ISBN : 978-602-70092-0-2

PROCEEDINGS

2nd International Conference on the Sources, Effects and Risks of Ionizing Radiation (SERIR 2016)

in conjunction with

14th Biennial Conference of the South Pacific Environmental Radioactivity Association (SPERA 2016)

Sanur Paradise Plaza Hotel
Bali, 5-9 September 2016

Organized and hosted by

National Nuclear Energy Agency (BATAN)

in cooperation with

South Pacific Environmental Radioactivity Association

Published by

Center for Technology of Radiation Safety and Metrology
National Nuclear Energy Agency (BATAN)

December 2016

Organized and hosted by the

National Nuclear Energy Agency (BATAN)

in cooperation with

South Pacific Environmental Radioactivity Association

Supported by :

Kementerian Riset, Teknologi dan Pendidikan Tinggi

Australian Radiation Protection and Nuclear Safety Agency

Australian Institute of Nuclear Science and Engineering

Royal Australian Chemical Intitute

COMMITTEE

President of The Conference

Dr. Ferhat Aziz, Deputy Chairman of BATAN, Indonesia

Scientific Committee : Susetyo Trijoko, M.App.Sc. – BATAN, Indonesia

Editors :

1. Prof. Dr. Yoshiyuki Suzuki, MD - University of Fukushima,Japan
2. Prof. Dr. Ross Antoni Jeffry - University of Technology Sydney, Australia
3. Dr. Heny Suseno - BATAN
4. Dr. Rer.nat. Budiawan - Universitas Indonesia
5. Dr. Freddy Haryanto - Institut Teknologi Bandung
6. Dr. Johannes R. Dumais - BATAN
7. Dr. Azhar Masiatullah - Pakistan Institute of Science and Technology (PINSTECH), Pakistan

Local Committee :

Chair	:	Dr. Mukh Syaifudin	- BATAN
Vice	:	Dr. Heny Suseno, M.Si.	- BATAN
Secretary	:	1. Drs. Nazar Wijaya Iskandarmouda	- BATAN
		2. Setyo Rini, SE	- BATAN
Treasure	:	Irwan Nursal, SE	- BATAN
Sections	:		
a. Scientific Boards	:	1. Dr. Dadong Iskandar, M.Eng.	- BATAN
		2. Dr. Iin Kurnia, M. Biomed.	- BATAN
		3. Drs. Mukhlis Akhadi, APU	- BATAN
		4. Dra. C. Tuti Budiantari	- BATAN
b. Publication, Documentation and Proceeding	:	1. Hasnel Sofyan, M.Eng.	- BATAN
		2. Toni Prihatna	- BATAN
		3. Suratman, ST.	- BATAN
c. Protocol-Accommodation	:	1. Budi Kurnia	- BATAN
		2. Nunuk Sunaryati	- BATAN
d. Logistics	:	1. Ir. Ismanto Djumadi	- BATAN
		2. Sandya Eko Restadhi, SH	- BATAN
		3. Teja Kisnanto, A.Md.	- BATAN
		4. Tisna Priatna	- BATAN
		5. Achmad Chabib	- BATAN
e. Security	:	1. Prasetyo, S.Sos.	- BATAN
		2. Nana Suyana	- BATAN

PREFACE

For the second time the Center for Technology of Radiation Safety and Metrology, National Nuclear Energy Agency of Indonesia (BATAN) was held the 2nd International Conference on the Sources, Effects and Risks of Ionizing Radiation (SERIR2) in Sanur Paradise Plaza Hotel, Sanur, Bali, Indonesia, which was the continued event that already held in last 2013. Similar as previously, Conference dealed with the efforts to enhance data collection and disseminate scientific findings related to the issues of sources, effects and risks of the ionizing radiation, as well as to seek the way of communication among stakeholders (scientific communities, regulatory authorities, and general public) on those issues. This conference was in conjunction with the 14th biennial conference of the South Pacific Environmental Radioactivity Association (SPERA2016) that provides a platform for discussion among scientists on the occurrence, behaviour, impact and measurement of radioactive species present in the environment through natural processes, or resulting from human activities. This international conference also facilitated knowledge sharing on environmental radioactivity and related topics of local and global significance.

In the SERIR2 there were three keynote speakers presented their own expertise : Dr. Stephen Solomon (Principal Scientific Adviser to the CEO, Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Prof. Yoshiyuki Suzuki (Department of Radiation Oncology, Fukushima Medical University), and Dr. Ferhat Aziz (National Nuclear Energy Agency of Indonesia (BATAN)).

In this conference there was a press conference that was attended by local and national journalists. This event was handled by Bureau of Legal, Public Relation and Cooperation (BHHK), BATAN. The speakers were : Dr. Andreas Bollhöfer (President of SPERA), Dr. Justin Lee (Deputy Head of Mission, Department of Foreign Affairs and Trade of Australian Embassy for Indonesia), Dr. Gillian Hirth (ARPANSA), Prof. Dr. Djarot Sulistio Wisnubroto (Chairman of BATAN), and Prof. Dr. Mohammad Nasir (Directorate General of Minister of Research, Technology and Higher Education (Menristekdikti).

In this conference, of 38 papers submitted by authors from three countries (Indonesia, India and Japan), 35 papers were presented as oral and poster presentation. For oral, there were 20 papers presented into two groups of paper (group A, Radiation Exposures and Instrumentation and group B, Occupational Exposures and Health Effects), and for poster there were 15 papers. Totally there were 35 papers that consists of 32 papers from BATAN, one paper from Pachhunga University College-India, one paper from University of Udayana, and one paper from Siloam Hospital.

We would like to thank all those who participated in the conference for the lively discussions as well as the director of the Center for Radiation Safety and Metrology, BATAN upon the opportunity to organize this event as well as the SPERA which was agree to conduct the events in the same venue. In addition, we are also grateful to all the authors for their valuable time and contributions to the conference. Last but not least, the conference would not have been possible without the great help of the staff of the Center and Australian Nuclear Science and Technology Organization (ANSTO), South Pacific Environmental Radioactivity Association (SPERA), Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). We would like to thank all of them for their assistance.

December 2016 SERIR2 Committee

WELCOME ADDRESS BY PRESIDENT OF THE CONFERENCE

His Excellency,
Dr. Muhammad Dimyati, Director General Research and Development, Representing Minister Science, Technology and Higher Education, The Republic of Indonesia;
Prof. Dr. Djarot SulistioWisnubroto, Chairman of National Nuclear Energy Agency (BATAN);
Dr. Andreas Bollhöfer, President of South Pacific Environmental Radioactivity Association (SPERA);
Dr. Justin Lee, Deputy Head of Mission, Department of Foreign Affairs and Trade of Australian Mission for Indonesia; and
Dr. HendigWinarno, Deputy Chairman of BATAN;

Distinguished keynote speakers,
Chairman of the organizing committee,
Participants, Ladies and Gentlemen,

Good Morning and Assalamu-Alaikum Wr.Wb.

On behalf of the National Nuclear Energy Agency (BATAN) of Indonesia, it is my great pleasure to welcome you to the "2nd International Conference on the Sources, Effects and Risks of Ionizing Radiation (SERIR) and 14th Biennial International Conference of SPERA", jointly organized by South Pacific Environmental Radioactivity Association (SPERA) and National Nuclear Energy Agency (BATAN), particularly The Center for Radiation Safety Technology and Metrology. I wish to welcome you to be in a beautiful Bali Island here.

This second International Conference on the SERIR is a continued of the first scientific meeting that had been done here in the same place three years ago. As in the first SERIR, this Conference is held under an urgent need to give contribution to the works of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The 2nd International Conference on the SERIR will be a 1-day conference (5 September). This conference is aimed to disseminate scientific findings related to the issues of sources, effects and risks of ionizing radiation, and to communicate with stakeholders (scientific communities, regulatory authorities and general public).

Ladies and Gentlemen,

Ionizing radiation is generated in a range of medical, commercial and industrial activities. The most familiar and the largest of these sources of exposure is medical X-rays. Natural radiation contributes about 88% of the annual dose to the population, and medical procedures contribute most of the remaining 12%. Natural and artificial radiation are not different in kind of effect. Ionizing radiation has always been present in the environment and in our bodies. However, we can and should minimise unnecessary exposure to significant levels of artificial radiation. Ionizing radiation is also very easily detected. There is a range of simple, sensitive instruments capable of detecting minute amounts of radiation from natural and anthropogenic sources.

