ISSN 2349-7203
IJPPR
INTERNATIONAL JOURNAL OF PHARMACY & PHARMACEUTICAL RESEARCH
An official Publication of Human Journals
HUMAN

Human Journals
Research Article
October 2020 Vol.:19, Issue:3

Changes in Environmental Radiation Dose on the University Campus

IJPPR
INTERNATIONAL JOURNAL OF PHARMACY & PHARMACEUTICAL RESEARCH
An official Publication of Human Journals
ISSN 2349-7203
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Submission: 22 September 2020
Accepted: 28 September 2020
Published: 30 October 2020

HUMAN JOURNALS

www.ijppr.humanjournals.com

Keywords: environmental radiation; university campus; airborne dust

ABSTRACT

We examined the factors that affect the environmental radiation dose on the Ike campus, University of Kochi, Japan. Environmental radiation dose, airborne dust concentration, air temperature, relative humidity, wind speed, and the number of parking spaces in the surrounding area were measured at five locations on the university campus (i.e., south parking space, athletic field ground, campus front entrance, shared rooftop, and west parking space). The results showed that environmental radiation depended more on the study location than on the date and time of the measurements. Such results were explained by the amount of radioactive contamination in the campus surroundings or radioactive particles transported from the neighboring regions. We concluded that soil-derived substances were the main cause of radiation on campus.

INTRODUCTION

The Great East Japan earthquake and tsunami occurred on March 11, 2011, and caused the release of radioactive materials at the Fukushima Daiichi Nuclear Power Station. Large amounts of radioactive materials (radionuclides) were released and diffused around the power plant and within and outside Fukushima prefecture[1)]. There are two types of radiation: artificial and natural. Artificial radiation is emitted due to the accidents at nuclear power plants, diffused from past nuclear test sites, and extremely small amounts are emitted from nuclear facilities during their regular operations[2)]. Medical uses of artificial radiation include X-rays and CT scans.

Natural radiation is represented by radioactive materials in rocks, soil, food, space, and soil diffused in the air[2)]. In daily lives, people in Japan receive an average annual radiation dose of 0.38 mSv from the earth, 0.29 mSv from cosmic rays, 0.41 mSv from food and drinks, and 0.40 mSv from the air[3)]. The dose of cosmic rays increases at higher altitudes[4)], and the radiation dose varies depending on the geological situation of the region. For example, granite contains high concentrations of natural radioactive substances, such as uranium, thorium, and potassium-40. As such, if granite flooring is used in houses, radiation exposure can be significantly elevated[5,6)].

Environmental radiation is a mixture of both artificial and natural radiation emitted from dust particles floating in the air[6)]or being carried away by the wind[7)]. Such dust particles then fall and are eventually deposited[7,8)]on the ground with rain or snowfall. Radioactive substances are known to be distributed in simple concentric circles. Aoyama et al. state that radiation diffusion patterns vary depending on wind direction, weather conditions, and terrain[9)]. It is crucial to understand how the airborne dust concentration, wind, and weather patterns affect the radiation dose variations and the formation of areas with higher radiation levels, the so-called hot spots. Several hot spots have been formed in Japan after the Fukushima Daiichi Nuclear Power Station accident[10)].

In recent years, most Japanese studies related to measuring environmental radiation have been focused on the 2011 Great East Japan earthquake, and much attention has been paid to the radioactive material scattering after the Fukushima Daiichi Nuclear Power Station accident. We investigated the variations in radiation levels after the Great East Japan earthquake on the university campus (outdoors), similar to many previous studies. However, few previous studies have investigated radiation dose changes at the same location, depending on the seasons and times of the day. Herein, we measured radiation on the Ike campus, University of Kochi, Japan, to reveal how radiation dose changes depending on the measurement location, season, and time of day. We also simultaneously monitored other environmental parameters, especially those that might affect the level of radiation.

METHODS

Measurement locations

The study was conducted at five locations on the Ike campus, University of Kochi: south parking space, athletic field, campus front entrance, shared rooftop, and west parking space. The south parking space is covered by asphalt and extends from north to south. The cars are parked on the eastern and western sides of the space using over 100 parking spaces. The northern side of the parking space is protected by a building, which easily blocks the northern winds. The athletic field consists of soil and a constructed floor for exercises. The existing buildings on the south side of the athletic field do not block the wind flow. The campus front entrance is a U-shape with the south side open, which permits the wind flow. This measurement location is surrounded by 12 parking spaces. The campus entrance is made of stone and the parking floor consists of soil. The shared rooftop has the floor made of concrete and the plants located along its perimeter so that nothing blocks the wind from the surroundings. The west parking space is characterized by approximately 65 parking spaces, and the floor is covered by asphalt, with the cars parked along its southern and northern sides. The mountains surround the western and northern sides of the west parking space, while the buildings located on the northern and southern sides effectively block the wind from the surroundings.

