Atom Indonesia

Journal homepage: http://aij.batan.go.id

Release of radioactive particulates into the Air during Forest Fire in Riau Province, Indonesia

Syarbaini[1*], Makhsun[2], Wahyudi[2], Syahrial[3] and Jasmiyati[3]

[1]*Center for Radioisotope and Radiopharmaceutical Technology, National Nuclear Energy Agency, Kawasan Puspiptek, Serpong Tangerang 15314, Indonesia*

[2]*Center for Radiation Safety Technology and Metrology, National Nuclear Energy Agency, Jl. Lebak Bulus Raya No. 49, Jakarta 12440, Indonesia*

[3]*Air Laboratory, Environmental Agency of Pekanbaru City Jl. Pepaya No. 75, Pekanbaru 28126, Indonesia*

ARTICLE INFO

Article history:
Received 22 February 2018
Received in revised form 29 August 2018
Accepted 27 December 2018

Keywords:
Supply some 4–6 keywords
Naturally-occurring radionuclides
Artificial radionuclides
Forest fire
Total suspended particulate

ABSTRACT

Forest fires are annual problem during the dry season and become a biggest threat to forest resources in Indonesia. The forest fires release into the atmosphere large quantities of particulate matter and volatilized substances. The present study investigates effects of forest fire on air quality in the case of a radiological event of ashes from forest fires emissions in Riau province during an intense forest fire season that occurred in 2015. Atmospheric aerosol samples were collected from May to December, 2015 using a large volume TSP (total suspended particles) sampler. Concentrations of radionuclides in airborne particulate matter were measured by using gamma spectrometry. It was shown that the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K ranged from 0.026 to 0.114 mBq/m^3, 0.005 to 0.011 mBq/m^3 and 0.99 to 5.64 mBq/m^3, respectively. The activity concentrations of ^{137}Cs in air was found lower than the minimum detectable activity of the gamma counting systems (<MDA), except for July and September 2015. The result showed that the smoke from forest fires contain radioactive particulates, which may have a potential health risk of population, and need to be considered in forest fire disaster. Inhaled smoke particles from forest fires may contribute to enhanced radiation doses to the general public.

INTRODUCTION

Forest fires become a problem every year in Indonesia during the annual dry season especially in Sumatera and Kalimantan islands [1-3]. Riau is one of a provinces in Sumatera where forest and peat fires mostly occur and are resulted from land clearance activities for plantation [4-6]. Sumatera has been the center area for large-scale plantations of palm oil and timber with Riau as the leading province. The high rate of deforestation in Riau Province was likely caused by a rapid expansion of palm oil as well as expansion of industrial timber and pulp plantations [7-9].

The continued expansion of oil palm and exploitation of forest resources have resulted in Riau becoming one of the provinces with the highest deforestation rates in Indonesia. Degradation of forests in Riau Province has increased during recent decades. The annual rate of forest cover loss has been increasing. Riau has lost 70 % of peatland areas and 52 % of lowland forest during 2000 - 2010 [10,11].

Generally, forest and peat fires occurring in Indonesia are not included as disasters that caused by natural factors since more than 90 % of these disasters due to human's factors, such as deliberateness and dereliction [12,13]. Burning is the fastest and low-cost way of clearing the land for agriculture purposes. Therefore, fire has been widely practiced as a tool for land clearing in Indonesia since a long time ago. When El Niño phenomenon strikes, the situation changes drastically. The extreme dry weather conditions during El Niño episodes, almost no rain falls and the

*Corresponding author.
E-mail address: sarbaini@batan.go.id
DOI: https://doi.org/10.17146/aij.2019.829

monsoon is delayed. Forest fires occurring in Indonesia are more frequent during El Nino years due to rainfall deficit [14-16].

In 2015, a strong El Nino has resulted in drier conditions and under these extremely dry conditions, the forest fire in Indonesia increases with the decrease of rainfall. The majority of fire alerts are concentrated in the Provinces of Riau on the island of Sumatera, as well as Central and West Kalimantan Provinces. Riau is one of the hardest area hit by the fires, due in part to its high concentration of peatland. The forest fires was dominated by smoldering process from peat fires that release into the atmosphere large quantities of volatilized substances and particulate matter.