The Organizing Committee has invited contributions, academic and practice-based paperson all aspects of the following two topics: Radiation Exposures and Instrumentation; and Occupational Exposures and Health Effects, induced by Medical Radiation uses and Environmental/Natural Radiation. Some of oral and poster presenters will deliver those topics in the afternoon.

This Conference has attracted more than 80 participants from 6 countries. About 39 scientific papers will be presented by their authors orally or as posters. This event will offer you plenty of opportunities for extensive discussions, making of new contacts and strengthening the existing relationships after the oral presentations, during the poster sessions, while visiting the exhibition by SPERA or at the other events.

For the SPERA 2016, the 14th Biennial Conference of the SPERA, to be held 6-9 September, will provides a platform for discussion and debate among scientists on the occurrence, behaviour, impact and measurement of radioactive species present in the environment through natural processes, or resulting from human activities.

The joint conference will include a one-day workshop on Trends in Environmental Sample Preparation on the 6th September, facilitated by The Radiochemistry Division of the Royal Australian Chemical Institute (RACI). The workshop will present an overview of the fundamentals, procedures, and applications of both historical and the most recently developed sample preparation techniques for the extraction, clean up, and concentration of radionuclides from environmental samples

Participants, Ladies and Gentlemen.

In this opportunity, I would like to thank to honorable three invited speakers who have been able to be here, Dr. Stephen Solomon, from Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)-Australia, Prof. Dr. Yoshiyuki Suzuki, MD, from Fukushima University-Japan; and Dr. Ferhat Azis, from BATAN-Indonesia**.** All of them are the prominent scientists in their own field and will providea comprehensive overview of the current status of the global sources, effects and risks of ionizing radiation.

I look very much forward to this Conference and hope there will be warm discussion, because this Conference is open for everybody to give a view, and certainly we will do our best to make sure that the floor is really life. So, please be prepared to give comments and questions for the topics to be delivered by the speakers and presenters.

In this occasion, I would also like to thank the organizer and resource persons who have made this event possible, and who I am sure will be working tirelessly to ensure the success of the conference and workshop over the next few days.

Finally, I wish all of you will enjoy being in Bali, which is one of 16 Most Beautiful Islands in the World. Bali is a feast for the senses. Bali's spirit will wash over you like a warm, tropical wave.

Thank you and Wassalamu-Alaikum WrWb.
President of the Conference
Susetyo Trijoko, M.App.Sc.

OPENING REMARKS
MINISTER OF RESEARCH, TECHNOLOGY AND HIGHER EDUCATION

(Represent by Director General Research and Development)

Honorable;
1. Dr. Andreas Bollhofer (President of SPERA)
2. Deputy Head of Mission, Department of Foreign Affairs and Trade of Australian Embassy for Indonesia
3. Prof. Dr. Djarot Sulistio Wisnubroto, Chairman of Batan
4. All Experts, Participants
5. Distinguish Guest, Ladies and Gentlements

First of all, let us thanks Allah SWT for His blessings; we can be here to attend this International Conference. On behalf of Ministry of Research, Technology and Higher Education, I would like to express my gratitude to all of you, for participating 2th International Conference on the Sources, Effects and Risk of Ionizing Radiation (SERIR) and 14th Biennial International Conference on SPERA in the beautiful island of Indonesia…called BALI.

Delighted Ladies and Gentlemen,

The development of science and technology in the field of health, food, and energy is very progressive. Many researchers doing very sportive competitions to express their knowledge to support the human being. In the other hand, there are many obstacles should be break it out by the researchers to reach the research goals. This forum can be use as an arena to prove that we are capable of doing it. But we need to keep our awareness that whatever the level of research we present now; we should not merely stop at research paper or conceptual design. We must continue and create research outputs that are ready to be commercialized and giving positive impact to the people. Therefore, the benefit of research can be optimized for the good and prosperity of Indonesian people and the world. And with this spirit, the Ministry of Research, Technology and Higher Education support the mutually-benefit linkage between researchers and industries, in order to minimize their mismatch.

To move further, the Ministry of Research, Technology and Higher Education has had and will continue to push and facilitate research outputs that are ready to be used by the people, to be synergized with other research outputs, to give greater benefits and multiplier effects to the community. For example, Indonesian Institute of Science (LIPI) has invented fertilizer that can make paddy stands out of many pests, while Bogor Agricultural Institute has invented new paddy variety that can yield more than 10 ton per hectare. Research and Development of Ministry of Agriculture had invented paddy field management with Jarwo-system that can improve paddy field productivity. Each of the inventions is directly benefiting the user, but synergizing them through government support, will create much greater benefits, and direct impact for the people, mainly local people.

Delighted Ladies and Gentlemen,

Through this conference, hopefully the discussion will lead toward acceleration of people prosperity. We should not put too much effort on just debates that only satisfying researchers themselves. We have to do more than that. Scientific debates outputs that have been perfectly completed can be posted in the international journals, so they could be used to push forward the acceleration of science development in the world.

Once again, I hope that the conference output will provide positive impact through science and technology development, that is benefiting the community.

To all overseas participants, I welcome you in Bali, a beautiful and peaceful island. Enjoy your stay and hope that the serenity of the island inspires you to create changes for a better future.

Finally, by saying BISMILLAH…. I open 2nd International Conference on the Sources, Effects and Risk of Ionizing Radiation (SERIR2) and 14th Biennial International Conference on SPERA2016.

May Allah SWT, the God Almighty give us His Blessing.
Wabilahi Taufiq Walhidayah, Wassalamualaikum Wr. Wb.

Bali, 5 September 2016
Minister of Research, Technology and Higher Education
Mohamad Nasir

Press Conference (organized by BHHK)

	**Dr. Andreas Bollhöfer** (President of SPERA)
	**Dr. Justin Lee** (Deputy Head of Mission, Department of Foreign Affairs and Trade of Australian Mission for Indonesia)
	**Dr. Gillian Hirts (ARPANSA)**
	**Prof. Dr. Djarot Sulistio Wisnubroto (Chairman of BATAN)**
	**Dr. Muhammad Dimyati** (Director General Research and Development, Ministry of Research, Technology and Higher Education, Kemenristekdikti)

TABLE OF CONTENT

KEYNOTE SPEAKERS

Keynote Speaker I

Dr. Stephen Solomon ***(Principal Scientific Adviser to CEO ARPANSA)***
"An ARPANSA Perspective on Radiation Protection of The Environment"

Keynote Speaker II

Prof. Dr. Yoshiyuki Suzuki, MD. ***(Fukushima Medical University, Japan)***
"Cutting Edge Radiotherapy" Including Combination Therapy with Immunotherapy)

Keynote Speaker III

Dr. Ferhat Aziz (*National Nuclear Energy Agency of Indonesia*)
"Environment Radioactivity Monitoring Activities in Indonesia and Its Public Concerning"

Environmental Radiation and Radioactivity levels around the Coal-fired Power Plants in Banten Province

Muji Wiyono, Dadong Iskandar, Wahyudi, Kusdiana and Syarbaini

Center for Technology of Radiation Safety and Metrology, National Nuclear Energy Agency of Indonesia,
Jalan Lebak Bulus Raya No. 49, Kotak Pos 7043 JKSKL, Jakarta 12070, E-mail: muji_w@batan.go.id

Abstract. *Coal is one of the most important fuel for power plant of electricity supply. However, coal contains trace quantities of the naturally occurring primordial radionuclides such as ^{40}K and ^{238}U, ^{232}Th and their decay products. Therefore, the combustion of coal is one of important sources release some natural radioactivities into the environment. The objective of this study is measurement of terrestrial gamma dose rate and radioactivity levels in areas surrounding thermal power plant fueled by coal in Banten Province. The natural gamma terrestrial radiation dose rates 1 m above ground level were measured in the vicinity of Suralaya, Labuhan and Lontar Coal-fired Power Plants in Banten Province. Soil samples were collected from these three Power Plants. Activity concentrations of the radionuclides of ^{226}Ra, ^{232}Th, ^{228}Th and ^{40}K were determined in the soil samples. Then, the terrestrial gamma dose rate and distribution of natural radioactivity concentration in surface soils were evaluated. The terrestrial gamma dose rate were ranged from 25.26 to 65.23 nSvh^{-1} with mean of 43.31 nSvh^{-1}. The activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th and ^{40}K were varied from 8.09 – 59.59 Bqkg^{-1}, 11.98 – 103.3 Bqkg^{-1}, 11.85 – 60.96 Bqkg^{-1}, 12.31 – 554.5 Bqkg^{-1} with a mean value of 22.76, 36.10, 31.00 and 131.6 Bqkg^{-1}, respectively. Generally, the terrestrial gamma dose rate and radioactivity levels are comparable with the normal regions or background area.*

Keywords: *Radioactive contamination; soil; coal power plant*

.

