IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Design & Nature and Ecodynamics
Vol. 19, No. 2, April, 2024, pp. 699-704
Journal homepage: http://iieta.org/journals/ijdne

Particulate Matter (PM) Levels and Associated Health Risks at the Indonesian National Nuclear Energy Agency

Elanda Fikri[1,2], Yura Witsqa Firmansyah[3,4*], Sari Arlinda[5], Tantin Retno Dwidjartini[6], Muhamad Yasin Yunus[7], Evan Puspitasari[8]

[1] Department of Environmental Health, Bandung Health Polytechnic, Bandung 40171, Indonesia
[2] Center of Excellence on Utilization of Local Material for Health Improvement, Bandung Health Polytechnic, Bandung 40171, Indonesia
[3] Department of Health Information and Medical Record, Vocational Faculty of Santo Borromeus University, West Bandung Regency 40553, Indonesia
[4] Environmental Science Doctoral Program, Graduate School of Sebelas Maret University, Surakarta 57126, Indonesia
[5] Department of Environmental Health, Health Polytechnic Ministry of Health Padang, Padang 25146, Indonesia
[6] Directorate of Research and Innovation Infrastructure Partnership Strengthening, National Research and Innovation Agency, Jakarta Pusat 10340, Indonesia
[7] Research Center for Radiation Process Technology, Research Organization for Nuclear Energy, National Research and Innovation Agency, Jakarta 10340, Indonesia
[8] Directorate of Partnership and Infrastructure Strengthening Research and Innovation, National Research and Innovation Agency, Jakarta 10340, Indonesia

Corresponding Author Email: yurawf@student.uns.ac.id

https://doi.org/10.18280/ijdne.190237

Received: 1 February 2024
Revised: 10 March 2024
Accepted: 20 March 2024
Available online: 25 April 2024

Keywords:
air pollution, air quality, health impact, particulate matter, workplace air quality

ABSTRACT

Air quality is one of the challenges to public health. Poor air quality is caused by the presence of air pollutants. WHO mentions particulate matter (PM) as one of the main pollutants. These pollutants have varied toxicity that can threaten public health. This study aims to measure PM pollutants. This study is an effort to monitor and improve air quality in the workplace. This study falls into the descriptive category, with a focus on detailing the levels of $PM_{2.5}$ and PM_{10}. The research design chosen was cross-sectional. The quantitative data collected shows the concentration of PM collected on filter paper. Sampling was carried out at six points (environmental health laboratory, radiochemistry laboratory, basement, sauna, facilities for Technologically Enhanced Natural Radioactive Material (TENORM) testing, and a parking lot) at the Indonesian National Nuclear Energy Agency by grab sampling. Air sample measurements were carried out using the direct method using the DustTrak DRX-8533 TSI tool with an MCE filter. The overall measurement results of PM concentrations exceeded the established quality standards. The highest concentrations of PM_{10} and $PM_{2.5}$ were 18.24 mg/m^3 outdoors. This can occur due to anthropogenic activities such as various human, household, and machine activities. Exposure to PM can cause respiratory problems (clinical codification category J00-J06 and its derivatives). Several ways can be done such as cleaning the office workspace in the morning and evening using a wet mop or vacuum pump. Air quality in the workplace needs to be monitored to create a healthy work environment and health.

1. INTRODUCTION

A public health critical concern is air quality. Approximately 91% of lower-middle-income countries experience air quality problems [1]. Decreased air quality is affected by air pollution. Air pollution can be defined as the presence of one or more pollutants outdoors, i.e. in the atmosphere, in quantities, and for a while sufficient to affect human, plant, and animal life, commercial or personal property, and environmental quality. Air pollutants that cause air pollution can be broadly classified based on their source of formation, whether or not they originate from living matter and their chemical structure. The World Health Organization (WHO) announced particulate matter (PM), Ozone (O_3), Nitrogen Oxides (NO_2), and Sulfur Dioxide (SO_2) are the main sources of pollutants [2]. This research focuses on PM pollutants, which are the main parameters for assessing air pollution. PM is composed of smoke, sulfate, sodium, mineral dust, nitrate, soot, dirt, water, and ammonia [3], which have high permeability to enter the human respiratory system. One of the sources of these pollutants is from the combustion of fossil fuels [4].