Equipment

In this study, we measured the following six parameters: environmental radiation dose, airborne dust concentration, temperature, relative humidity, wind speed, and the number of parked vehicles. Environmental radiation was measured in μSv/h for 1 min using a radiation meter (PA-1000, Horiba Co., Kyoto, Japan). Radiation measurements were recorded in two directions (i.e., northern and southern) at180° forward. The value averaged for both directions was then used as the radiation value at that location. To prevent contamination from a radiation substance adhered to the equipment, the radiation meter was covered by a vinyl bag and discarded immediately after use. Airborne dust concentration was measured in mg/m^3 for 1 min in the northward and southward directions using a digital dust meter (ME-C101A; Andes Electric Co., Aomori). The value averaged for both directions was used as the airborne dust concentration value at that location. The temperature in °C, relative humidity in %, and wind speed in m/s were measured using a multi-functional anemometer (TM-413, Tenmars, Taiwan). After detecting the predominant wind direction, the device was turned upwind to take the measurements for 1 min, and the median value was used for later calculations.

General conditions for the measurements

To confirm the seasonal variations in radiation dose, the measurements were recorded approximately every two weeks from May 2019 to October 2019, excluding the summer vacation period. To examine the variations in radiation dose depending on the time of day, we took measurements in the morning (starting around 8:00), in the daytime (starting around 10:30), and in the evening (starting around 17:00). Because radioactive materials fall and get deposited on the floor due to rainfall[7,8], we also recorded the weather conditions at the time of the measurement and the day before. Table 1 presents information on the measurement dates, measurement start time, and weather conditions. On August 8, 2019, we took three measurements on the same day: in the morning, at noon, and in the evening to investigate daily variations in environmental radiation. The measurements were taken in the same order throughout the study period: south parking space → athletic field → west parking space → shared rooftop → campus front entrance. Each round of measurements took approximately 30 min. The environmental radiation dose, airborne dust concentration, temperature, relative humidity, and wind speed were measured at the height of 1 m. To reduce the measurer's deviation from the data, the operator of the equipment was changed daily. The number of parked cars was visually counted at the time of the measurement within a radius of 10 m from the measurement location.

RESULTS AND DISCUSSION

Variations by place

The radiation dose measurement results are shown in Fig. 1. The maximum difference of 2.3 times (0.035 μSv/h) existed between the highest and the lowest measured radiation doses. The highest value was estimated at the campus front entrance, followed by the shared rooftop and athletic field. The same tendency was observed on all measurement days. The lowest value was acquired either in the south parking space in the west parking space, depending on the measurement date (not shown in figures or tables). We reason that such a difference in values between the two parking spaces was due to the contribution by a fixed or moving source with a continuously high radiation dose at a short distance to the measurement site.

We consider that the highest value measured at the campus front entrance was due to the presence of radioactive materials in the soil forming the floor of the surrounding parking space. The shared rooftop floor made of concrete showed the second-highest radiation dose after the campus front entrance location. We suggest that such a high radiation dose at the shared rooftop was caused by the surrounding plants and associated soil movement. The athletic field flooring consists of soil, but we think that its soil quality differs from the other two locations the floors made for exercise[11)] with a low content of radioactive substances. The south and west parking spaces presented the lowest radiation doses compared to the other three locations. This is probably due to the asphalt floor with a negligible scattering of soil-derived radioactive materials.

We presume that predominantly radioactive materials derived from the soil and soil movement influenced changes in the radiation doses depending on the measurement site. For example, Fig. 2 shows no significant difference in the amount of dust between the measurement sites. Moreover, we did not record any high radiation doses on days with abundant dust. As such, we conclude that the measured radiation was received not only from the radioactive material adhered to the suspended dust particles but also from the radioactive material deposited on the floor.

Another reason for the radiation dose differences between the measurement sites is the particle size: the smaller the particle size, the greater the adsorption capacity for radioactive substances[8)]. As such, the amount of attached radioactive material differs depending on the size of the suspended dust particles, and the radiation dose does not necessarily increase when the suspended dust concentration is high. The dust measuring equipment used in this study was unable to distinguish the particle sizes and only measured the dust total weight.