Introduction

President of Republic of Indonesia has launched a program designed to provide an additional 35 GW of power capacity by 2019 to cope with electricity shortages and to reduce the country's dependence on fossil fuels. Electricity demand growth in 2015-2019 is predicted to reach 8.7%/year, on average (BAPPENAS, 2014). The government's overall stra-tegy for its energy sector is outlined in Presidential Decree No. 5/2006 on National Energy Policy which emphasizes diversification, environmental sustain-ability, and maximum use of domestic energy resources (Presidential Decree. No. 5, 2006). National Energy Policy was revised in 2014, setting a target energy mix of oil (25%), gas (22%), coal (30%), and new and renewable energy (23%) by 2025. Indonesia's total primary energy supply in 2013 was about 1.61 billion barrels of oil equivalent. The majority of Indonesia's primary energy supply comes from fossil fuels: oil (46.08%), coal (30.90%), and gas (18.26%) (ADB, 2015). The share of other renewable energy resources in the energy mix was below 5%, mostly through hydropower (3.21%), geothermal power (1.15%), and biofuel (0.40%). It is also important to note that the use of traditional biomass is prevalent for basic cooking and thermal purposes among millions of rural households in Indonesia. According to Indonesia's Ministry of Energy and Mineral Resources data (ESDM, 2014), Indonesia's final commercial energy consumption in 2013 was 1.12 billion barrels of oil equivalent. This figure has increased by nearly 40% since 2001.9 Share of final energy consumption is divided into industry (42.12%), households (11.56%), transpor-tation (38.80%), commercial use (4.25%), and other sectors (3.26%).

Indonesia has coal resources at around 120.5 billion tons, proven oil resources at around 3.69 billion barrels, and proven natural gas reserves at around 101.54 trillion cubic feet (ESDM, 2014). This translates into about 23 remaining years of oil reserves, 59 years of gas, and 146 years of coal at current production rates. Indonesia's renewable energy sources are also considerable. The country is endowed with significant potential for hydropower (75,000 MW), micro/mini hydropower (1,013 MW), solar (4.80 kWh/m2/day), biomass (32,654 MW), and wind (3-6 m/s), and holds 40% of the world's geothermal reserves (28,000 MW). The Government plans that the construction of the 20 GW of coal-fired power capacity should increase the need of 80-90 Mt/year of coal, of which 40% are expected to be supplied internally. Supply of electricity will mainly be generated through the use of coal comprising 65.6% of total fuel mix, followed by natural gas at 16.6%, geothermal at 11%, water at 5.1%, oil and other resources up to 1.7%. Indonesian coal mining association, in its 2025 energy mix long-term plan, has stated that coal will be the main source of energy in the mix.

Coal contains primordial radionuclides ^{40}K, ^{232}Th, ^{235}U, ^{238}U and the members of the decay series of the last three nuclides (Amin, et al. 2013; Papp, et al. 2002; Flues, at al. 2002). According to UNSCEAR (2000), the mean natural radionuclide concentrations in coal are 35 Bq kg^{-1} (range: 16–110) for ^{238}U, 35 Bq kg^{-1} (range: 17–60) for ^{226}Ra, 30 Bq kg^{-1} (range: 11–64) for ^{232}Th and 400 Bq kg^{-1} (range: 140–850) for ^{40}K. In the process of combustion, these radionuclides are distributed in solid and gaseous combustion products and are discharged to and accumulate in man's environment. Most of the radionuclides accumulate in the ash (Karangelos, et al. 2004). The overwhelming majority of the ash is the so-called bottom ash or slag that can be kept under control. But some small proportion of the ash, called the fly ash, is discharged through the stacks to the environment without any control. Coal, burned as fuel material in power plants, produces energy and solid wastes, such as heavy and light ashes. The ashes tend to be enriched in inorganic elements (metals and radionuclides). The heavy ash fraction is deposited at the bottom of the furnaces, and is called bottom ash. The light ash (fly ash) is carried through the furnaces with the gases flow toward the stack. Depending on the emission control system of the stack, most of the ash is collected and any leftover is released into the atmosphere and deposited on the soil around the coal-fired power plant (Flues, at al. 2002).

The present work evaluates the influence of coal-fired power plants on radiation and radioactivities levels in environment. The coal-fired power plants under study are Suralaya, Labuhan and Lontar Coal-fired Power Plants located in Banten Province. The plants have been operating for several years and a filter systems were installed to reduce the particulate emission through their stacks. The evaluation of the environmental impact of these coal-fired power plants operation is very important. This information is important for authorities especially Banten province in their decisions about the radioactive impact in future.

Materials and Methods

Sampling Strategy

This study was performed on Suralaya, Labuhan and Lontar Coalfired Power Plants in Banten Province. The study area were divided into a 1; 3; 5; 10; 15 and 25 km radius of each of Coal-fired Power Plants site. The region within 1; 3; 5; 10; 15 and 25 km radius of the sites were divided into 1; 3; 5; 10; and 15 km square grids respectively. Then, soil was collected at each point using shovel and scoop. At each sampling point, soil samples were collected from two different profiles, named horizon A (depth from 0 to 5 cm) and horizon B (depth from 5 to 20 cm), and approximately 2 kg of soil was collected. Geographical coordinates of sampling points were determined using GPS Map 60CHx manufactured by Garmin. At a collection point the soil sample was wrapped in black plastic bag and then taken to the laboratory. Sampling positions were far from trees,

Figure 1. Sampling locations around Suralaya, Labuhan and Lotar Coal-fired Power Plants in Banten Province

buildings, roads or other constructions to avoid the impact of strange materials. Samples were obtained by clearing the surface vegetation and removing dead organic matter from the surface of the location (Syarbaini, et al. 2015).

All dried soil samples were grounded to 2 mm, homogenized and hermetically sealed in a 1 liter marinelli beakers. The marinelly beakers were allowed to stand for at least 4 weeks for secular equilibrium to be established between the long-lived parent radionuclides of ^{226}Ra and ^{232}Th and their short-lived daughters before measurement.

Gamma Spectrometry Measurements

The concentrations of ^{226}Ra, ^{232}Th, ^{228}Th and ^{40}K contents were measured by direct gamma spectrometry, with a P-type coaxial germanium detector, ORTEC with a resolution of 1.95 keV and a relative efficiency of 60% both measured at 1332 keV. The detector was calibrated using standard matrix with radionuclide activities certified by Amersham. The ^{226}Ra activities were determined by taking the mean activity of three separate photopeaks of its decay product radionuclides: ^{214}Pb at 295.2 and 351.9 keV, and ^{214}Bi at 609.3 keV. The ^{232}Th content of the samples was determined by measuring the intensities of the 911 and 968 keV gamma-ray peaks of ^{228}Ac, and the ^{40}K content from its 1460 keV gamma-ray peak. The ^{228}Th content of the samples was determined by measuring the intensities of the 238,63 keV gamma-ray peak of ^{212}Pb and 583,19 keV and 2614 keV gamma-ray peaks of ^{208}Tl.

Terrestrial Gamma Dose Rate Determination

The terrestrial gamma dose rate was measured by using a portable gamma spectrometer (Model GR-130 MiniSpec, produced by Exploranium Company, Canada). The surveymeter was placed at one meter above the ground as basically the same as described before (Syarbaini, et al. 2015). Some environmental parameters such as temperature, pressure, relative humidity and weather conditions at the time of measurement were recorded.

