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Study on Variation of Environmental Radiation Dose in Tunnels

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ABSTRACT

We previously measured the radiation dose in several tunnels in Kochi prefecture and examined the differences according to the various locations (outside, entrance, and inside) in the tunnel. Only one tunnel exhibited a tendency that deviated from the general trend. Generally, the radiation dose is high inside the tunnel; however, no difference between the exit and the interior of the tunnel is observed. We examined the reason for this difference in radiation doses in different areas of the tunnel in the current study. In a previous study, it was thought that the radiation dose was higher inside the tunnel because the tunnel space was surrounded by numerous rocks and contained a large amount of radioactive substances. It was inferred from this result that the radioactive material contained in the dust enters the tunnel via wind action and stays there. This may cause the difference in radiation dose, depending on the position in the tunnel. From the results of our study, the strength of the wind appears to depend on the inclination of the road in the tunnel, the direction of the natural wind, and the traveling direction of the vehicle. This conclusion is consistent with previous results.

INTRODUCTION

Tunnels exist on flat land, underwater rivers, seas, and mountainous areas in order to traverse roads, railroads, and waterways[1]. Currently, tunnels are being dug in various places to support the movement of people and the transportation of materials, thereby improving our lives.

In a previous report[2], we focused on the east and west sides of three tunnels in the southern part of the Kochi prefecture (six tunnels in total). Environmental measurements, including environmental radiation, were obtained to determine the environmental characteristics inside the tunnel and compare them with those outside the tunnel. The results showed that only the west side of one tunnel had a different radiation dose inside the tunnel than that outside the tunnel, wherein the inside had a lower dose. Therefore, herein we focus only on the east and west sides of this tunnel to determine the causes of this varied environmental radiation dose.

Because the inside of the tunnel is a semi-closed environment where air is stagnant, as compared with the outside, it is considered to have unique environmental characteristics. Previous studies regarding environmental measurements in tunnels include reports of environmental radiation doses measured in various parts of Japan, wherein the effects of the 2011 Fukushima Daiichi Nuclear Power Station accident caused by the Great East Japan Earthquake are evaluated. It has been reported that in most cases, the air dose rate inside the tunnel tends to be higher than that outside[3-7]. This could be because of the surrounding ground and soil above the tunnel. Moriyama and Minato *et al.* reported that the air dose rate inside the tunnel was lower than that outside between Koriyama and Fukushima[8-9]. This could be because the soil surface is contaminated with radioactive materials from the reactor accident, which affects places near the outside of the tunnel, while radiation deep inside the tunnel is shielded by the thick bedrock[7]. The radiation dose in a tunnel tends to differ depending on the amount of naturally occurring radionuclides contained in the surrounding geology and the pollution status of the soil surface.

Therefore, in this study, we measured the environmental radiation, dust, wind speed, and traffic volume with reference to our previous report[2]. Note that our previous study is the only work that measures these parameters while simultaneously measuring the amount of environmental radiation in the tunnel. We believe that the results of this study will help us to further understand how radiation interacts with tunnels.

METHODS

Equipment

To measure the environmental radiation, a radiation meter (PA-1000, HORIBA, Saitama, Japan) was used, and measurements were taken according to manufacturer's guidelines. The light-receiving part of the device was pointed toward the measurement target, and a range of approximately 180° forward was measured over 1 min. In addition, to avoid the effects of contaminants adhering to the equipment, the radiation meter was placed in a plastic bag for measurements and discarded immediately after use[6]. Dust levels were measured for 1 min with the intake port of the digital dust meter (ME-C101A, Andes Electric, Aomori, Japan) facing the road side in accordance with the manufacturer's guidelines. The median wind speed was recorded using a multifunctional anemometer (TM413, TENMARS, Taiwan). All measurements were taken at a height of 1 m. In order to reduce the influence of the varied operation methods caused by the operator on the data bias, the device operator was changed every measurement day. The traffic volume was evaluated as the traffic volume within a certain period of time by recording the number of cars and motorcycles that passed from the entrance to the exit of the tunnel using a mechanical tally counter.

