A multi-year study of natural radionuclides Beryllium-7 (Be-7) activity concentrations in surface air in Tanah Rata, Cameron Highlands, Pahang

F I A Rashid¹, a) and M Z Zolkaffly ¹, b)

¹ Planning and International Relations Division, Malaysian Nuclear Agency, 43000 Kajang, Selangor, Malaysia.

a)faisal_izwan@nuclearmalaysia.gov.my
b)zulfakar@nuclearmalaysia.gov.my

Abstract. The Comprehensive Nuclear-Test-Ban Treaty (CTBT) is a multilateral treaty that bans any nuclear explosions, either for military or civil purposes. The treaty is supported by an international network of monitoring stations, which inter-alia include radionuclide monitoring stations. Malaysia is a Member State to the CTBT and hosts a radionuclide monitoring station (Site code: RN42) in Tanah Rata, Cameron Highlands, Pahang. The continuous daily measurement at RN42 has created an invaluable resource for understanding variations in natural background radioactivity, including natural radionuclide, Beryllium-7 (Be-7). This study aims at assessing seasonal variations of Be-7 in surface air in Tanah Rata, Cameron Highlands, Pahang and determining its correlation with local meteorological parameters using statistical analysis. The results have been found that Be-7 activity concentration at the RN42 showed a seasonal variation and strong inverse correlation with precipitation data. The findings from this study could serve as basis for further studies on local and regional radiological impact assessment as well as for exploring the potential application of Be-7 as atmospheric tracer for civil and scientific purposes.

1. Introduction

The Comprehensive Nuclear-Test-Ban-Treaty (CTBT) is a multilateral treaty which bans all nuclear explosions – everywhere and by anyone. Under the provisions of the treaty, a global monitoring system based on waveform and radionuclide technologies known as the International Monitoring System (IMS) is currently being set up to verify country’s compliance to the treaty [1]. The IMS is one of the key components of the verification regime of the CTBT [2]. Malaysia is among the CTBT contracting states through its commitment in signing the treaty on 23 July 1998 and ratifying it on 17 January 2008 [3]. Under the CTBT, Malaysia has hosted an IMS Radionuclide Monitoring Station RN42 in Tanah Rata, Cameron Highlands, Pahang since 2010. The continuous daily measurement of atmospheric radionuclides indicative of nuclear explosion at RN42 has created an invaluable resource for understanding variations in atmospheric radioactivity.

Among the atmospheric radionuclides regularly measured at the station is Beryllium-7 (Be-7). Be-7 is a sampled particle-bound natural radionuclide which is mainly produced in the upper troposphere and lower stratosphere by spallation of nitrogen and oxygen nuclei of atmospheric molecules induced by galactic cosmic rays [4]. It decays with a 53.3 days half-life which make it suitable tracer for
Over two thirds of Be-7 is produced in the lower stratosphere (around 20 km altitude) while the remaining is produced in the upper troposphere [6]. The Be-7 production rate in the air is associated with solar activity, seasonal variation and latitude dependence [7]. Once formed in the atmosphere, it attached to submicron-size aerosol particles and transport with air masses. The aerosols are transported by winds and redistributed vertically to earth’s surface via atmospheric vertical mixing and gravitational sedimentation [8][9]. Moreover, Be-7 is removed from the atmosphere by wet and dry deposition in addition to its radioactive decay. Studies have showed that worldwide Be-7 concentrations on ground level follow an annual cycle whereby the transport of the radionuclide in the atmosphere is strongly governed by seasonal atmospheric processes [7].

In general, Be-7 has been used for numerous applications. Accordingly, several studies have proposed the radionuclide as natural atmospheric tracer [10][11][12]. Additionally, there are also studies on connection between air mass transport and ground level Be-7 concentration, such as seasonal variations caused by stratosphere-troposphere exchange, vertical air mass transport and transport from mid-latitudes to polar regions [13][14][15]. Hence, the variation of Be-7 deposited near the earth’s surface can be used as atmospheric tracer to study the behaviour of radionuclides in aerosols and atmospheric processes including tropospheric dynamics, stratosphere-troposphere coupling and cosmic ray flux variations due to solar activity. This understanding could serve as basis for further studies on local and regional radiological impact assessment as well as for exploring the potential application of Be-7 as atmospheric tracer for civil and scientific purposes.

This study aims at assessing seasonal variations of Be-7 in surface air in Cameron Highlands, Pahang and determining its correlation with local meteorological parameters using statistical analysis. The study takes advantage of the detection capabilities of the IMS Radionuclide Monitoring Station RN42, wherein Be-7 is regularly measured in the air particulate samples collected by station.