The hot spots from forest fires which occurred in Riau Province were detected on March 2015. The haze appearred covering Riau Province from July and reached its peak on September and October 2015. Then entering November 2015, the haze gradually lifted as the rain fell almost every day all over Riau Province. The total burnt area in Riau Province during forest fire is reported to be about 90,709 km^2, which is about 19.02 % of the total burnt area in Sumatera Island. Thick smoke due to forest fire has caused serious haze in Pekanbaru city, the capital of Riau Province [17-19].

Naturally as well as artificially produced radionuclides can be found in all compartments of the environment. Forest is longterm reservoir for radionuclides of both natural and artificial origin. These radionuclides are accumulated in plants generally in low concentrations. Several studies found that radionuclides absorbed by wild vegetation can be released and dispersed with smoke aerosols during a forest fires. Re-suspension and re-distribution of radionuclides by forest fires, and the transport of radionuclides in the atmosphere have also been evaluated [20-24].

Natural radionuclides such as ^{40}K and radionuclides from the ^{232}Th and ^{238}U series and their decay products and anthropogenic radionuclides in environment are the main source of radiation dose to the human body. The knowledge of anthropogenic and naturally ocurring radionuclides content in air during forest fire is of great importance as it lays the background level in order to have an early warning of the radiological impact on members of the public, or to asses occupational exposures. The impact of contaminant resuspension during forest fires and human health have attracted extensive attention and have resulted in many publications [25-27]. Radionuclides content in aerosol particles can pose a health hazard. Inhaled smoke particles from vegetation during forest fires may contribute to enhanced radiation doses in the human lung [28].

The data for the release of radionuclides from forest fire in Indonesia is not available. The aim of the present work is to study the impact of particulates matter during forest fire on atmospheric radioactivity. The main focus is on the particulates matter released from Riau Province forest fire that occurred in 2015 and its impact on natural (^{226}Ra, ^{232}Th and ^{40}K) and anthropogenic radionuclides (^{137}Cs). This study is important to assess and predict the potential radiological doses and hazards from potential forest fire in Indonesia especially Riau Province.

EXPERIMENTAL METHODS

Description of the study area

Riau Province is located in the eastern part of Sumatera island, and has a total area of 8.9 million ha. The capital city of the province is Pekanbaru City. Riau Province is rich with a wide variety of abundant natural resources, the main ones being petroleum, natural gas and gold as well as huge forest reserves, rubber, oil palm and fibre plantations. Until the 1960s, Riau still had extensive forest areas. The province has both natural and plantation forest, and deep contiguous tropical peat swamp forests distributed over several districts. Figure 1 shows the study area and the distribution of peatlands within it [29].

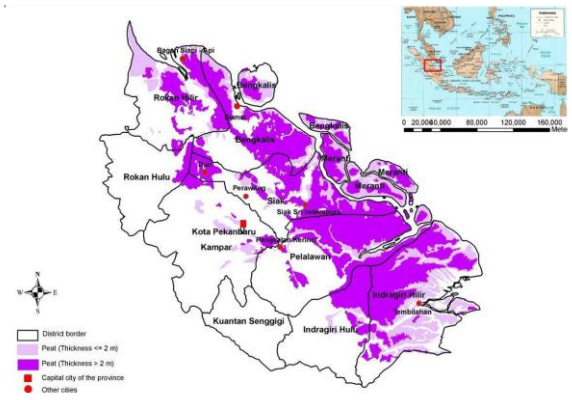

Fig. 1. Location map of study area.

Sampling and sample preparation

Atmospheric aerosols samples were collected from May to December, 2015, in Pekanbaru City at Fix Station of Environmental Agency of Pekanbaru City ($0^0$27'55.3'' N, $101^0$23'15.5''E) at the height of 3 m above the ground using a high volume air

sampler (HV-1000R, Sibata Scientific Technology LTD, Japan) with a rectangular glass fiber filter for TSP (TE-G653 8" x 10", Tisch Environmental Inc. USA). The sampling site was located in an open area and was not influenced by local pollution sources, but potentially by particulates matter from forest fire emissions. Total suspended particles (TSP) samples were collected for 24 h, two - three times per week.