In terms of particle size, PM has two types of sizes, namely 2.5 and 10 µm (micrometers), which are often used as pollutant standards. $PM_{2.5}$ contains various complex elements such as Pb, Al, Na, Fe, K, Cl, Mg, Si, S, Ca, Sc, Ti, V, Cr, Mn, Co, Cu, Ni, Zn, As, Se, Br, Ba, P, and Hg [5]. Meanwhile, PM_{10} is a combination formed from liquid and solid air-suspended matter [6]. The ability of very small particles, PM can penetrate respiratory organs, which can cause public health problems if exposure occurs latently [7, 8]. PM has been shown to contribute to increased cases of death from heart and lung disorders [6, 9].

Particulate matter Natural sources of PM involve volcanic activity, aerosols, sea salt, wind-blown soil particles, fires, desert sand, organic matter, and microorganisms [10]. Anthropogenic resources, on the other hand, include dust generated from the activities of cement plants, thermal power plants, metal industries, construction works, mining activities, vehicles; fly ash formed due to the combustion of coal and petroleum derivatives, and finally, the particles dispersed into the atmosphere during agricultural activities [10]. Among these resources, especially those of anthropogenic origin, generally have small particle sizes and are considered more harmful to human health [11].

We can categorize PM based on its aerodynamic diameter as PM_1-$PM_{2.5}$-PM_5-PM_{10}. Regarding aerodynamic diameter, particles with a diameter of 10-2.5 μm are called coarse particles, while particles with PM ≤ 2.5 μm are called fine particles, and particles with PM ≤ 0.1 μm are called ultrafine particles. Coarse particles of PM_{10} and above are mostly formed through mechanical processes, while fine particles are formed as a result of exhaust gas and photochemical activity [12]. Particles smaller than 0.1 μm behave like molecules, constantly moving randomly [13]. Regardless of size, sooner or later particles will return to the earth through wet and dry deposition mechanisms. Particles that return to the earth's surface due to the force of gravity are called sedimentation. When particles collide in the air, they can come together to form larger particles, in a process called coagulation. Due to their increased density, coagulated particles return to the earth more easily [14].

PM, as an atmospheric pollutant, poses a variety of environmental problems. PM is detrimental to homes, property, soil, plants, and people. If we examine the adverse effects of airborne PM on human health, we can conclude that these effects have a linear relationship with particle size. PM particles ≥ 10 μm can be absorbed by the nasal passages and upper respiratory tract, while PM particles ≤ 2.5 μm can accumulate in the pulmonary bronchi [15]. In addition to its ability to absorb heavy metals such as mercury, lead, cadmium, and carcinogenic chemicals, this PM, which contains toxic-carcinogenic chemicals, can pose health risks. Matter (PM) is one of the pollutants consisting of a complex mixture of particles such as dust, dirt, soot, smoke, and liquid droplets found in the air with a fairly small size [16]. $PM_{2.5}$ (inhalable fine particulate matter) is particles ≤ 2.5 μm in size, with its main sources coming from combustion, cigarette smoke, nuclear industry, cooking with firewood, and agricultural activities. $PM_{2.5}$ is respirable dust that can be retained from the bronchiolus terminals to the alveolus, so it is the most dangerous dust [17]. Health effects caused by particulate matter include premature death in people with heart and lung disease, heart attack, irregular heartbeat, asthma, decreased lung function, and increased respiratory symptoms such as irritation of the respiratory tract, coughing, and difficulty breathing [18, 19].

This study aims to measure the concentration of PM pollutants in the work area of the Indonesian National Nuclear Energy Agency. The concentration of PM in the air has an important role in health impacts for workers. The description of these concentrations will be considered by the agency in monitoring and improving air quality in the workplace.

2. METHOD

This study falls into the descriptive category, with a focus on detailing the levels of $PM_{2.5}$ dan PM_{10}. The research design chosen was cross-sectional. The quantitative data collected shows the concentration of PM collected on filter paper.

The investigation was conducted at BRIN (Badan Riset dan Inovasi Nasional), an Indonesian government agency tasked with coordinating, developing, and promoting research and innovation in various sectors. The study covered indoor locations, such as the environmental health laboratory, radiochemistry laboratory, and basement. Outdoor areas include a sauna, facilities for Technologically Enhanced Natural Radioactive Material (TENORM) testing, and a parking lot.