Figure 2. Gamma dose rate measurement by using *EXPLORANIUM GR 130*

Results and Discussion

Terrestrial Gamma Dose

The terrestrial gamma dose rate measurements at one meter above surface soil in study areas were found to be varying in different Coalfired Power Plants sites as shown in Table 1, 2 and 3. The terrestrial gamma dose rate of Suralaya, Labuhan and Lontar Coal-Fired Power Plants ranged from 30.79± 10.96 to 62.54±15.27 $nSvh^{-1}$ with means of 45.95± 12.62 $nSvh^{-1}$ and from 25.26±10.33 to 65.23±14.28 $nSvh^{-1}$ with means of 39.97±11.79 $nSvh^{-1}$ and from 27.00±10.47 to 61.03±15.47 $nSvh^{-1}$ with means of 44.01±12.55 $nSvh^{-1}$, respectively. It can be seen that generally the average and ranges of gamma dose rate around those Coal-fired Power Plants sites are comparable of each other.

Further, the in-situ measured data of terrestrial gamma dose rates were mapped using Surfer GIS software to simulate the whole study areas. The resulting map of terrestrial gamma dose rate is shown in Fig. 3; it shows the distribution of terrestrial gamma absorbed dose rates measured in around Coal-fired Power Plants. It can be seen from Fig. 3 that the comparable gamma dose rates are found in the region of 1; 3; 5; 10; 15 and 25 km radius of each of Coal-Fired Power Plants site.

Distribution of Natural Radionuclides Activity Concentration in Surface Soils

The results of activity concentration measurements in the soil samples collected from Suralaya, Labuhan and Lontar Coalfired Power Plants are shown in Tabel 4, 5 and 6, respectively. The activity concentrations of ^{226}Ra ranged from 11.58±1.24 to 59.59±3.91 $Bqkg^{-1}$ in soils around Suralaya Coal-fired Power Plant and from 33.24± 2.40 to 44.54±2.94 $Bqkg^{-1}$ in soils around Labuhan Coal-fired Power Plant and from 8.09±1.17 to 40.29 ±2.94 $Bqkg^{-1}$ in soils around Lontar Coal-fired Power Plant with means of 22.94±1.85 $Bqkg^{-1}$ and 22.94±1.93 $Bqkg^{-1}$ and 22.66±2.33 $Bqkg^{-1}$, respectively.

The activity concentrations of ^{232}Th ranged from 21.34±0.65 to 89.89±5.55 $Bqkg^{-1}$ in soils around Suralaya Coal-fired Power Plant and from 11.98± 0.40 to 103.33± 6.15 $Bqkg^{-1}$ in soils around Labuhan Coal-fired Power Plant and from 12.29±1.67 to 49.23±5.02 $Bqkg^{-1}$ in soils around Lontar Coal-fired Power Plant with means of 36.69±2.23 $Bqkg^{-1}$ and 37.82±2.49 $Bqkg^{-1}$ and 33.80±3.18 $Bqkg^{-1}$, respectively.

Table 1. The terrestrial gamma dose rate around Suralaya Coal Power Plant in Banten Province

No.	Sample Code	Location	GPS Coordinates		Gamma dose rate (nSv/h)
			S	E	
1	PLTU-1A	Desa Margagiri, Kec. Bojanegara, Kab. Serang	-5.96588	106.0956	56.20 ± 13.35
2	PLTU-2A	Desa Puloampel, Kec. Puloampel, Kab. Serang	-5.90772	106.0885	48.98 ± 13.53
3	PLTU-3A	Desa Salira, Kec. Bojanegara, Kab. Serang	-5.88842	106.0446	48.69 ± 13.41
4	PLTU-4A	Desa Suralaya, Kec. Suralaya, Kab. Serang	-5.89911	106.0289	13.16 ± 11.18
5	PLTU-5A	Desa Suralaya, Kec. Suralaya, Kab. Serang	-5.89438	106.0232	43.57 ± 13.16
6	PLTU-6A	Kel. Lebak Gede, Kec. Pulo Merak, Kota Cilegon	-5.92328	106.00448	38.20 ± 11.83
7	PLTU-7A	Kel. Gerem, Kec. Pulo Merak, Kota Cilegon	-5.96721	106.00463	47.71 ± 12.46
8	PLTU-8A	Kel. Gerem, Kec. Pulo Merak, Kota Cilegon	-6.03786	106.0877	52.57 ± 12.12
9	PLTU-9A	Desa Kemang, Kec. Cipondoh, Kab. Serang	-6.12259	106.17657	62.54 ± 15.27
10	PLTU-10A	Kel. Mancak, Kec. Ciwandan, Kota Cilegon	-6.02364	105.96069	42.74 ± 12.42
11	PLTU-11A	Kel. Anyer, Kec. Anyer, Kota Cilegon	-6.05966	105.90504	44.21 ± 11.37
12	PLTU-12A	Desa Cinangka, Kec. Luwuksari, Kab. Serang	-6.12399	105.86676	30.79 ± 10.96
13	PLTU-36A	Desa Luwuk, Kec. Luwuksari, Kab. Serang	-6.13021	106.00033	42.46 ± 12.09
14	PLTU-65A	Desa Kasunyatan, Kec. Kasemen, Kab. Serang	-6.05488	106.15872	51.48 ± 13.48
	Range				30.79 – 62.54
	Average				45.95 ± 12.62

Table 2. The terrestrial gamma dose rate around Labuhan Coal Power Plant in Banten Province

No.	Sample Code	Location	GPS Coordinates		Gamma dose rate (nSv/h)
			S	E	
1	PLTU-13A	Desa Sukarame, Kec. Carita, Kab. Pandeglang	-6.28221	105.82665	38.57 ± 11.44
2	PLTU-14A	Desa Banjarmasin, Kec. Carita, Kab. Pandeglang	-6.33133	105.83308	31.16 ± 11.63
3	PLTU-15A	Desa Margagiri, Kec. Labuhan, Kab. Pandeglang	-6.40607	105.82883	39.61 ± 11.78
4	PLTU-16A	Desa Margasana, Kec. Pagelaran, Kab. Pandeglang	-6.39804	105.83641	31.60 ± 11.09
5	PLTU-17A	Desa Margasana, Kec. Pagelaran, Kab. Pandeglang	-6.39254	105.85776	44.80 ± 13.17
6	PLTU-18A	Desa Cipucung, Kec. Cikedal, Kab. Pandeglang	-6.38897	105.89616	39.53 ± 11.61
7	PLTU-19A	Desa Sodong, Kec. Saketi, Kab. Pandeglang	-6.40082	105.97417	30.70 ± 10.51
8	PLTU-20A	Desa Palurahan, Kec. Kaduhejo, Kab. Pandeglang	-6.3313	106.07686	32.16 ± 10.76
9	PLTU-21A	Desa Palurahan, Kec. Kaduhejo, Kab. Pandeglang	-6.40987	105.82742	33.16 ± 10.15
10	PLTU-22A	Kp. Tegalpapak, Kec. Labuhan, Kab. Pandeglang	-6.4436	105.82253	34.64 ± 11.44
11	PLTU-23A	Kp. Panimbang, Kec. Panimbangan, Kab. Pandeglang	-6.49824	105.79535	25.26 ± 10.33
12	PLTU-24A	Kp. Ciseukeut, Kec. Panimbangan, Kab. Pandeglang	-6.52669	105.75529	38.34 ± 11.64
13	PLTU-25A	Kp. Citeureup, Kec. Panimbangan, Kab. Pandeglang	-6.51637	105.68173	57.68 ± 13.44
14	PLTU-26A	Kp. Nampu, Kec. Cigeulies, Kab. Pandeglang	-6.55814	105.70207	65.23 ± 14.28
15	PLTU-27A	Kp. Panimbang, Kec. Cigeulies, Kab. Pandeglang	-6.59632	105.69528	30.67 ± 10.21
16	PLTU-28A	Kec. Saketi, Kab. Pandeglang	-6.46571	105.9996	34.75 ± 11.24
17	PLTU-29A	Desa Cidahu, Kec. Banjarsari, Kab. Lebak	-6.55082	105.99929	41.43 ± 11.78
18	PLTU-30A	Desa Cisampih, Kec. Muncul, Kab. Pandeglang	-6.58405	105.9872	49.55 ± 13.10
19	PLTU-31A	Desa Kota Dukuh, Kec. Muncul, Kab. Pandeglang	-6.58873	105.89937	54.03 ± 12.55
20	PLTU-60A	Desa Pari, Kec. Mandalawangi, Kab. Pandeglang	-6.30668	105.98293	36.47 ± 11.64
21	PLTU-61A	Desa Sukasari, Kec. Pulo Sari, Kab. Pandeglang	-6.32376	105.94353	42.77 ± 12.72
22	PLTU-63A	Desa Pagelaran, Kec. Pagelaran, Kab. Pandeglang	-6.42201	105.84925	47.14 ± 12.80
	Range				25.26 – 65.23
	Average				39.97 ± 11.79