The TSP filters were folded in half lengthwise after sampling, so that only surfaces with collected particulate matter were in contact, when placed in the filter holder. The sampling filters were pre-conditioned in a dry box at constant temperature (22-25 ^{o}C) and relative humidity (30-35 %) for at least one day before being subjected to weighing [30].

The filters were weighed on a microbalance with a sensitivity of 0.0001 mg. The balance was regularly checked with NIST-traceable standard calibrated weights. The pre- and post-sampling weights were used to obtain the particulate mass collected on the filters.

Radionuclide analyses

The TSP filter samples were subjected to analyzed by gamma spectrometer using a coaxial HPGe detector with relative detection efficiency of 40 %. The instrument operated in underground laboratory with very low level background and detector shield made of lead, iron and electrolytical copper. The samples were counted for three to four days. The radionuclide activity concentrations were calculated from the peak areas of registered gamma-rays using commercial software. The results uncertainties were mainly due to counting statistics, which were mostly between 2 and 20 %. The count rates in the full-energy peaks were corrected for the background of the counting system. In order to achieve high quality in the reported radionuclide results, regular participation in International Atomic Energy Agency (IAEA) intercomparison exercises of IAEA reference materials were carried out.

For the determination of ^{226}Ra and ^{232}Th, the filter samples are sealed in gas-tight perspect boxes and stored for at least four weeks to allow ingrowth to radioactive equilibrium in the ^{238}U and ^{232}Th series. After that time, ^{226}Ra is measured via the gamma lines of its daughter products ^{214}Pb (295.2, 352.0 keV) and ^{214}Bi (609.3 keV). ^{232}Th is determined via the gamma lines of the daughter products ^{212}Pb (238.6 keV), ^{208}Tl (583.1 keV) and ^{228}Ac (911.1 keV) and that of ^{40}K was determined from the gamma line of 1460.83 keV.

RESULTS AND DISCUSSION

The concentrations of TSP determined in this study is presented in Fig. 2. The monthly average concentration of TSP (µg.m^{-3}) varies during different month of the study period in Pekanbaru city, Riau Province. The ranges of monthly average concentrations of TSP were 61.60 - 703.71 µg.m^{-3}, respectively. The monthly average concentrations of TSP has increased during May to November 2015 which indicates that release of particles of forest fire is the major source of particles in the study area.

In the period from July to November 2015, the monthly average concentrations of TSP were recorded above the maximum allowable limits of Indonesia's National Ambient Air Quality standards (230 µg. m^{-3}) [31].

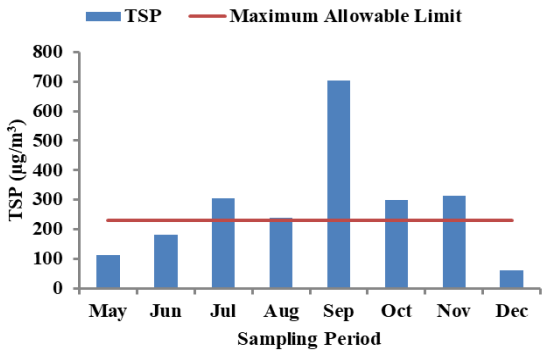

Fig. 2. TSP average monthly concentration.

In September 2015, the concentrations of TSP has reached its highest level which was three times of maximum allowable limit. There was almost no rainfall during September 2015 due to the El Nino phenomenon. The sea surface temperature in Indonesia region was lower than the normal temperature causing low rainfall in the region such that the wet deposition is relatively low at this period. On this period forest fire, therefore most probably due to forest fire, which generated particulate matters. The El Nino phenomenon still continued until the end of November [32]. By mid-November, rains had extinguished the majority of forest and land fires throughout Indonesia, while in some cases the risk of peat fires to re-ignite continued due to uncertain trends of the impact of El Nino.