2. Methods

2.1. Site description
Be-7 data used in this study was obtained from the IMS CTBTO Radionuclide Monitoring Station RN42 (4.48°N, 101.37°E) as illustrated in Figure 1. RN42 is a particulate radionuclide monitoring station co-located with the Meteorological Station in Tanah Rata, Cameron Highlands, Pahang. The station is situated 1545 m above sea level. The station is one of the 80 radionuclide monitoring stations under the IMS that monitor atmospheric radionuclides particles indicative of a nuclear explosion.

Figure 1. The location of IMS CTBTO Radionuclide Monitoring Station RN42.
Tanah Rata is located in the district of Cameron Highlands in the state of Pahang, Malaysia. It is situated in the main mountain range of Banjaran Titiwangsa, with elevations ranging from 100 m at the east to 2031 m at the west [16]. The climate in Tanah Rata’s vicinity is between a tropical rainforest climate and a subtropical highland climate. It has recorded a temperature ranged from 15.0 °C to 25.4 °C with an average temperature of 19.4 °C [17]. Moreover, the historical meteorological record showed that the mean rainfall is 95.8 mm with the maximum of 365.1 mm and minimum of 8.9 mm [18].

2.2. Sample collection

The RN42 is equipped with a high-volume air sampler, detection equipment, computers and a communication set-up. At high-volume air sampler, the air is forced through a 57 cm × 46 cm polypropylene air filter for 24 hours with a sampling rate of 300 - 900 m³/h. Next, the air filter was compressed to a 5 cm diameter disc using a hydraulic press and placed on a plastic sample holder before being allowed for decay for 24 hours. Then, the filter is analysed for another 24 hours using a high-purity Germanium (HPGe) gamma spectrometer with a relative efficiency of 40%. The generated gamma radiation spectra are sent to the International Data Centre (IDC) in Vienna, Austria for further analysis and sample categorisation.

2.3. Statistical analysis

In this study, the daily activity concentrations of Be-7 from 1 January 2011 to 31 December 2018 were obtained from the CTBTO Concentration Reporting Tool (CRTool) [19]. Additionally, the daily precipitations in Tanah Rata, Cameron Highlands, Pahang for 1 January 2011 to 31 December 2018 were acquired from the Malaysian Meteorological Department. For both data, monthly average activity concentrations and precipitation for each year were plotted against acquisition month using Microsoft Excel. The generated graphs and tables were then examined for seasonal variation in activity concentrations of Be-7 and its correlation with precipitation data.

In order to determine the influence of meteorological conditions on the deposition of atmospheric radionuclide on earth’s surface, this study has attempted to correlate the Be-7 activity concentration data with meteorological data such as precipitation. In this context, monthly average activity concentrations of Be-7 were overlay against monthly average rainfall measured at the RN42 using Microsoft Excel. The correlation was determined using simple linear regression, with value of correlation (R²) nearest to 1 indicates strong linear relationship, and vice versa. In addition, for confirmation and verification purposes, the correlation between Be-7 activity concentrations with precipitation was also assessed using Pearson correlation coefficient (ρ), with values between ± 0.50 to ± 1.00 considered as having strong correlation, between ± 0.30 to ± 0.49 as moderate, and between 0 to ± 0.29 as having weak correlation.

3. Results and Discussion

3.1. Seasonal variation and frequency distribution of Be-7

Figure 2 shows the time series plot of average monthly Be-7 activity concentrations against month of sample collection measured at RN42 from 2011 to 2018. Table 1 summarises the average monthly Be-7 activity concentrations measured at RN42 from 2011 to 2018 and its standard deviations by months. Over the period of 2011 to 2018, the average monthly Be-7 activity concentrations ranged from 1.13 mBq/m³ to 2.85 mBq/m³ as shown in Table 1. Be-7 activity concentrations show two noticeable annual peaks, with the highest maximum activity concentration in March and second maximum in June as illustrated in Figure 2. Conversely, two annual minimums occurred throughout the year, with the lowest occurring in November and second lowest in May. The elevated Be-7 concentrations observed during the months of March and June as shown in Figure 2 can be explained by the low amount of precipitation in the vicinity of Tanah Rata recorded during these months. Additionally, the finding also suggest that the study area could experiencing stratosphere-troposphere exchange of air
masses in the mid-latitudes caused by an intense vertical jet stream which lead to an increase in Be-7 depositional fluxes to the Earth's surface [20]. The finding is also consistent with the fact that the variation of near surface Be-7 activity concentrations is contributed by several factors including wet scavenging, vertical mixing and horizontal atmospheric transport [21].