Measurement locations and conditions

The measurement locations are on the east and west sides of the B tunnel (two locations in total) in the southern part of Kochi City in the Kochi Prefecture. Both tunnels were made by mining the same mountain, but they were mined at different times (east side: 2000, west side: 1997). The tunnels are adjacent and extend to the north and south. The University of Kochi Ike Campus, Kochi Medical Center, and Kochi Nangoku Road (expressway) surround the tunnels. Table 1 summarizes the outline of the tunnels. The road gradients in the tunnels were calculated from map data with the assumption that the roads in the tunnels were flat and smooth, and unilaterally descended or rose from the altitude of the entrance to exit of the tunnel along the total length of the tunnel [11].

Measurements were taken at 6 sites spaced approximately 100 m apart, which included the entrance, exit, and 2 sites outside the tunnel placed approximately 100 m away from the entrance and exit based on the position of the emergency button in the tunnel. Measurements were obtained over 8 days in 2019: May 30, June 12, June 24, July 8, July 22, August 8, October 11, and October 25. The measurement start time was set to 3 patterns of 9:00

(morning), 12:00 (noon), and 18:00 (evening) to consider variations in traffic volume, with the exception of August 8, wherein measurements were taken three times in the morning, noon, and evening on the same day to observe the diurnal variation. The measurement order began on the south side of the B tunnel (west) to the north side, and then from the north side of the B tunnel (east) to the south side for all dates and times. The weather and time information for each measurement date is summarized in Table 2.

RESULTS AND DISCUSSION

Radiation dose inside and outside the tunnel

As shown in Fig. 1, the radiation dose in the B tunnel (east) tended to be higher in the tunnel than that outside, regardless of the day. Conversely, as shown in Fig. 2, the B tunnel (west) was not always higher inside the tunnel than the outside. This was also the same regardless of the day. Therefore, the eastern and western sides showed different tendencies, as is consistent with our previous findings[2]. Outside both tunnels, a similar radiation dose of approximately 0.05 μSv/h was detected. This may be because both tunnels run through the same mountain and are, to the same extent, affected by fixed sources. Previous studies found that the factors that cause different trends in radiation levels in tunnels differ depending on the amount of radionuclides contained in the surrounding geology and soil[3-9]. However, because the conditions of both tunnels were nearly identical, other factors must have an influence.

Radiation and dust

Half of the exposure dose from natural radiation is caused by radon, which attaches to dust in the atmosphere and moves[13-14]. Thus, it is presumed that the radiation dose increase in the B tunnel (east) is due to dust movement effects. We estimated that there was a correlation between the amount of dust and the radiation dose, and subsequently analyzed it. However, no significant correlation was found between the two tunnels (data not shown). The equipment used to measure the dust only measures the weight of the dust and not the size. Studies have shown that dust varies in particle size from 1 nm to 1 mm, and that radioactive substances are more often adsorbed on smaller particles[15-16]. Thus, we inferred that we did not find a correlation because the amount of attached radioactive material varies depending on the particle size.

Radiation dose and wind speed

There was a significant correlation between wind speed and radiation dose variations in both tunnels (B tunnel (east): r = 0.5; B tunnel (west): -0.3). It is presumed that there is more dust movement in the tunnel when the air volume is higher at high wind speeds, making it easy for dust inside to be carried outside. Herein, the wind speeds in the B tunnel (west) were faster than those of the B tunnel (east) at almost all points when compared on the same day, as shown in Fig. 3. This variation may be caused by the influence of wind direction and slope of the road in the tunnels.