The relationship between monthly average of TSP concentrations and rainfalls are shown in Fig. 3. A good correlation was observed between the mean TSP concentrations and the mean monthly rainfalls. The concentration of TSP exhibit marked troughs coinciding with periods of stronger rainfall due to washout effects in the lower air layers.

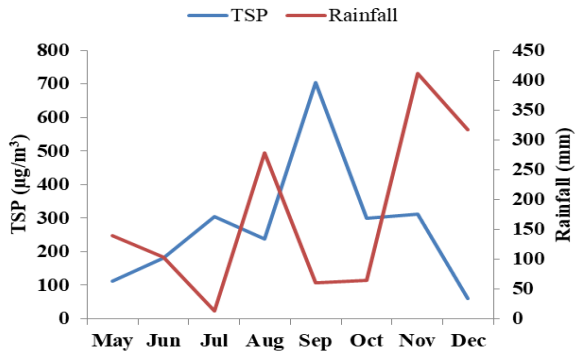

Fig. 3. The monthly average of TSP and rainfalls.

The variations of monthly activity concentrations of naturally occurring radionuclides of ^{226}Ra, ^{232}Th, and ^{40}K in air (mBq/m^3) during May to December 2015 are shown in Fig. 4. The activity concentrations of ^{226}Ra and ^{232}Th ranged from 0.026 to 0.114 mBq/m^3 and from 0.005 to 0.011 mBq/m^3, respectively. The activity concentrations of ^{40}K was ranged from 0.99 to 5.64 mBq/m^3.

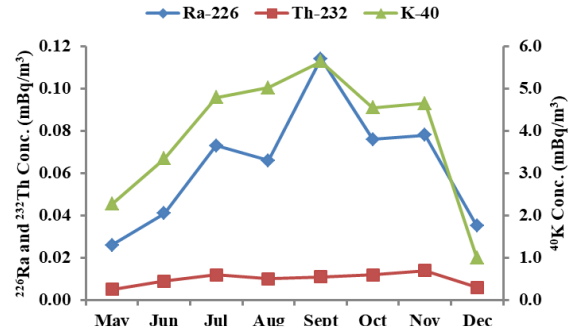

Fig. 4. Trend of natural radionuclide released during forest fire.

The activity concentration of anthropogenic radionuclide of ^{137}Cs in air during May to December 2015 was ranged from the ND (not detected) to 0.0004 mBq/m^3. ^{137}Cs in some particulates samples was found to be lower than the minimum detectable activity of the gamma counting systems (<MDA). A peak of ^{137}Cs content was observed on July and September 2015 (Fig. 5).

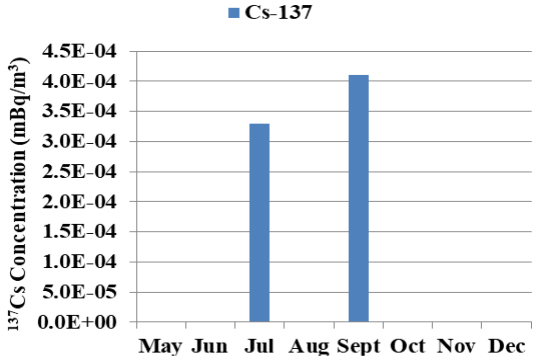

Fig. 5. The activity concentration of ^{137}Cs in air.

In those months, there was a great number of forest fires in Riau Province with large amount of smoke produced. Maximum concentrations level of those natural and anthropogenic radionuclides are found in September and July, corresponding to maxima TSP contents.

Previous studies on natural and anthropogenic radionuclides level in ambient air from Riau Province or neighboring locations during normal condition (before or after the forest fire disaster) were not available to be compared with this study. Therefore, data obtained in this work were compared with data reported in literature from other countries.