Figure 2. Average monthly Be-7 activity concentrations measured at RN42 from 2011 to 2018

Table 1. Summary of average monthly Be-7 activity concentrations measured at RN42 from 2011 to 2018

| Months (2011-2018) | Average monthly Be-7 activity concentration (mBq/m³) | Standard deviation, \( \rho \) |
|-------------------|-----------------------------------------------------|------------------|
| January           | 1.90                                                | 0.63             |
| February          | 2.55                                                | 0.81             |
| March             | 2.85                                                | 0.95             |
| April             | 2.13                                                | 0.78             |
| May               | 1.50                                                | 0.31             |
| June              | 2.37                                                | 0.53             |
| July              | 2.21                                                | 0.96             |
| August            | 1.95                                                | 0.60             |
| September         | 1.94                                                | 0.26             |
| October           | 1.88                                                | 0.74             |
| November          | 1.13                                                | 0.28             |
| December          | 1.26                                                | 0.37             |
3.2. Correlation of Be-7 activity concentrations with precipitation data

The relationship of precipitation and Be-7 activity concentrations is showed in Figure 3 and Figure 4. Figure 3 shows the average monthly radionuclide activity concentrations and average monthly precipitation at RN42 from 2011 to 2018 plotted against month of sample collection. The interpretation of Be-7 activity concentrations trendline is already discussed as Figure 2 in previous section. On the other hand, the trendline of precipitation showed two annual peaks which indicate the high amount of precipitation occurred over the study area, with the highest in November and the second highest in April. The first peak in April is largely caused by the South-West monsoon winds which usually starts in the last week of April and northward motion of the Intertropical Convergence Zone (ITCZ) which passes over Peninsula Malaysia between April and May [22]. Additionally, the second peak in November is attributed by the southward motion of the ITCZ which crosses Peninsula Malaysia around November [22].

Figure 3. Correlation of average monthly Be-7 activity concentrations with average monthly precipitation.

Figure 4 represents the result of simple linear regression analysis using Be-7 activity concentrations and precipitation. It could be seen that the trendline is sloping downward which indicates inverse correlation. The $R^2$ value of 0.2277 specifies moderate linear correlation. Furthermore, Pearson correlation coefficient also showed the value of -0.65 which validate that both parameters have strong inverse correlation. This draw the conclusion that the increase of precipitation will decrease the Be-7 activity concentrations, and vice versa. This conclusion is well-concurred with the findings from other studies which found that wet scavenging as the dominant mechanism for the removal of Be-7 in surface air [23].
Figure 4. Simple linear regression of Be-7 activity concentrations and precipitation.

4. Conclusion
The study presents the seasonal variation of natural atmospheric radionuclide Be-7 activity concentrations in Tanah Rata, Cameron Highlands, Pahang from 2011 to 2018. The mean monthly activity concentration of this radionuclide ranged between 1.13 mBq/m$^3$ to 2.85 mBq/m$^3$. Over the period of this study, there were two annual peaks of Be-7 activity concentrations throughout the year, with the highest maximum activity concentration in March and second maximum in June. These elevated concentrations are due to low amount of precipitation in the vicinity of Tanah Rata as well as strong vertical atmospheric jet stream which lead to an increase in Be-7 depositional fluxes.

Based on correlation and simple linear regression of radionuclide data with precipitation data, a strong inverse correlation was found. This observation concurred with the findings from other studies that recognize wet scavenging as the main mechanism of Be-7 removal in surface air. Overall, this study concludes that the seasonal variation of Be-7 activity concentration in Tanah Rata, Cameron Highlands, Pahang are dependent on atmospheric processes and conditions affecting the study area. This study could serve as basis for further studies on local and regional radiological impact assessment as well as for exploring the potential application of Be-7 as atmospheric tracer for civil and scientific purposes.