Point 1 is the Environmental Safety Lab where service activities are carried out to measure radionuclide concentration levels in various types of media/materials. This laboratory activity uses various types of chemicals. Potential hazards exist in chemicals that can be inhaled by laboratory staff. Point 2 is the Radiochemistry Lab where analysis and research activities using radioactive compounds are carried out. Radioactive exposure can occur in internal exposure and external exposure caused by radionuclides used in analysis and research. Potential hazards that have high health effects can be caused by internal exposure, which can occur through inhalation of radioactive particles in the air. Point 3 is a room where samples are tested using a gamma spectrometer. The condition of the room has no windows because the room is located in the basement of the building, with air circulation using exhaust. Point 4 is the shelter area. The saung area is a storage area for motorized vehicles, used as a place to cull research mice. Motorized vehicles can produce particulate dust from combustion, and the rotation of vehicle wheels can cause particles on the ground to fly and contaminate the air. Because the saung area is a former place to destroy mice that have been used in research, it can be contaminated with radioactivity used in the mice research. Point 5 is the Tenorm Test Facility. In the tenorm facility test area, radioactive particle contamination can occur in the environment. Point 6 is the parking area. The parking area is a place where motorized vehicles pass, the incomplete combustion of motorized vehicles will produce airborne particulates besides that tire rotation will cause dust from the ground to float in the breathing zone.

Areas that have the potential for particulate dust contamination are determined as sampling points for air sampling using the grab sampling method. The sampling method is easy to carry out and does not require complicated equipment. This makes it ideal for use in field studies and routine monitoring. In addition, grab sampling can be done quickly, allowing the measurement of PM concentrations in a short period of time. This can be useful for monitoring changes in PM concentrations in real-time. Air sample measurements were carried out using the direct method using the DustTrak DRX-8533 TSI tool with an MCE filter. DustTrak is an aerosol monitor tool used to capture dust with a diameter of 10 μm;

2.5 μm; and 1 μm. This tool is a portable instrument that can be operated using batteries and with a laser photometer technique that can measure and record dust concentrations in the air. DustTrak is a suitable tool used to determine the concentration of dust in the air. Measurements were taken at six predetermined sampling points, three sampling points for indoor air quality and three sampling points for outdoor air quality, and measurements were taken for eight working hours.

3. RESULTS AND DISCUSSION

The measurement of $PM_{2.5}$ PM_{10} particulate dust concentration was carried out at six sampling points consisting of three indoor and outdoor points. Each sampling point was measured three times for eight hours. Measurements using the DustTrak DRX-8533 TSI tool with an MCE filter. The measurement results were compared with the threshold values set in. Minister of Health Decree No. 1405/Menkes/SK/XI/2002. The measurement results are presented in Table 1 and Table 2.

Based on observations made at the six sampling locations, dust comes from employees carrying particulates from shoes, clothes, and jackets; dust comes from samples to be tested; poor air exchange systems; dust comes from the soil and dust originating due to the rotation of vehicle tires so that dust on the ground will experience rotation and rise into the air; dust originating from the combustion of motor vehicles; dust originating from cooking activities; particulate dust from burning garbage; and dust originating from workshop activities.

Table 1. Measurement results of PM_{10} particulate dust concentration in the work area of the radiation safety and metrology technology center

	Sampling Location	**Average Measurement Results Eight Hours (mg/m^3)**			**Average (mg/m^3)**	**Threshold Limit**
		Day 1	Day 2	Day 3		
Indoor	Point 1	1.18	1.30	1.36	1.28	< 0.15 mg/m^3
	Point 2	1.37	1.38	1.41	1.39	
	Point 3	1.50	1.78	1.79	1.69	
Outdoor	Point 4	1.87	1.63	1.73	1.74	
	Point 5	1.81	1.70	1.76	1.76	
	Point 6	17.94	18.5	18.27	18.24	

Table 2. Measurement results of $PM_{2.5}$ particulate dust concentration in the work area of the radiation safety and metrology technology center

	Sampling Location	**Average Measurement Results Eight Hours (mg/m^3)**			**Average (mg/m^3)**	**Threshold Limit**
		Day 1	Day 2	Day 3		
Indoor	Point 1	1.17	1.30	1.35	1.27	< 0.035 mg/m^3
	Point 2	1.03	1.38	1.40	1.27	
	Point 3	1.49	1.78	1.78	1.68	
Outdoor	Point 4	1.87	1.62	1.73	1.74	
	Point 5	1.80	1.70	1.75	1.75	
	Point 6	17.92	18.4	18.4	18.24	