There are some information available for others locations in the literature on the activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in ambient air level. Baeza et al. [33] reported mean values of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs content in near surface air in Careces, Spain are 2.1±0.8; 1.0±0.5 33±18; and 0.63±0.45 µBq/m^3 respectively. The mean values of ^{40}K and ^{137}Cs obtained by Valles et al. [34] in airborne particulate matter in the Barcelona area (Spain) during the period from January 2001 to December 2005 are 26±11 µBq/m^3 and 0.65±0.29 µBq/m^3, respectively. Activity concentrations of <MDA to 26.0 µBq/m^3 have been measured by Alkhomashi et al. [35] for ^{137}Cs in air at Riyadh, Saudi Arabia for the period 08 April 2011 – 28 April 2011. Zyton et al., [36] reported ^{40}K, ^{232}Th and ^{238}U activity concentrations in ambient PM2.5 aerosols 14.697±10.137; 0.630±0.518 and 0.742±0.769 µBq/m3. Boucier et al., [37] reported ^{137}Cs concentrations of 0.10 to 1.78 µBq/m^3 in the central part of France. The concentrations of radionuclides in the air obtained in this study were higher than the values reported in these reports, except for ^{137}Cs.

The variations of ^{137}Cs activity level was observed by Baeza et al. [33] during forest fires in Portugal 2010. The activity level was higher in this period in about a factor 4 regarding the weeks before and after, and in a factor about 2 regarding the maximum content.

The forest in the highly contaminated exclusion zone 5 km from the Chernobyl reactor accident have been used in the development and adaptation model modules in predicting parameters for radionuclides resuspension, transport and deposition during forest and grassland fires. During the forest fire, up to 4 % of ^{137}Cs can be released from the forest litter according to the model calculations. However, theses results depend on the parameters of fire events [23].

L. Zhou *et al*., [38] observed that a majority of ^{137}Cs radioactivity present in the organic soil was adsorbed onto soil minerals. The ^{137}Cs releases are highly dependent on the combustion temperature

and type of vegetation. High ^{137}Cs mobility is observed from combustion of vegetation (i.e., alder leaves and twigs) while low ^{137}Cs mobility is observed from combustion of organic soil, even at the high temperature of 800 ^{o}C. The low release of ^{137}Cs from the forest fires may be attributed to ^{137}Cs being strongly adsorbed onto soil minerals and accumulated in plants in low concentrations.

It is a well-known that a major source of ^{137}Cs present in the environment mainly from global fallout of nuclear weapons tests and nuclear facilities accidents such as Chernobyl and Fukushima, has primarily been deposited on the Earth's surface by wet and dry deposition [39,40].

The enhancement of radionuclides concentration in air could be related to sources generated by aerosol particles, during forest fire. As shown in Fig. 4, the trend associated with the radionuclides release during the combustion of plants. The radionuclide concentrations in air are enhanced when the release of particles during forest fire increased. Although the vegetations and other forest plants contain radionuclides that they absorb from the soil and from the surface air with low concentrations, the burning of them could increased the radionuclides concentrations in air. Since high volume and mass reduction of vegetation occurs during combustion, some radionuclides, especially non-volatile elements are enriched in the resulting ash residues [33,41].

During forest fires, radionuclides may be released through direct ejection of particulates associated with radioactivity or volatilization of radioactive species. The radionuclides dissolved in the moisture of the vegetation may also be carried away by the generated steam resulting from rapid evaporation [38].

Figure 6 showing a correlation between activity concentrations of radionuclides and smoke particles in surface air. The activity concentrations of radionuclides in surface air increase with the increase of the load smoke particles from forest fires. On the other hand, the concentrations of all radionuclides per unit of air volume (mBq/m^3) are correlated with specific concentration of the smoke in air.

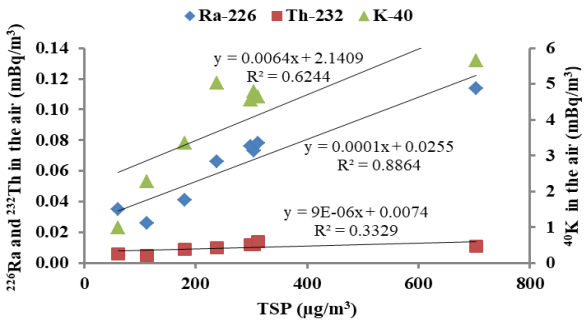

Fig. 6. Relationship between the concentration of ^{226}Ra, ^{232}Th, ^{40}K and TSP.

