Rn}$) respectively. The WLP is stored temporarily in the plant premise. Radon and thoron gas will naturally be emanated, released and dispersed into the ambient air. Radionuclides $^{226}\text{Ra}$ and $^{228}\text{Ra}$ in residue/waste might also leach into the groundwater system. Besides solid waste, the plant also produces wastewater which will be treated before released into a stream and finally into the Balok river.

The public around the Lynas plant may be exposed to radon/thoron gases and progenies in the air released by the plant. They might also be exposed to radon/thoron in water from fishing and recreation activities and also from drinking water. To assess these potential risks, the level of radon/thoron in air and water around the Lynas plant needs to be quantified. Therefore, a study was carried out with the main objective was to measure the radon/thoron levels in the vicinity of Lynas rare-earth processing plant and thereby to assess potential radiological hazards to the general public. This paper reports the results of the measurement of radon and thoron around GIE and its associated dose to the general public.

MATERIALS AND METHODS

Study Area

There were 32 and 8 locations in GIE selected for measurement of radon/thoron in air and in water respectively (Figure 1). The radon/thoron in air measurement locations (Ly1 – Ly32) were randomly selected while radon/thoron in water measurement locations was selected based on the water flow direction from the plant into surface or groundwater which can affect the public. These include 4 locations each for surface water and groundwater sampling. Surface water sampling points were located at wastewater discharge point (DP), small stream outside Lynas compound (2 locations i.e., upstream (US) and downstream (DS1)) and Balok river (DS2). The upstream location will be used as a reference as its water was not affected by Lynas plant discharge. Boreholes (BH1 – BH4) which are already available around the plant were used for groundwater sampling.

Measurement of Radon/Thoron in Air

Radon and thoron concentrations in air were measured a few times during the study period at the pre-selected locations. Their concentrations were measured and analysed based on the active method performed using continuous radon progeny monitors model Doseman Pro (Sarad, Germany). The monitors were calibrated by the manufacturer. The monitor is equipped with alpha spectroscopy system capable of discriminating alpha energy peaks emitted by radon and thoron progenies. The equipment consists of a membrane pump, a USB interface, a semiconductor detector, a filter paper holder and a rechargeable battery. The sampling of radon and thoron progenies was performed by pumping the air through a filter paper. The monitor was placed on a
tripod stand at a height of 1 m above the ground. The measurement was conducted for a period of about 6 – 7 hours in order to obtain a representative average radon concentration during working hours. A few measurements were also performed for 24 hours period for the purpose of comparing the pattern of radon (and thoron) variation with time. Measurements were also performed in other areas such as Balok, Damansara Hill, Semambu, Sungai Ular and Telok Chempedak for comparison with the result within GIE.

![Figure 1](image_url)

**Figure 1:** Location map for radon/thoron measurement around Gebeng Industrial Estate

**Measurement of Radon/Thoron in Water**

Surface water samples were taken using a pail while ground water samples were taken with a bailer. Surface and groundwater sample (1 litre) were collected and put into the plastic bottles. About 400 mL water sample was then transferred into a bubbling flask. Care was taken to prevent aeration of the samples during the process in order to avoid loss of radon. The bubbling flask then connected to the radon monitor to create a closed air loop. The radon monitor used was Sarad RTM1688 (Sarad, Germany). The monitor is also equipped with alpha spectroscopy system. It consists of a membrane pump, a USB interface, a semiconductor detector chamber and a rechargeable battery. The air volume of the system circulates through the loop drawn by the internal pump of the radon monitor. The radon gas solved in the water sample will be de-gassed and the small bubbles created by the pump will transfer radon gas into a detector chamber. Radon gas decayed to progenies by emitting alpha particles which will be subsequently counted by the semiconductor detector. The equilibrium state between the radon activity concentration in air and water is achieved after approximately 30 minutes (Sarad, 2007). The measurement of radon concentration (in Bq/m³) can be started at the earliest after 30 minutes of bubbling. By using the appropriate values (i.e., radon gas concentration, water volume, water temperature) radon in water concentration (in Bq/L) can be calculated. Additional water samples i.e., tap water and seawater at a few locations was also collected and analysed their radon/thoron concentrations for comparison.
RESULTS AND DISCUSSION