Anthropogenic particulate matter emissions start with various human activities, such as fossil fuel combustion, industry, transportation, agriculture, and household activities. For example, gases and particles released from vehicle exhaust, dust from construction, or smoke from factories are common types of emissions. The combustion of fossil fuels, such as coal, oil, and natural gas, is a major source of particulate matter emissions. The combustion process produces exhaust gases containing compounds such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO) [20]. In addition, incomplete combustion conditions and oxidation can produce solid particles. The released exhaust gases then react in the atmosphere with other existing compounds. For example, SO_2 can react with oxygen and water in the atmosphere to form sulfuric acid (H_2SO_4) [21]. This process creates conditions that favor the formation of solid particles through oxidation and condensation. The particles formed can then become aerosol nuclei, which are particle nuclei that can attract other compounds to adhere to them. Aerosolization and transport by airflow, wind, or human activities such as vehicles and industry, carry these particles to various locations in the atmosphere. The particles formed can undergo growth through condensation of gases and water vapor in the atmosphere. For example, condensation of water vapor on sulfate particles can form larger particles. Once formed, PM particles can be transported and dispersed in the atmosphere. Rain and other natural processes can remove particles from the atmosphere through gravitational deposition. Furthermore, PM particles can undergo resuspension, which means they are lifted back into the air through strong winds or human activity. Dust that has settled on roads, for example, can be resuspended by vehicle traffic or construction activities. Through this series of mechanisms, anthropogenic particulate matter is formed, transformed, and dispersed in the air [22]. A thorough understanding of these mechanisms helps in the development of effective emission control policies and technologies to reduce their negative impacts on human health and the environment.

The formation of soil-derived dust and dust generated by vehicle tire rotation is a phenomenon that occurs due to the interaction between the soil surface and transportation activities. When the soil is not covered or protected by vegetation, especially in dry or wind-affected areas, soil particles can easily be lifted into the air. At the same time, the rotation of vehicle tires on the road surface can trigger the release of fine particles from asphalt, metal, or other materials on the road. This process creates conditions where dust originally attached to the ground can be picked up and swirled in the air, creating visible dust plumes [23-25].

The formation of dust from poor air exchange systems is the result of several factors that contribute to the accumulation of small particles indoors. Inadequate air exchange system conditions can create an environment where dust can be trapped and linger for longer periods. A poor air exchange system is usually characterized by a lack of fresh air circulation and the removal of dirty air from the room. Without adequate air circulation, dust particles generated by various sources can remain trapped indoors. An under-ventilated room can also hinder the removal of contaminated air, allowing dust to settle on various surfaces. This condition is exacerbated by the low efficiency of the ventilation system or the availability of windows and doors that can be opened to allow fresh air flow. Heating, ventilation, and cooling (HVAC) systems that are poorly maintained or not customized to the needs of the space can also contribute to an imbalance in air exchange, increasing the likelihood of dust formation. In addition, internal dust sources, such as human skin flakes, construction dust, or particles from furniture materials, can contribute to the formation of dust in the room. External factors, such as dust entering from outside through cracks or vents that are not sealed, can also worsen the situation. When fresh air does not properly replace polluted air, dust particles can settle on the surfaces of indoor objects, including walls, furniture, and furnishings. Over time, dust can be lifted back into the air through human activity or changes in air conditions, such as wind movement or flow. In the long run, dust build-up from poor air exchange systems can hurt the health of indoor occupants and the air quality within [26-28]. Therefore, it is important to ensure adequate air exchange, maintenance of a good ventilation system, and general cleanliness of the space to reduce dust generation and maintain indoor air quality.

Dust from the soil can contain minerals, microorganisms, or organic matter, while dust from vehicle tire rotation can contain chemical compounds from asphalt or metal. Over time, these particles can reach atmospheric levels and potentially have an impact on the surrounding air quality. This can be exacerbated by factors such as dry weather, frequency of vehicle traffic, and road surface conditions [28, 29].