Nevertheles, ^{232}Th in smoke particles was always lower than ^{226}Ra released from the vegetation by the combustion. Specific activities in smoke particles were higher for ^{226}Ra than for ^{232}Th. This is likely related to the lower volatilization temperature of radium in comparison with the thorium [28]. Specific activities in smoke particles were higher for ^{40}K than for other radionuclides, such as radium and thorium isotopes due to the lower volatilization temperature of potassium in comparison with the other radioelements. Beside that, ^{40}K in dust ash is found to be in excess and it may therefore be concluded that this nuclides is also constituents of airborne organic material. Potassium is a macronutrient for plants and one of the main elements in ash.

These findings clearly show that forest fires season that occurred in 2015 in Riau Province increase the radioactivity levels in the atmoshere and thus, smoke particles from forest fires may also increase the lung exposure to enhaced levels of alpha emitting radionuclides. Therefore, the respiratory tract protection of public is needed because of the presence of carcinogenic radionuclides.

CONCLUSION

The forest fire has released particles pollution to the public in Riau Province with a concentration in the air varied during months of observation. The average activities of ^{226}Ra, ^{232}Th, and ^{40}K in the air showed similar distribution, with maximum values found on September during the period of forest fire. The ^{137}Cs levels peaked in July and September, which were caused by the high particles from forest fires. There is positive correlation between the mass of the smoke particulates collected and the radionuclides activitis measured in the collected particulates.

ACKNOWLEDGMENT

The authors acknowledge the National Nuclear Energy Agency for the financial support throughout this work. The authors also gratefully acknowledge all staff members of the Environmental Safety group for their technical assistance.

REFERENCES

1. Arifudin, B. Nasrul and Maswadi, Procedia Environmental Sciences **17** (2013) 129.
2. Kustiyo, R. Dewanti and I. Lolitasari, Int. Journal of Remote Sensing and Earth Sciences **12** (2015) 151.