Table 3 . The terrestrial gamma dose rate around Lontar Coal Power Plant in Banten province

No.	Sample Code	Location	GPS Coordinates		Gamma dose rate (nSv/h)
			S	E	
1	PLTU-33A	Desa Cikuang, Kec. Pabuaran, Kab. Serang	-6.3478	106.26327	37.63 ± 11.48
2	PLTU-34A	Desa Barengkong, Kec. Pabuaran, Kab. Serang	-6.20724	105.98772	39.65 ± 11.87
3	PLTU-35A	Desa Cikurai, Kec. Cinangka, Kab. Serang	-6.19848	105.92641	40.54 ± 12.66
4	PLTU-36A	Desa Luwuk, Kec. Luwuksari, Kab. Serang	-6.13021	106.00033	42.46 ± 12.09
5	PLTU-37A	Desa Majasari, Kec. Jawilen, Kab. Serang	-6.27349	106.34078	43.03 ± 12.55
6	PLTU-38A	Desa Kiara, Kec. Balaraja, Kab. Tangerang	-6.22133	106.43885	39.96 ± 10.32
7	PLTU-39A	Desa Rantaiilat, Kec. Kronjo, Kab. Tangerang	-6.12544	106.42695	44.63 ± 13.26
8	PLTU-40A	Desa Pesilihan, Kec. Kronjo, Kab. Tangerang	-6.06974	106.42379	43.04 ± 12.70
9	PLTU-41A	Kec. Kronjo, Kab. Tangerang	-6.07053	106.43891	59.18 ± 14.30
10	PLTU-42A	Kec. Kronjo, Kab. Tangerang	-6.03839	106.38854	37.33 ± 11.37
11	PLTU-43A	Kec. Kronjo, Kab. Tangerang	-6.01982	106.2683	54.75 ± 14.89
12	PLTU-44A	Desa Ciomas, Kec. Ciomas, Kab. Serang	-6.08432	106.24583	49.28 ± 13.40
13	PLTU-45A	Desa Ciduha, Kec. Cirenang, Kab. Serang	-6.08001	106.3316	44.26 ± 12.45
14	PLTU-46A	Desa Lontar, Kec. Kemiri, Kab. Tangerang	-6.0769	106.44832	27.00 ± 10.47
15	PLTU-47A	Desa Lontar, Kec. Kemiri, Kab. Tangerang	-6.08132	106.46374	35.57 ± 11.45
16	PLTU-48A	Desa Lontar, Kec. Kemiri, Kab. Tangerang	-6.07499	106.48524	39.96 ± 12.34
17	PLTU-49A	Desa Lontar, Kec. Kemiri, Kab. Tangerang	-6.06886	106.5354	38.22 ± 10.75
18	PLTU-50A	Kec. Paku Aji, Kab. Tangerang	-6.07061	106.5354	44.04 ± 13.67
19	PLTU-51A	Kec. Paku Aji, Kab. Tangerang	-6.14164	106.58356	59.68 ± 15.47
20	PLTU-55A	Desa Sukawati, Kec. Paku Aji, Kab. Tangerang	-6.03926	106.5922	40.33 ± 12.63
21	PLTU-56A	Desa Margamulya, Kec. Mauk, Kab. Tangerang	-6.03188	106.53025	43.78 ± 12.44
22	PLTU-58A	Kec. Kronjo, Kab. Tangerang	-6.12958	106.48917	46.97 ± 12.03
23	PLTU-67A	Desa Renged, Kec. Kresek, Kab. Serang	-6.14941	106.39106	61.03 ± 14.08
	Range				27.00 – 61.03
	Average				44.01 ± 12.55

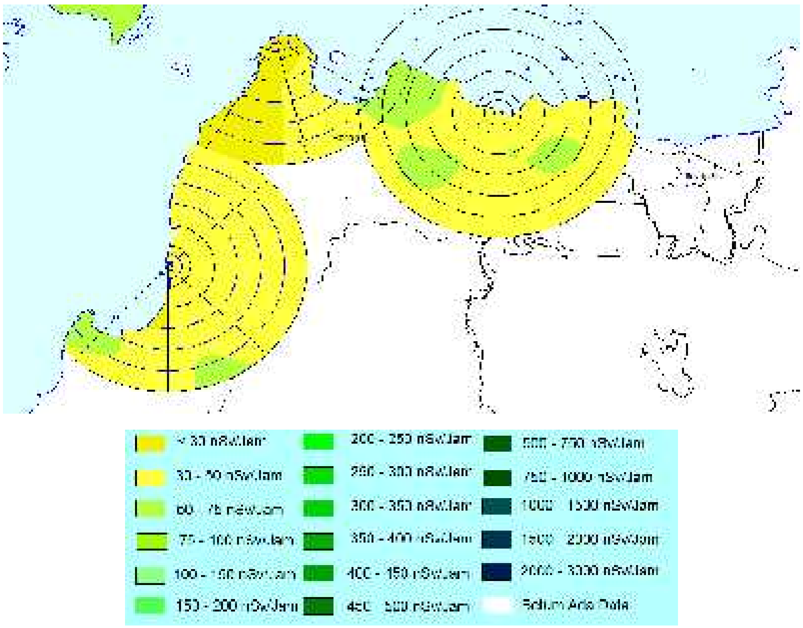

Figure 3. The map of terrestrial gamma dose rate around Suralaya, Labuhan and Lontar Coalfired Power Plants

Table 4. Activity concentrations of radionuclides in soils around Suralaya Coal Power Plant in Banten Province