The formation of dust from the sample to be tested involves several factors and mechanisms, depending on the type of sample and its condition. The process of dust formation can vary from physical activity, natural processes, or interaction with the environment. Samples that have a rough texture or are mechanically unstable tend to produce more dust [30]. Shifting or physical activity on the sample can cause small particles to be released. Moisture in the sample can affect the ability of particles to bond with each other. Dry samples tend to produce more dust than moist ones. Samples that have aerosolized properties can produce dust when exposed to wind or airflow [31, 32]. This can happen, for example, with powdered samples or fine powders. Samples that undergo oxidation or certain chemical reactions can produce smaller particles that can then form dust [33].

Waste combustion is a complex process in which a certain amount of particulate matter is formed as a result of the chemical and physical reactions that occur during combustion. When waste is exposed to heat, the organic material in the waste undergoes pyrolysis or initial combustion, producing gases and small particles. This combustion is often incomplete, and gases that have not been fully combusted may form, along with large particles, especially in open burning conditions. The process of aerosolization occurs when the resulting gases undergo rapid cooling and condensation, forming particles that are dispersed in the air as aerosols [34]. During combustion, oxygen in the air interacts with various organic and inorganic compounds in the waste, producing oxide compounds and other chemical compounds. The resulting particles can be transported by the wind, causing the dispersion of dust particles into the surrounding environment. In addition, the particles can undergo deposition processes and settle on soil, water, or the surfaces of surrounding objects. As a result, particulate matter generated from waste combustion can have negative impacts on human health and the environment, especially very small particles ($PM_{2.5}$) that can enter the respiratory tract and potentially cause respiratory problems and other health impacts [35-37]. Therefore, managing waste incineration with clean technologies and sustainable disposal practices is crucial to reduce its negative impacts.

Particles enter the human body mainly through the respiratory system. Therefore, direct adverse effects mainly occur in the respiratory system. The factor that affects the severity caused by particles is the size of the particles because the particle size determines the extent of particle penetration into the respiratory system. The respiratory system has a defense system that prevents the entry of large particles, while smaller particles will be prevented from entering by the mucous membrane which is located along the respiratory system and is the surface to which particles stick [38]. In some parts of the respiratory system, there are fine hairs (cilia) that move back and forth together with the mucosa to form a flow that carries the particles it catches out of the respiratory system to the throat, where the particles are swallowed [39, 40]. Particles larger than 5 μm in diameter are stopped and collected mainly in the nose and throat. Although these particles can partially enter the lungs, they never go further than the air sacs or bronchi and are immediately expelled by cilia friction. Particles that are 0.5-0 μm in diameter can collect in the lungs up to the bronchioli and only a small proportion reach the alveoli [41, 42]. Most of the particles collected in the bronchioli will be expelled by the cilia within 2 hours. Particles less than 0.5 μm in diameter can reach and stay in the alveoli. Clearance of these very small particles from the alveoli is very slow and incomplete compared to that in the larger ducts. Some particles that remain in the alveoli may be absorbed into the blood [43, 44]. The limitations of this study did not measure the relationship of particulate matter to worker health. So that the presence of pollutants inside and outside the room is only descriptive of air quality.

4. CONCLUSIONS

Air quality plays an important role in the environment and occupational health. Particulate matter measurements are carried out as a form of monitoring air quality in the workplace. $PM_{2.5}$ and PM_{10} concentration levels at all six sampling points exceeded the threshold limit (PM_{10} < 0.15 mg/m^3; $PM_{2.5}$ < 0.035 mg/m^3). The PM_{10} highest concentration level at point 3 (basement room) is 1.69 mg/m^3 in indoor air measurements, and at point six (parking area) is 18.24 mg/m^3 in outdoor air measurements. The $PM_{2.5}$ highest concentration level at point three (basement room) is 1.68 mg/m^3 in indoor air measurements, and at point six (parking area) is 18.24 mg/m^3 in outdoor air measurements. Control of particulate dust contaminants based on the recommendations of the Decree of the Minister of Health number 1405 / Menkes / SK / XII / 2002 in control efforts, several ways can be done such as cleaning the office workspace in the morning and evening using a wet mop or vacuum pump, especially in hours that have high concentrations of particulate dust; opening windows, so that natural air exchange occurs; monitoring temperature and humidity; using laboratory shoes, when working, and cleaning shoes periodically. Further research should assess the impact of indoor and outdoor air quality on workers' health.

ACKNOWLEDGMENT

The authors would like to thank the Bandung Health Polytechnic; National Research and Innovation Agency; and Santo Borromeus University.

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