Radon/Thoron in Air Concentration

Radon/thoron progenies were measured in the form of potential alpha energy concentrations (PAEC) in the Working Level (WL) unit. PAEC was then converted to equilibrium equivalent concentration (EEC) in Bq/m\(^3\) using the following conversion factors (UNSCEAR, 2000):

\[
0.27 \text{ mWL} = 1 \text{ Bq/m}^3 \text{ for } ^{222}\text{Rn} \quad \text{and} \\
3.64 \text{ mWL} = 1 \text{ Bq/m}^3 \text{ for } ^{220}\text{Rn}.
\]

The mean EEC radon and thoron in GIE are shown in Figure 2. Overall, the concentration (EEC) of radon and thoron in the air around GIE was low. More than 50% of the measured EEC radon and thoron were less than 6 Bq/m\(^3\) and 2 Bq/m\(^3\), respectively. Their frequency (percentage) distributions are shown in Figure 3. The EEC radon in the air around GIE varied from 0.7 – 20.0 Bq/m\(^3\) with a mean value of 6.5 Bq/m\(^3\), while EEC thoron varied from 0.1 – 8.2 Bq/m\(^3\) with a mean value of 2.5 Bq/m\(^3\). The above mean values are equivalent to the concentrations (EEC) of radon and thoron in the air outside building in Peninsular Malaysia of 5.6 Bq/m\(^3\) and 0.5 Bq/m\(^3\) respectively (Sulaiman et al., 1994). The world outdoor average radon EEC (calculated from outdoor radon) and thoron EEC are 6 Bq/m\(^3\) and 0.1 Bq/m\(^3\), respectively (UNSCEAR, 2000).

Figure 2: The mean radon and thoron EEC at each measurement location in Gebeng Industrial Estate
The results of this study were slightly higher than the values obtained during the preoperational monitoring period (before the plant was built) probably due to different technique and type of equipment used (i.e., more sensitive and advanced alpha spectroscopy system used in this study compared to gross alpha count and delay method). The difference was also due to variations in measurement locations (and hence soil radioactivity) between the pre-operational monitoring period and this study. The radon EEC measured during the preoperational period ranged from 0.4 – 7.8 Bq/m³ with a mean value of 2.2 Bq/m³ while thoron EEC ranged from 0.1 – 1.7 Bq/m³ with a mean value of 0.5 Bq/m³ (MNA, 2009).

Measurement results showed that there was no location indicating significantly high levels of radon and thoron that could be attributed to the release from Lynas plant. The highest readings were recorded at the station located in front of the Lynas entrance gate (Ly6). The radon and thoron EEC at the above station was 20.0 Bq/m³ and 8.2 Bq/m³, respectively. It is believed that slightly high radon and thoron concentrations were due to the radioactivity of soil in the surroundings. Yii (2016) reported that a high concentration of radium was found at this location.

Radon and thoron concentrations at locations near the WLP residue storage area (Ly14 and Ly15) and wastewater discharge point (Ly7) were also low. The mean radon and thoron EEC at Ly14 were 5.4 Bq/m³ and 2.7 Bq/m³, respectively. Whilst at Ly15 their respective values were 8.7 Bq/m³ and 1.7 Bq/m³. Their respective mean concentrations at Ly7 were 5.7 Bq/m³ and 2.6 Bq/m³. It was obvious that the measured radon and thoron concentrations were not affected by the WLP residue and discharge of wastewater from the Lynas plant.