No.	Sample Code	Location	GPS Coordinates	Depth (cm)	Activity Concentrations (Bq/kg)			
					^{226}Ra	^{232}Th	^{228}Th	^{40}K
1	PLTU-1A	Desa	S -5.96588	0-5	13.26 ± 1.08	21.34 ± 0.65	23.53 ± 1.56	216.16 ± 12.76
	PLTU-1B	Margagiri	E 106.0956	5-20	14.21 ± 1.23	23.32 ± 0.78	22.56 ± 1.98	215.41 ± 13.26
2	PLTU-2A	Desa	S -5.90772	0-5	14.37 ± 1.13	23.38 ± 0.70	26.80 ± 1.85	102.11 ± 6.39
	PLTU-2B	Puloampel	E 106.0885	5-20	16.18 ± 1.28	36.91 ± 2.42	25.67 ± 1.76	105.89 ± 6.65
3	PLTU-3A	Desa	S -5.88842	0-5	25.66 ± 1.90	40.52 ± 3.11	32.85 ± 2.63	55.12 ± 5.99
	PLTU-3B	Salira	E 106.04462	5-20	24.63 ± 1.82	41.38 ± 2.96	31.46 ± 2.71	55.94 ± 4.92
4	PLTU-4A	Desa	S -5.89911	0-5	31.91 ± 2.23	25.12 ± 1.73	16.95 ± 1.19	165.15 ± 10.10
	PLTU-4B	Suralaya	E 106.0289	5-20	19.07 ± 2.03	30.26 ± 2.30	27.64 ± 2.22	176.77 ± 11.89
5	PLTU-5A	Desa	S -5.89438	0-5	15.36 ± 1.43	27.04 ± 1.91	22.67 ± 1.59	95.44 ± 6.39
	PLTU-5B	Suralaya	E 106.0232	5-20	15.59 ± 1.20	26.26 ± 0.79	29.54 ± 1.98	84.09 ± 5.26
6	PLTU-6A	Kel. Le-	S -5.92328	0-5	14.51 ± 1.14	23.97 ± 0.70	27.44 ± 1.82	110.14 ± 6.74
	PLTU-6B	bak Gede	E 106.00448	5-20	16.92 ± 1.30	25.81 ± 0.76	29.66 ± 2.03	112.23 ± 7.00
7	PLTU-7A	Kel.	S -5.96721	0-5	14.53 ± 1.18	27.82 ± 0.84	32.11 ± 2.16	109.45 ± 6.77
	PLTU-7B	Gerem	E 106.00463	5-20	18.48 ± 1.42	46.84 ± 2.94	31.73 ± 2.07	42.63 ± 3.11
8	PLTU-8A	Kel.	S -6.03786	0-5	33.11 ± 2.33	46.93 ± 1.36	55.62 ± 3.53	44.38 ± 3.45
	PLTU-8B	Gerem	E 106.0877	5-20	37.19 ± 2.83	59.90 ± 3.72	52.91 ± 3.34	42.85 ± 5.05
9	PLTU-9A	Desa	S -6.12259	0-5	28.78 ± 2.16	32.27 ± 2.14	30.50 ± 2.05	53.60 ± 4.39
	PLTU-9B	Kemang	E 106.17657	5-20	31.94 ± 2.20	50.96 ± 3.22	34.63 ± 2.25	25.13 ± 2.41
10	PLTU-10A	Kel.	S -6.02364	0-5	15.50 ± 1.21	23.00 ± 0.67	27.95 ± 1.85	197.87 ± 11.77
	PLTU-10B	Mancak	E 105.96069	5-20	23.05 ± 2.24	31.23 ± 2.27	27.29 ± 2.12	121.84 ± 8.86
11	PLTU-11A	Kel.	S -6.05966	0-5	59.59 ± 3.91	89.89 ± 5.55	60.96 ± 3.90	113.61 ± 7.11
	PLTU-11B	Anyer	E 105.90504	5-20	33.81 ± 2.73	62.94 ± 4.27	40.46 ± 2.83	245.67 ± 15.21
12	PLTU-12A	Desa	S -6.12399	0-5	16.83 ± 1.31	28.67 ± 1.91	18.92 ± 1.31	170.07 ± 10.27
	PLTU-12B	Cinangka	E 105.86676	5-20	11.58 ± 1.24	22.22 ± 1.59	18.44 ± 1.33	174.32 ± 10.94
13	PLTU-36A	Desa	S -6.13021	0-5	14.83 ± 1.44	33.55 ± 2.09	25.55 ± 1.28	30.71 ± 2.93
	PLTU-36B	Luwuk	E 106.00033	5-20	16.91 ± 1.30	37.09 ± 2.35	27.77 ± 1.77	32.62 ± 2.59
14	PLTU-65A	Ds. Kasu-	S -6.05488	0-5	31.11 ± 3.11	39.93 ± 3.96	34.96 ± 3.45	460.21 ± 43.73
	PLTU-65B	nyatan	E 106.15872	5-20	32.32 ± 3.32	48.71 ± 4.75	43.48 ± 2.38	554.52 ± 52.58
Range					11.58 - 59.59	21.34 - 89.89	18.44 - 60.96	25.13 - 554.52
Average					22.94 ± 1.85	36.69 ± 2.23	31.41 ± 2.18	139.78 ± 10.30

Table 5. Activity concentrations of radionuclides in soils around Labuhan Coal Power Plant in Banten Province

No.	Sample Code	Location	GPS Coordinates	Depth (cm)	Activity Concentrations (Bq/kg) ^{226}Ra	^{232}Th	^{228}Th	^{40}K
1	PLTU-13A	Desa	S -6.28221	0-5	21.13 ± 1.62	62.50 ± 3.89	41.86 ± 2.69	126.06 ± 7.75
	PLTU-13B	Sukarame	E 105.82665	5-20	20.17 ± 1.89	63.26 ± 3.42	42.34 ± 3.01	126.89 ± 6.42
2	PLTU-14A	Desa Ban-	S -6.33133	0-5	21.08 ± 1.53	29.39 ± 0.86	33.40 ± 2.19	17.10 ± 1.66
	PLTU-14B	jarmasin	E 105.83308	5-20	21.91 ± 1.55	29.54 ± 0.84	34.95 ± 2.26	15.73 ± 1.65
3	PLTU-15A	Desa	S -6.40607	0-5	17.87 ± 1.48	26.15 ± 0.85	28.38 ± 2.09	129.26 ± 8.34
	PLTU-15B	Margagiri	E 105.82883	5-20	20.83 ± 1.85	40.26 ± 2.91	27.42 ± 2.04	130.19 ± 8.58
4	PLTU-16A	Desa Mar-	S -6.39804	0-5	10.60 ± 1.02	27.23 ± 1.91	17.37 ± 1.26	147.48 ± 9.27
	PLTU-16B	gasana	E 105.83641	5-20	8.20 ± 0.83	14.97 ± 0.51	16.25 ± 1.20	139.14 ± 8.71
5	PLTU-17A	Desa Mar-	S -6.39254	0-5	33.24 ± 2.4	49.45 ± 3.26	33.42 ± 2.22	79.14 ± 5.40
	PLTU-17B	gasana	E 105.85776	5-20	32.97 ± 2.18	50.31 ± 2.53	33.98 ± 2.68	80.27 ± 4.68
6	PLTU-18A	Desa	S -6.38897	0-5	24.96 ± 1.79	45.35 ± 2.89	29.96 ± 1.96	68.00 ± 4.49
	PLTU-18B	Cipayung	E 105.89616	5-20	22.64 ± 1.62	34.04 ± 0.98	38.97 ± 2.48	46.63 ± 3.18
7	PLTU-19A	Desa	S -6.40082	0-5	22.51 ± 1.78	39.89 ± 2.71	26.74 ± 1.84	42.14 ± 3.46
	PLTU-19B	Sodong	E 105.97417	5-20	16.82 ± 1.48	25.34 ± 1.70	22.04 ± 1.55	31.91 ± 3.43
8	PLTU-20A	Desa	S -6.3313	0-5	13.06 ± 1.05	21.52 ± 0.67	24.73 ± 1.64	54.15 ± 3.55
	PLTU-20B	Palurahan	E 106.07686	5-20	18.58 ± 1.65	35.93 ± 2.56	23.57 ± 1.71	47.79 ± 3.87
9	PLTU-21A	Desa	S -6.40987	0-5	17.16 ± 1.27	28.91 ± 0.85	32.27 ± 2.11	47.76 ± 3.23
	PLTU-21B	Palurahan	E 106.82742	5-20	24.32 ± 1.76	37.12 ± 2.42	26.20 ± 1.73	71.06 ± 4.62
10	PLTU-22A	Kp.Tegal-	S -6.4436	0-5	15.02 ± 1.22	27.25 ± 1.87	19.60 ± 1.33	100.7 ± 6.22
	PLTU-22B	papak	E 105.82253	5-20	12.63 ± 1.02	23.40 ± 0.69	25.64 ± 1.73	122.9 ± 7.52
11	PLTU-23A	Kp. Panim	S -6.49824	0-5	9.77 ± 0.8	14.51 ± 0.47	15.97 ± 1.08	15.35 ± 1.47
	PLTU-23B	bang	E 105.82253	5-20	9.45 ± 0.8	11.98 ± 0.40	14.74 ± 1.02	12.31 ± 0.97
12	PLTU-24A	Kp. Ciseu-	S -6.52669	0-5	24.00 ± 2.58	29.00 ± 3.10	28.85 ± 2.92	229.3 ± 22.40
	PLTU-24B	keut	E 105.75529	5-20	18.55 ± 2.06	25.87 ± 2.80	25.02 ± 2.55	236.23 ± 23.05
13	PLTU-25A	Kp. Citeu-	S -6.51637	0-5	37.85 ± 2.49	39.01 ± 1.11	44.63 ± 2.82	238.36 ± 13.96
	PLTU-25B	reup	E 105.68173	5-20	40.28 ± 2.66	43.39 ± 1.21	50.44 ± 2.20	260.56 ± 15.27
14	PLTU-26A	Kp. Nampu	S -6.55814	0-5	44.54 ± 2.94	103.3 ± 6.15	58.59 ± 3.65	482.51 ± 27.78
	PLTU-26B		E 105.70207	5-20	38.00 ± 2.63	85.46 ± 5.18	3.76 ± 0.22	28.27 ± 1.28
15	PLTU-27A	Kp. Penim	S -6.59632	0-5	30.44 ± 3.20	30.39 ± 3.24	30.17 ± 3.04	63.82 ± 6.82
	PLTU-27B	bang	E 105.69528	5-20	28.07 ± 3.61	33.43 ± 4.31	31.01 ± 3.56	64.37 ± 8.60
16	PLTU-28A	Kec.	S -6.46571	0-5	31.54 ± 3.03	61.42 ± 4.76	40.15 ± 2.16	51.37 ± 3.68
	PLTU-28B	Saketi	E 105.9996	5-20	28.50 ± 2.02	55.97 ± 3.48	37.31 ± 2.40	49.93 ± 3.51
17	PLTU-29A	Desa	S -6.55082	0-5	22.94 ± 1.65	34.19 ± 0.98	38.95 ± 2.52	204.67 ± 12.14
	PLTU-29B	Cidahu	E 105.99929	5-20	16.75 ± 1.27	28.56 ± 0.84	32.6 ± 2.09	86.41 ± 5.37
18	PLTU-30A	Desa	S -6.58405	0-5	21.35 ± 2.29	38.28 ± 3.93	36.97 ± 3.65	238.02 ± 23.11
	PLTU-30B	Cisampih	E 105.9872	5-20	31.37 ± 3.28	38.74 ± 4.04	37.48 ± 3.73	260.99 ± 25.37
19	PLTU-31A	Desa Kota	S -6.58873	0-5	34.36 ± 2.54	63.42 ± 4.07	42.37 ± 3.01	178.45 ± 10.15
	PLTU-31B	Dukuh	E 105.89937	5-20	36.17 ± 2.46	65.62 ± 4.05	44.74 ± 2.89	180.58 ± 10.85
20	PLTU-60A	Desa Pari	S -6.30668	0-5	22.71 ± 2.46	36.38 ± 3.81	35.07 ± 3.51	81.96 ± 8.54
	PLTU-60B		E 105.98293	5-20	18.32 ± 2.33	35.01 ± 4.07	34.44 ± 3.66	66.12 ± 7.87
21	PLTU-61A	Desa	S -6.32376	0-5	12.61 ± 1.48	22.03 ± 2.43	21.20 ± 2.19	35.79 ± 4.14
	PLTU-61B	Sukasari	E 105.94353	5-20	13.69 ± 1.96	25.55 ± 3.28	24.07 ± 2.76	28.82 ± 4.49
22	PLTU-63A	Desa	S -6.42201	0-5	15.85 ± 1.71	15.71 ± 1.72	15.13 ± 1.56	82.64 ± 8.34
	PLTU-63B	Pagelaran	E 105.84925	5-20	15.57 ± 1.68	14.89 ± 1.64	14.81 ± 1.52	76.21 ± 7.70
Range					33.24 - 44.54	11.98 - 103.3	18.44 - 58.59	12.31 - 482.51
Average					22.69 ± 1.93	37.82 ± 2.49	31.54 ± 2.31	110.85 ± 8.34