5. References
[1] Gerhard W, Lars-Erik D G, Philippe D, Martin K, Harri T, Real D, Franco D, Jean-Pierre I, Matthias L, Petra S, Andreas F, Craig S and Hiromi Y 2003 Atmospheric transport modelling in support of CTBT verification—overview and basic concepts Atmospheric Environ. 37 (18) 2529-37.
[2] Auer M, Kumberg T, Sartorius H, Wernsperger B and Schlosser C 2010 Ten years of development of equipment for measurement of atmospheric radioactive xenon for the verification of the CTBT Pure Appl. Geophys. 167 471–86.
[3] Rashid F I A and Zolkaffly M Z 2018 Stakeholder engagement for promoting the Comprehensive Nuclear Test-Ban Treaty (CTBT): Malaysia’s experience IOP Conf. Ser. Mater. Sci. Eng 298 012054.
[4] Yoshimori M 2005 Production and behavior of beryllium 7 radionuclide in the upper atmosphere Adv. in Space Res. 36 922–926.
[5] Leppanen A P, A Pacini A, Usoskin I G, Aldahan A, Echer E, Evangelista H, Klemola S, Kovaltsov G A, Mursula K and Possnert G 2010 Cosmogenic 7Be in air: A complex mixture
of production and transport *Journal of Atmospheric and Solar Terrestrial Physics* 72 pp 1036–43.

[6] Lal D and Peters B 1967 Cosmic ray produced radioactivity on the earth ed. Sittle K *Handbuchder Physik* 46(2) pp 551–612.

[7] Lal D and Peters B 1962 Cosmic ray produced radioactivity on the earth *Kosmische Strahlung II/Cosmic Rays II* 9/46/2551–612.

[8] Ananthakrishnan R and Soman M K 1991 The onset of the southwest monsoon in 1990 *Curr. Sci.* 61 447–53.

[9] L. Terzi and M. Kalinowski 2017 World-wide seasonal variation of 7Be related to large-scale atmospheric circulation dynamics *J. of Environ. Radioact.* 178–179 1–15.

[10] Vecchi R and Valli G 1997 7Be in surface air: a natural atmospheric tracer *J. Aerosol Sci.* 28(5) 895–900.

[11] Brost R A, Feichter J and Heimann M 1991 Three-dimensional simulation of 7Be in a global climate model *J. Geophys. Res.* 96 22423–45

[12] Lal D and Peters B 1962 Cosmic ray produced isotopes and their application to problems in geophysics ed. Wilson J, Woutheuysen S *Prog. in Element. Particle and Cosmic Ray Phys.* 6 77–243

[13] Feely H W, Larsen R J and Sanderson C G 1989 Factors that cause seasonal variations in beryllium-7 concentrations in surface air *J. Environ. Radioact.* 9 223–49

[14] Aldahan A, Possnert G and Vintersved I 2001 Atmospheric interactions at northern high-latitudes from weekly Be-isotopes in surface air *Appl. Radiat. Isotop.* 54 345–53

[15] Usoskin I G, Field C V, Schmidt G A, Leppanen A P, Aldahan A, Kovaltsov G A, Possnert G and Ungar R K 2009a Short-term production and synoptic influences on atmospheric 7Be concentrations *J. Geophys. Res.* 114 D06108.

[16] Muhammad B G, Ismail S, Ekhwan T, Joy J P, Mazlin M and Md P A 2009 Integrated water resource management and pollution sources in Cameron Highlands, Pahang, Malaysia, *American-Eurasian J. Agric. and Environ. Sci.* 5 (6) pp 725–32.

[17] Malaysian Meteological Department 2014 *Monthly Weather Bulletin* 2014 45

[18] Malaysian Meteological Department 2009 *Accumulated Rainfall Observation Data* 2009 32

[19] Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty 2020 Concentration Reporting Tool (CRTool) (https://crttool.ctbto.org Accessed on 1 February 2020).

[20] Du J, Baskaran M, Bi Q, Huang D and Jiang Y 2015 Temporal variations of atmospheric depositional fluxes of 7Be and 210Pb over 8 years (2006–2013) at Shanghai, China, and synthesis of global fallout data *J. Geophys. Res. Atmos.* 120 4323–39.

[21] Gerasopoulos E, Zanis P, Stohl A, Zerefos C S, Papastefanou C, Ringer W, Tobler L, Hubener S, Gaggeler H W, Kanter H J, Tossitti L and Sandrini S A climatology of 7Be at four high altitude stations at the Alpsand the Northern Apennines *Atmos. Environ.* 35 6347–60.

[22] Alejandro L C, Mohd N S, Ahmad S A and Mohd R O 1998 Monthly distribution of precipitation in Peninsular Malaysia *Pertanika J. Sci. and Technol.* 6(1) 59 - 70

[23] Kuśmierczyk-Michulec J and Bourgouin P 2018 Influence of mineral dust on changes of 7Be concentrations in air asmeasured by CTBTO global monitoring system *J. Environ. Radioact.* 192 454–66