Variations within a day

We compared the morning, noon, and evening radiation doses from August 8, 2019, to reveal daily radiation dose variations. The obtained results are shown in Fig. 3. We observed minimal changes in radiation dose in the west parking space, a change of approximately 1.4

times (0.010 μSv/h) in the south parking space, and a change of approximately 1.2 times (0.009 μSv/h) on the shared rooftop. The west parking space is surrounded by buildings and mountains, prohibiting the wind flow. The south parking space and shared rooftop have no associated obstacles to the wind. Therefore, we consider that those large daily variations in radiation doses occurred in places with free movement of radioactive materials, especially of airborne dust. This conclusion is consistent with the results presented in Section 3-1.

In terms of the temperature variation, it was significant at the campus front entrance and west parking space, dissimilar to the variation in radiation dose (not shown in figures or tables). We did not register any significant differences in the relative humidity with the measurement location, and no correlation with changes in radiation dose could be made. Based on these facts, the influence of daily variations of temperature and relative humidity on radiation dose is minor.

Changes in radiation dose by season and time of day

The average radiation dose value was calculated for each measurement site and time of day and was later compared as the variation by season. There was no significant difference in the average daily radiation dose compared with the intra-daily variations. Although air temperature varies greatly with the time of day, the radiation dose did not change significantly, demonstrating that the influence of the air temperature on the radiation dose was inappreciable.

We calculated the monthly average radiation dose and analyzed it seasonally (not shown in the figure). The difference between the highest and the lowest average radiation doses was 1.25 times (0.009 μSv/h) for the athletic field, 1.19 times (0.009 μSv/h) for the shared rooftop, 1.16 times (0.005 μSv/h) for the south parking space, and approximately 1.1 times (0.003 μSv/h) for the campus front entrance and west parking space. Similar to the results of the daily variation in radiation dose, the monthly averaged values were higher in places with no obstructions to the wind (e.g., athletic field, shared rooftop) and free movement of radioactive materials. We also noted that the temperature varied substantially in the west parking space, where the monthly average radiation dose hardly changed. As such, the temperature did not influence monthly variations in radiation.

Effect of other measured parameters on radiation dose

Previous research published on radiation has stated that environmental radiation is partially shielded by the metal frame of the vehicle body and metal engine parts[12)]. The south parking space, campus front entrance, and west parking space are characterized by the presence of parked vehicles. As the radiation dose varies based on the number of parking spaces, we calculated the number of parking spaces surrounding the measurement sites (Fig. 4). We determined that changes in radiation dose were independent of the number of parked vehicles, likely due to the open measurement locations so that the shielding effect by the vehicle body was not obvious. That is, if the influence of radioactive substances on one side of the vehicle can be reduced, the influence on the other side cannot be prevented.

We recorded weather conditions at the time of the measurement and a day before (Table 1) due to the tendency of radioactive materials to be deposited by rain, resulting in higher radiation than on a sunny or cloudy day. We compared the radiation doses obtained on the rainy days (or when the previous day was rainy) and sunny or cloudy days (or when the previous day was sunny or cloudy). The average radiation dose was independent of the weather, probably due to the diminished concentration of airborne dust on the rainy days.

CONCLUSIONS

Our study results from the Ike campus, University of Kochi, Japan, showed that the radiation dose varied depending on the measurement site and time of day. High radiation measurements were recorded at the campus front entrance and shared rooftop, where the floor is made of soil (front entrance), or there is the soil around (shared rooftop). Even though the athletic field floor also consists of soil, it demonstrated low radiation doses, likely because the content of radioactive materials was distinct due to the difference in soil quality compared with the other two sites. The measured radiation doses were low at the south and west parking spaces, where the floor is made of asphalt and lacks soil. Accordingly, the radiation dose variation in each location depended on the number of radioactive materials in the soil.

We observed that daily and intradaily variations in radiation doses were negligible, and there was no apparent correlation between the temperature, relative humidity, and radiation dose. We consider that temperature and relative humidity had little effect on radiation dose changes. Radiation dose significantly varied in places where the wind could blow freely. As such, we conclude that the radioactive substances adhering to the suspended dust mainly influence variations in radiation doses.

In the future, we consider adding another campus measurement location. We think that the effect of environmental factors on the radiation dose can be evaluated better by analyzing data from another place, where the floor is made of soil or with the stagnant wind flow. Although the radiation dose measured at the campus front entrance was high, we aim to confirm whether it was due to the influence of the nearby soil or suspended dust.