The activity concentrations of ^{228}Th ranged from 18.44±1.33 to 60.96±3.90 Bqkg^{-1} in soils around Suralaya Coal-fired Power Plant and from 18.44± 1.33 to 58.59±3.73 Bqkg^{-1} in soils around Labuhan Coal-fired Power Plant and from 11.85±1.41 to 47.65±4.69 Bqkg^{-1} in soils around Lontar Coal-fired Power Plant with means of 31.41±2.18 Bqkg^{-1} and 31.54±2.31 Bqkg^{-1} and 30.06±2.83 Bqkg^{-1}, respectively.

The activity concentrations of ^{40}K ranged from 25.13±2.41 to 554.52±52.58 Bqkg^{-1} in soils around Suralaya Coal-fired Power Plant and from 12.31±0.97 to 482.51±27.78 Bqkg^{-1} in soils around Labuhan Coal-fired Power Plant and from 29.71± 2.93 to 255.65±25.95 Bqkg^{-1} in soils around Lontar Coal-fired Power Plant with means of 139.78±10.30 Bqkg^{-1} and 110.85±8.34 Bqkg^{-1} and 144.05±13.27 Bqkg^{-1}, respectively.

Table 6. Activity concentrations of radionuclides in soils around Lontar Coal Power Plant in Banten Province