The results also showed that the measurements performed at the same location and time but on different days delivered slightly different values and patterns. Usually, radon, thoron and their progenies concentrations contributed from the environmental sources such as soil and rocks, are high/maximum in the early morning and low/minimum in the evening (Omar et al., 2015). This situation was also observed in GIE and other areas such as Balok when measurements were performed for 24 hours period. The radon and thoron EEC outside GIE range from 3.3 – 8.7 Bq/m³ and 0.1 – 5.3 Bq/m³, respectively with their mean concentration is shown in Figure 4. A typical variation pattern of radon and thoron concentrations in the air with time in GIE is shown in Figure 5. These patterns are similar to those measured outside the GIE (i.e., Balok, Sg. Ular, Damansara Hill, Semambu and Telok Chempedak). From the graph, it can be observed that radon progenies were always available and detected by the monitor at all times but not thoron progenies. At a certain time there were no thoron progenies detected due to very low thoron gas concentration emanated.
from the soil and most of them decayed, dispersed or carried away by the wind. Measured radon and thoron concentrations were contributed by the sources in the environment around the GIE (e.g. soil, rock) rather than from the Lynas plant. Radon, thoron and their progenies concentrations in the air depend on their parent’s radioactivity ($^{226}$Ra and $^{228}$Ra), properties of local soil/rock (such as porosity and permeability) and meteorological parameters (especially wind speed and directions).

**Figure 4:** The mean radon and thoron EEC outside Gebeng Industrial Estate

**Figure 5:** Variation of radon and thoron concentrations with time in Gebeng Industrial Estate

Wind plays an important role in affecting radon and thoron concentrations in the air outside the building as it can carry radon, thoron and progenies away from its sources (the materials containing radionuclides from the uranium/thorium decay series). Even if there were some releases of radon/thoron from Lynas plant, their concentrations decreased rapidly because they are carried away by the wind and dispersed in various directions causing the concentrations in the air to be low.

**Radon/Thoron in Water Concentration**

Generally, all types of water sources contained very low radon concentrations. About 80% and 70% of measured surface water and groundwater samples contained radon concentration of less than 1 Bq/L, respectively. Their distribution patterns are shown in Figure 6 while, the mean concentrations
at each measurement location are shown in Figure 7. The mean radon concentration in water samples at the wastewater discharge point was low i.e., 0.13 Bq/L (range 0.03 – 0.68 Bq/L). The results indicate that wastewater released by Lynas plant contained a very low concentration of radionuclide radium. This may also due to the dilution of radionuclides with freshwater or rainwater before discharged into the small stream outside the plant. For downstream water locations (DS1 and DS2), their mean radon concentrations were also low i.e., 0.35 Bq/L (range 0.05 – 0.82 Bq/L). Both locations did not show much difference in radon concentrations but slightly higher than discharge water probably due to contribution from the emanation of radon from bed sediment and runoff containing radionuclide radium. The mean radon concentration in water samples at the upstream location was 1.32 Bq/L (range 0.16 – 2.30 Bq/L). Upstream water (which was not affected by Lynas discharge) contained slightly higher radon concentrations compared to other surface water samples. This is due to the contribution from radon emanation of stream’s bed sediment and also runoff containing radionuclide radium. Low volume of water in the stream (narrow and shallow) also contributes to less dilution of radon in water. The mean radon concentration for all surface water was 0.55 Bq/L and comparable with the UNSCEAR reported value of 1 Bq/L (UNSCEAR, 2000).

Figure 6: Distribution of radon in surface and ground water concentration around Gebeng Industrial Estate

Figure 7: The mean radon in water concentration around Gebeng Industrial Estate
The mean radon concentrations in groundwater samples were also low i.e., 1.46 Bq/L (range 0.01 – 7.73 Bq/L) but slightly higher than surface water. This mean value is less than the UNSCEAR reported value of 10 Bq/L (UNSCEAR, 2000). Borehole number 4 (BH4) contained slightly higher radon concentrations compared to the others probably due to different types of bedrocks (and hence natural radioactivity) in the surrounding area. Radon concentrations in groundwater generally differ among rock types and can vary considerably within the same geologic formation (Sloto, 2000). The variations of radon concentrations in groundwater were due to differences in released and flowed of radon emanated from soil/rock which in contact with water. Sloto and Senior (1998) noted that radon concentration can change with time due to dilution by recharge. Changes in the contributing aquifer due to fluctuation in the water table can also cause the variation. Due to the above reason, radon concentrations can vary significantly in wells just a few meters away. Even concentrations from the same well can vary seasonally depending on groundwater flow patterns. Generally, all types of water samples showed some variations in radon concentration over the study period. The variations were observed between sampling intervals. The concentrations were slightly high in the dry season and low in the wet season due to dilution in a large volume of water. Overall, the mean radon in water (surface and ground) concentration in GIE was 0.98 Bq/L.