3. B.A. Margono, A.B. Usman, Budiharto *et al.*, Indonesian Journal of Geography **48** (2016) 7.
4. P.H. Thah and I.S. Sitanggang, Procedia Environmental Sciences **33** (2016) 258.
5. N.L. Febriana and I.S. Sitanggang, IOP Conf. Series: Earth and Environmental Sciences **58** (2017) 012004.
6. P. Thariqa and I.S. Sitanggang, Procedia Environmental Sciences **24** (2015) 277.
7. B.A. Margono, S. Turubanova, I. Zhuravleva *et al*., Environ. Res. Lett. **7** (2012) 034010
8. S.A. Rehman, S. Sabiham, U. Sudadi *et al.*, International Journal of Plant & Soil Science **6** (2015) 34.
9. Prayoto, *Analysis of Forest and Land Fires in Riau Province Based on the use of Land for Mitigation of Smoke Disaster*, Proceedings of the International Conference of Indonesian Forestry Researchers (INAFOR) (2011) 407.
10. P. Rosul, Analysis of Policy Effectiveness on Forest Fires in Riau Indonesia, M.Sc. Thesis, Duke University (2015).
11. J.S.H. Lee, S. Abood, J. Ghazoul *et al.*, Conservation Letters **7** (2013) 25. Doi: 10.1111/conl.12039
12. E.A. Riyanto, Forum Geografi **29** (2015) 41. Doi: https://doi.org/10.23917/forgeo.v29i1.790
13. Muksin, The Impacts of the Smoke Haze Pollution on Urban Environment a Case of Pekanbaru City, Riau Province, Indonesia, M.Sc. Thesis, Gadjah Mada University (2006).
14. N. Yulianti, H. Hayasaka and A. Sepriando, Open Journal of Forestry **3** (2013) 129.
15. G.P. Siknun and I.S. Sitanggang, Procedia Environmental Sciences **33** (2016) 332.
16. N. Yulianti, H. Hayasaka and A. Usup. Global Environmental Research **16** (2012) 105.
17. J. Miettinen, C. Shi and SC. Liew, Environ Manag **60** (2017) 747. Doi: 10.1007/s00267-017-0911-7
18. E. Heriyanto, L. Syaufina and M. Sobri, Procedia Environmental Sciences **24** (2015) 111.
19. H.L. Tata, B.H. Narendra and Mawazin, Biodiversitas **19** (2018) 544.
20. W.M. Hao, O.O. Bondarenko, S. Zibtsev *et al*., *Vegetation Fires, Smoke Emissions, and Dispersion of Radionuclides in the Chernobyl Exclusion Zone*, in: Developments in Environmental Science Vol. 8, A. Bytnerowicz, M. Arbaugh, A. Riebau and C. Andersen (Ed.) (2008) 265.
21. N. Evangeliou, S. Zibtsev, V. Myroniuk *et al*., *Resuspension and atmospheric transport of radionuclides due to wildfires near the Chernobyl Nuclear Power Plant in 2015*: An impact assessment, Scientific Reports 6, (2016) 1.
22. S.A. Strode, L.E. Ott, S. Pawson *et al*., Journal of Geophysical Research **117** (2012) 1.
23. V.I. Yoschenko, V.A. Kashparov, S.E. Levchuk *et al*., J. Environ. Radioact. **87** (2006) 260.
24. S.V. Jargin, J. Environ. Radioact. **102** (2011) 218.
25. N. Evangeliou, Y. Balkanski, A. Cozic *et al*., Environment International **73** (2014) 346.
26. J.G. Goldammer, *Early Warning System for the Prediction of an Appropriate Respose to Wildfires and Related Environmental Hazards*, in: Health Guidelines for Vegatation Fire Events, K.T. Goh, D. Schwela, J.G. Goldammer, O. Simpson (Ed.), Background papers WHO, Lima, Peru (1999) 9.
27. P.P. Povincec, I. Sykora, K. Holy *et al*., J. Environ. Radioact. **114** (2012) 81.
28. F.P. Carvalho, J.M. Oliveria and M. Malta, *Vegetations Fires and Release of Radioactivity into the Air*, in: Environmental Health and Biomedicine Vol. 15, Part I: Environemntal Health, Section 1 : Air pollution, C.A. Brebbia, M. Eglite, I. Knets, R. Miftahof, V. Popov (Ed.), WIT Press, UK (2011) 3.
29. A. Susanti and P. Burgers, *Oil Palm Expansion in Riau Province, Indonesia: Serving People, Planet, Provit?*, European Report on Development 2011/2012, European union, Belgium (2012). https://ec.europa.eu/europeaid/node/43973. Retrieved in February (2018)
30. Anonymous, Standard Method for Total Suspended Particulate using High Volume Air Sampler and Gravimetry, SNI 7119-3:2017, National Standardization Agency of Indonesia.
31. Anonymous, Government Regulation No 41/1999 on Air Pollution Control, The Republic of Indonesia, Jakarta (1999).
32. Supari, R. Muharsyah and N. Wahyudi, Science and Engineering **3** (2016) 26.
33. A. Baeza, A.R. Perulero and J. Guillen, J. Environ. Radioact. **165** (2016) 24.

34. I. Valles, A. Camacho, X. Ortega *et al*., J. Environ. Radioact. **100** (2009) 102.
35. N. Alkhomashi and F.I. Almasoud, J. Environ. Radioact. **152** (2016) 70.
36. M.A. Zyton, H.M. Aburas and M.I. Abdulsalam, J. Environ. Radioact. **129** (2014) 148.
37. L. Boucier, O. Masson, P. Laj *et al*., J. Environ. Radioact. **102** (2011) 294.
38. L. Zhou, R. Rao, E. Corcoran *et al*., J. Environ. Radioact. **165** (2016) 159.
39. M.K. Pham, E. Chamizo, J.L. M. Balbuena *et al*., J. Environ. Radioact. **166** (2017) 2.
40. Syarbaini and G. Suhariyono, Atom Indonesia **42** (2016) 47.
41. S. Stoulos, A. Loannidou, E. Vagena *et al*., J. Environ. Radioact. **128** (2014) 68