ACKNOWLEDGEMENTS

The authors would like to thank Kuroishi a 4th-year student of the Health Ecology Laboratory, University of Kochi whose thesis formed the research base. We also thank the students enrolled in the Health Ecology Laboratory in 2019 for their participation in the environmental measurements.

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Table No. 1: Measurement dates and weather conditions

Number	Date	Time	Weather on the day	Weather on the day before
1	May 30	Morning	Sunny	Cloudy
2	June 12	Noon	Sunny	Sunny
3	June 24	Evening	Sunny	Cloudy
4	July 8	Noon	Cloudy	Sunny
5	July 22	Morning	Rainy	Cloudy
6	August 8	Morning	Sunny	Rainy
7		Noon		
8		Evening		
9	October 11	Noon	Sunny	Sunny
10	October 24	Evening	Sunny	Rainy

Measurement time intervals: morning, 8:00–8:30; noon, 10:30–11:00; and evening, 17:00–17:30.

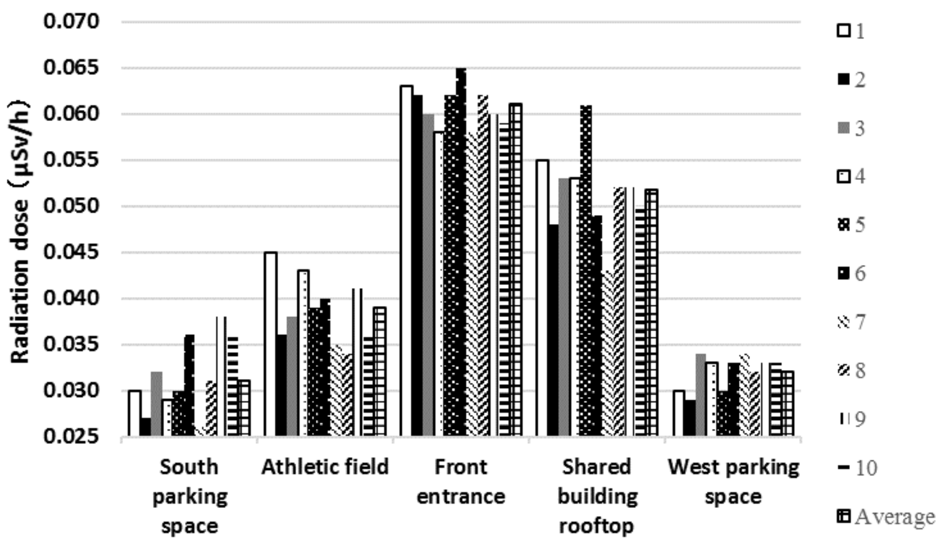

Figure No. 1: Variations in radiation dose depending on the measurement site

The annotation numbers indicate the measurement numbers in Table 1.

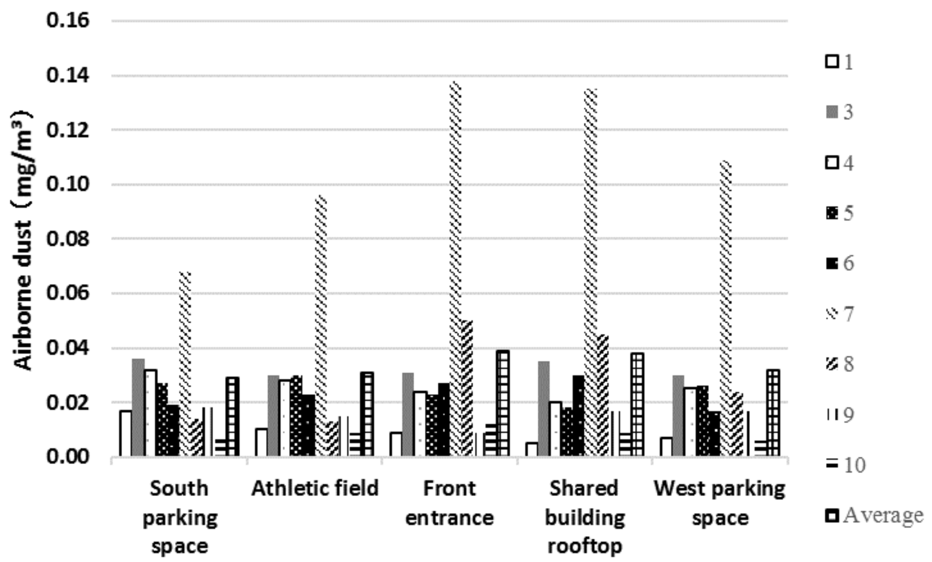

Figure No. 2: Variations in suspended dust concentration depending on the measurement site.