Lynas WLP residue was kept in the storage area which has a multiple layer lining/filtering system to prevent or slow down the radionuclides leaching process. High concentrations of radon in groundwater may indicate that the occurrence of leaching and accumulation of radionuclide radium in the well. Lynas plant was operated for several years and the results of the study (low radon concentrations in groundwater) showed that no leaching or migration of radionuclides has occurred. Usually, the migration of radionuclides (if any) occurs very slowly and takes a long time to reach groundwater depends on the distribution coefficient of radionuclides and properties of the local soil. Based on a radiological impact assessment (RIA) study, radionuclides $^{226}$Ra from oil sludge disposal entered the groundwater system after 30 years and the maximum migrated radionuclide occurred after 200 years (Khairuddin et al., 2015).

Seawater contained very low radon concentrations (i.e., < MDA - minimum detectable activity) due to low concentrations of dissolved radionuclide radium and it is safe for reactional activities. Tap or drinking water also contained very low radon concentrations (< MDA) and far below the World Health Organization (WHO) reference level of 100 Bq/L (WHO, 2011). This is because the loss of radon due to degassing as a result of water turbulence within the supply system and natural radioactive decay while the water is resident in the household supply system. Seawater and tap water were not affected by the Lynas plant operation.

As for thoron in water measurements, there was no thoron detected in all types of water samples. Due to its very short half-life (56 s) and 30 minutes degassing process during measurement has completely removed thoron gas from water. Besides, most of the thoron gas from radionuclide $^{228}$Ra decay process will recoil in water and rapidly decay before it can be transported long distances from its point of emanation. Therefore, the initial thoron concentration in water (before sampling) was already low and cannot be detected by the measurement system.

**Effective Dose**

In order to assess the annual effective dose received by the public from radon/thoron in air around GIE, appropriate UNSCEAR’s conversion factors i.e., outdoor occupancy factor of 0.2, dose conversion factor of 9 nSv h$^{-1}$/Bqm$^{-3}$ and 40 nSv h$^{-1}$/Bqm$^{-3}$ for radon and thoron progenies respectively (UNSCEAR, 2000) were used. The estimated effective dose received by the public was 0.3 mSv/y. For exposure to the stomach wall due to radon ingestion, dose conversion factor of
3.5 × 10⁻⁹ Sv/Bq (for adult) and average water consumption per year of 500 L (UNSCEAR, 2000) were used. By using the mean radon in water concentration in GIE of 0.98 Bq/L, the estimated effective dose from drinking water containing radon was about 1.7 µSv/y. The dose from water was negligible and will not have harmful effect on human and marine organism. Total annual effective dose from exposure to radon and thoron from natural background sources in GIE was 0.3 mSv.

CONCLUSION

The mean radon and thoron EEC in GIE were low i.e., 6.5 and 2.5 Bq/m³ respectively and equivalent with values measured outside the GIE area. Overall, there was no enhancement of radon and thoron concentrations in the air due to activities carried out by Lynas. The mean radon concentration in water in GIE area was about 1 Bq/L which is very far below the WHO reference level for drinking water. The discharge water from the Lynas plant does not enhance the radionuclides concentrations in surface water. There was also no evidence of migration of radionuclides into groundwater system. There was no thoron detected in all sources of water around GIE. The effective dose received by the public from exposure to radon/thoron in air and water (from natural background sources) was 0.3 mSv/y. Thus, these findings reflected a negligible radiological hazard that may affect the people living in the surrounding areas.

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REFERENCES