No.	Sample Code	Location	GPS Coordinates	Depth (cm)	Activity Concentrations (Bq/kg)			
					^{226}Ra	^{232}Th	^{228}Th	^{40}K
1	PLTU-33A	Desa	S -6.3478	0-5	24.41 ± 2.49	34.91 ± 3.50	30.74 ± 3.06	150.95 ± 14.73
	PLTU-33B	Cikuang	E 106.26327	5-20	22.32 ± 2.31	39.30 ± 3.92	35.36 ± 3.51	58.28 ± 6.05
2	PLTU-34A	Desa Ba-	S -6.20724	0-5	17.12 ± 1.35	35.82 ± 2.34	23.53 ± 1.60	146.33 ± 8.93
	PLTU-34B	rengkong	E 105.98772	5-20	19.36 ± 1.46	31.74 ± 2.10	20.53 ± 1.40	106.53 ± 6.58
3	PLTU-35A	Desa	S -6.19848	0-5	24.77 ± 1.78	42.87 ± 2.74	29.11 ± 1.89	87.36 ± 2.52
	PLTU-35B	Cikurai	E 105.92641	5-20	26.45 ± 2.03	45.53 ± 3.02	32.47 ± 3.06	89.75 ± 2.87
4	PLTU-36A	Desa	S -6.13021	0-5	14.83 ± 1.44	35.55 ± 2.09	25.55 ± 1.28	29.71 ± 2.93
	PLTU-36B	Luwuk	E 106.00033	5-20	16.91 ± 1.30	37.09 ± 2.35	27.27 ± 1.77	36.62 ± 4.59
5	PLTU-37A	Desa	S -6.27349	0-5	25.33 ± 1.76	31.93 ± 0.91	31.95 ± 2.11	67.10 ± 4.26
	PLTU-37B	Majasari	E 106.34078	5-20	27.35 ± 2.82	36.66 ± 3.74	34.86 ± 3.43	50.68 ± 5.38
6	PLTU-38A	Desa	S -6.22133	0-5	22.83 ± 1.69	27.92 ± 0.85	32.18 ± 2.18	69.40 ± 4.57
	PLTU-38B	Kiara	E 106.43885	5-20	24.83 ± 1.76	36.39 ± 2.36	25.16 ± 1.72	31.61 ± 2.45
7	PLTU-39A	Desa	S -6.12544	0-5	26.04 ± 2.76	31.81 ± 3.35	30.60 ± 3.07	101.70 ± 10.38
	PLTU-39B	Rantaiilat	E 106.42695	5-20	30.80 ± 3.23	36.26 ± 3.80	35.58 ± 3.55	141.43 ± 14.14
8	PLTU-40A	Desa	S -6.06974	0-5	24.49 ± 2.47	27.80 ± 2.80	26.15 ± 2.60	181.90 ± 17.55
	PLTU-40B	Pesilihan	E 106.42379	5-20	27.46 ± 3.32	33.08 ± 3.98	30.69 ± 3.37	192.08 ± 20.14
9	PLTU-41A	Kec.	S -6.07053	0-5	22.92 ± 2.49	27.19 ± 2.94	27.26 ± 2.77	64.36 ± 6.92
	PLTU-41B	Kronjo	E 106.43891	5-20	28.96 ± 3.06	37.89 ± 3.96	35.87 ± 3.58	174.84 ± 17.28
10	PLTU-42A	Kec.	S -6.03839	0-5	27.07 ± 2.86	33.37 ± 3.50	33.47 ± 3.34	248.57 ± 24.19
	PLTU-42B	Kronjo	E 106.38854	5-20	21.37 ± 2.72	35.91 ± 4.26	32.83 ± 3.58	252.66 ± 25.89
11	PLTU-43A	Kec.	S -6.01982	0-5	20.56 ± 2.25	30.33 ± 3.22	29.67 ± 2.99	237.12 ± 23.12
	PLTU-43B	Kronjo	E 106.2683	5-20	25.63 ± 3.08	37.66 ± 4.36	36.12 ± 3.84	241.58 ± 24.55
12	PLTU-44A	Desa	S -6.08432	0-5	40.29 ± 4.13	49.23 ± 5.02	47.65 ± 4.69	97.40 ± 9.99
	PLTU-44B	Ciomas	E 106.24583	5-20	34.48 ± 3.89	46.81 ± 5.16	45.00 ± 4.65	90.74 ± 10.22
13	PLTU-45A	Desa	S -6.08001	0-5	22.75 ± 2.31	30.90 ± 3.09	28.65 ± 2.84	47.31 ± 4.90
	PLTU-45B	Ciduha	E 106.3316	5-20	22.96 ± 1.69	42.18 ± 2.74	30.27 ± 2.02	48.67 ± 3.37
14	PLTU-46A	Desa	S -6.0769	0-5	18.34 ± 2.45	25.42 ± 3.65	25.35 ± 3.12	174.46 ± 16.54
	PLTU-46B	Lontar	E 106.44832	5-20	20.50 ± 2.63	27.90 ± 3.47	27.45 ± 3.06	176.78 ± 18.69
15	PLTU-47A	Desa	S -6.08132	0-5	22.46 ± 2.78	38.41 ± 4.64	35.35 ± 3.82	87.43 ± 10.04
	PLTU-47B	Lontar	E 106.46374	5-20	20.32 ± 2.56	36.67 ± 4.25	34.85 ± 3.72	86.66 ± 9.97
16	PLTU-48A	Desa	S -6.07499	0-5	22.87 ± 2.50	34.46 ± 3.65	33.58 ± 3.38	111.55 ± 11.41
	PLTU-48B	Lontar	E 106.48	5-20	21.90 ± 2.80	34.31 ± 4.16	31.34 ± 3.45	224.44 ± 23.24
17	PLTU-49A	Desa	S -6.06886	0-5	15.96 ± 1.54	40.38 ± 2.83	27.25 ± 1.92	208.51 ± 12.85
	PLTU-49B	Lontar	E 106.5354	5-20	20.26 ± 1.60	40.72 ± 2.71	28.11 ± 1.91	208.94 ± 12.63
18	PLTU-50A	Kec. Paku	S -6.07061	0-5	19.13 ± 2.08	28.38 ± 3.00	27.12 ± 2.73	187.11 ± 18.35
	PLTU-50B	Aji	E 106.5354	5-20	17.05 ± 2.28	31.51 ± 3.83	30.99 ± 3.39	172.36 ± 18.20
19	PLTU-51A	Kec. Paku	S -6.14164	0-5	14.66 ± 1.19	19.87 ± 0.61	19.83 ± 1.36	161.35 ± 9.77
	PLTU-51B	Aji	E 106.58356	5-20	17.59 ± 1.43	29.65 ± 2.09	19.92 ± 1.42	188.94 ± 11.44
20	PLTU-55A	Desa	S -6.03926	0-5	10.08 ± 1.20	17.72 ± 1.98	17.15 ± 1.78	199.89 ± 19.47
	PLTU-55B	Sukawati	E 106.5922	5-20	8.09 ± 1.17	12.26 ± 1.67	11.85 ± 1.41	181.23 ± 18.40
21	PLTU-56A	Desa Mar-	S -6.03188	0-5	11.80 ± 1.38	22.99 ± 2.49	21.99 ± 2.25	242.73 ± 23.58
	PLTU-56B	gamulya	E 106.53025	5-20	9.58 ± 1.47	26.65 ± 3.32	24.60 ± 2.76	255.65 ± 25.95
22	PLTU-58A	Kec.	S -6.12958	0-5	33.47 ± 3.48	38.56 ± 4.02	36.98 ± 3.68	170.77 ± 16.89
	PLTU-58B	Kronjo	E 106.48917	5-20	33.46 ± 3.76	42.95 ± 4.75	43.13 ± 4.45	80.73 ± 9.18
23	PLTU-67A	Desa	S -6.14941	0-5	33.02 ± 3.44	34.83 ± 3.66	34.44 ± 3.44	243.19 ± 23.69
	PLTU-67B	Renged	E 106.39106	5-20	29.44 ± 3.06	34.93 ± 3.61	32.89 ± 3.27	222.71 ± 21.68
Range					8.09 - 40.29	12.26 - 49.23	11.85 - 47.65	29.71 - 255.65
Average					22.66 ± 2.33	33.80 ± 3.18	30.06 ± 2.83	144.05 ± 13.27

Table 4, 5 and 6 shows that, in general the average and ranges of activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th and ^{40}K in soil collected from Suralaya, Labuhan and Lontar Coal-fired Power Plants are comparable to each other.

Conclusions

Generally, the average and ranges of the terrestrial gamma dose rate and activity concentrations of radionuclides in soil collected from Suralaya, Labuhan and Lontar Coal-fired Power Plants in Banten Province are comparable to each other. Based on the results of the measurement, it has been that the environmental radiation and radioactivity levels in all sites around of Suralaya, Labuhan and Lontar Coal-fired Power Plants in Banten Province are comparable with normal area. Therefore, there is no indication that the coal-fired power plants activities in study areas appear to have any impact on the radiation burden of the environment.

Acknowledgements

The authors acknowledge the Center for Technology of Radiation Safety and Metrology, National Nuclear Energy Acency 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

Amin, Y. M., Khandaker, M. U., Shyen, A. K. S., Mahat, R. H., Nor, R. M., Bradley, D. A. (2013). Radionuclides Emissions from a Coal-fired Power plant, *Applied Radiation and Isotopes, 80*: 109-116

Asian Development Bank (2015). Sumary of Indonesia's Energy Sector Assessment, ADB Papers on Indonesia, Jakarta.

Bem, H., Wieczorkowski, P., Budzanowski, M. (2002). Evaluation of Technologically Enhanced Natural Radiation near the Coal-fired Power plants in the Lodz Region of Poland, *J. Environmental Radioactivity, 61*: 191-201

Flues, M., Moraes, V., Mazzilli, B. P. (2002). The Influence of a Coal-fired Power Plant Operation on Radionuclide Concentrations in Soil, *J. Environmental Radioactivity, 63*: 285-294

Indonesia's Ministry of Energy and Mineral Resources (2014). Handbook of Energy & Economic Statistics of Indonesia.

Karangelos, D.J., Petropoulos, N. P., Anagnostakis, E. P., Hinis, E. P., Simopoulos, S. E. (2004). Radiological Characteristics and Investigation of the radioactive equilibrium in the Ashes produced in Lignite-fired Power Plants, *J. Environmental Radioactivity, 77*: 233-246

National Development Planning Agency (BAPPENAS). 2014. Medium-Term Economic Infrastructure Strategy–Background *Report for RPJMN*, 2015–2019. Jakarta

Papp, Z., Dezso, Z., Daroczy, S. (2002). Significant Radio-active Contamination of Soil around a Coal-fired plant, *J. Environmental Radioactivity, 59*: 191-205.

Papastefanou, C. (2010). Escaping Radioactivity from Coal-fired Plants (CPPs) due to Coal burning and the associated hazards: a review, *J. Environmental Radioactivity, 101*: 191-200

Presidential Regulation No. 5/2006 on National Energy Policy of Indonesia (dated January 25, 2006).

Syarbaini, Kusdiana, Iskandar, D. (2015). Concentration of Natural Radionuclides in Soil and Assessment of External Exposure to the Public in Bangka-Belitung Islands Indonesia, *International Journal of Sustainable Energy and Environment, 3 (1)* : 1 – 11.

Syarbaini, Setiawan, A. (2015). Terrestiral Gamma Radiation Exposure in Bangka-Belitung Islands, Indonesia, *Atom Indonesia Journal 41 (1*) : 41 – 45.

UNSCEAR, 2000. United Nations Scientific Committee on the Effects of Atomic Radiation 1993. Sources, Effects and Risks of Ionizing Radiation. United Nations, New York.