The annotation numbers indicate the measurement numbers in Table 1.

No. 2 data could not be acquired due to equipment failure.

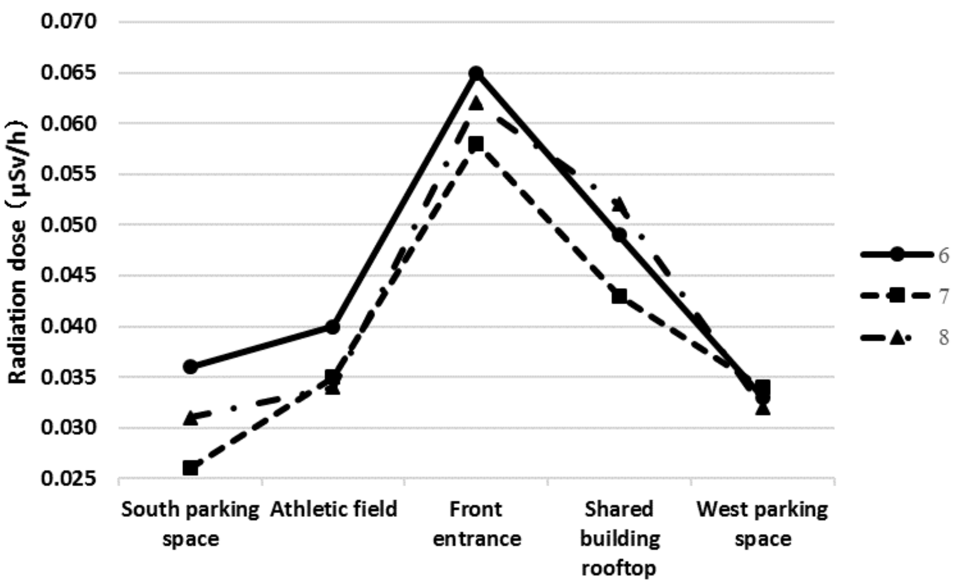

Figure No. 3: Daily variations in radiation dose depending on the measurement site

The annotation numbers indicate the measurement numbers in Table 1.

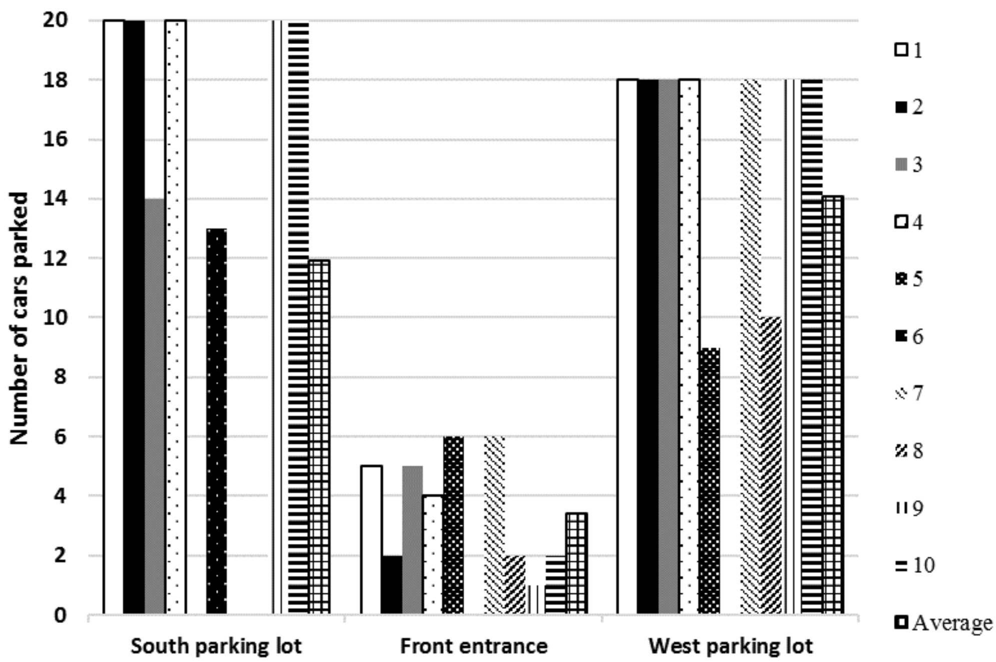

Figure No. 4: Number of parked cars within 10 m of the measurement site

The annotation numbers indicate the measurement numbers in Table 1.