Regarding wind direction, the wind speed is stronger in the B tunnel (west) because the wind generated by vehicles (south wind) and the natural monsoon wind are in the same direction. Thus, we assume that the large-particle dust that enters the tunnel is carried outside without remaining in the tunnel, which means that the radioactive material does not stay in the tunnel. In the B tunnel (east), the wind generated by vehicles (north wind) and the natural monsoon wind flow in opposite directions. Thus, the wind speeds negate each other, limiting their influence. Thus, radioactive substances are suggested to remain in the tunnel.

Regarding the slope of the road, the B tunnel (west) was approximately twice as high as that of the B tunnel (east) (Table 1). Therefore, the west side has faster wind speeds. Similarly, although they were not measured in this study, the four tunnels measured in our previous report had lower slopes than the B tunnel (east), as listed in Table 1. Therefore, we can infer that the wind speed becomes weak and the dust only moves slightly. Consequently, as radioactive materials remain in the tunnel, the environmental radiation level tends to be higher in the B tunnel (east).

CONCLUSION

Herein, we investigated the causes of different radiation dose trends on the east and west sides of the B tunnel from various perspectives. Based on the results of the roadside radiation dose, the inside of the B tunnel (east) tended to have higher radiation values than the outside, whereas the inside of the B tunnel (west) was not necessarily higher. As both tunnels run through the same mountain, they seem to be affected by a fixed source to the same extent. This is consistent with the fact that the radiation doses outside both tunnels are nearly identical. Therefore, it is presumed that the increase in radiation dose in the tunnel on the east side is caused by source movement, wherein radioactive material moves by adhering to dust.

Further, we found that the faster the wind speed and the larger the air volume, there is more dust movement inside the tunnel, meaning the radioactive dose does not remain in the tunnel. In this case, the wind speed of the B tunnel (west) is faster than that of the east side at all points of the same day. Thus, the difference in radiation dose may be caused by the difference in direction between the wind caused by vehicles in the tunnel and natural monsoon winds, and the inclination influence of the tunnel. The soil and concrete surrounding the tunnel are the fixed sources of environmental radiation in the tunnel. However, the radioactive substances that adhere to dust cause source movement depending on the wind direction, slope, and wind speed in the tunnel. Therefore, the environmental radiation amount in each tunnel is different because of the difference in the degree of source retention in the tunnels.

These results are contrary to those in our previous report[2]. Previously, we thought that the varied radiation amounts in the tunnels were due to the amount of radioactive material contained in the soil derived from the original mountain. However, this is not the case as the radiation amount distribution would not vary if the source was the mountain soil, which is inconsistent with previous research by Tagami, *et al*[5-6]. It is speculated that these findings were obtained because the concrete of the tunnel wall has a high radiation shielding effect, causing the tunnels to be uniformly affected by the fixed source.

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Table No. 1: Survey tunnel overview Tunnel names (A, B, and C) are the same as in the previous report[2].

Tunnel name	Year tunnel was built	Elevation (m)		Slope (%)	Length (m)
		North exit	South exit		
Tunnel B (east)	2000	18.1	23.5	1.2	445
Tunnel B (west)	1997	12.3	24.1	2.3	507
Tunnel A (east)	2013	13.3	8.5	0.6	819
Tunnel A (west)	2001	11.0	10.9	0.01	885
Tunnel C (east)	2002	7.4	10.7	0.7	490
Tunnel C (west)	1994	9.6	10.8	0.2	490

Table No. 2: Measurement date/start time, weather

Number	Date	Start time	Weather (measuring)	Weather (day before)
1	May 30	9：00	Sunny	Sunny
2	June 12	12：00	Sunny	Sunny
3	June 24	18：00	Cloudy	Cloudy
4	July 8	12：00	Cloudy	Cloudy
5	July 22	9：00	Rainy	Cloudy
6	August 8	9：00	Sunny	Cloudy
7		12：00	Sunny	
8		18：00	Sunny	
9	October 11	12：00	Sunny	Sunny
10	October 25	18：00	Sunny	Rainy

The weather at the time of measurement was visually confirmed and the weather on the previous day was inferred from the data of the Japan Meteorological Agency[12].

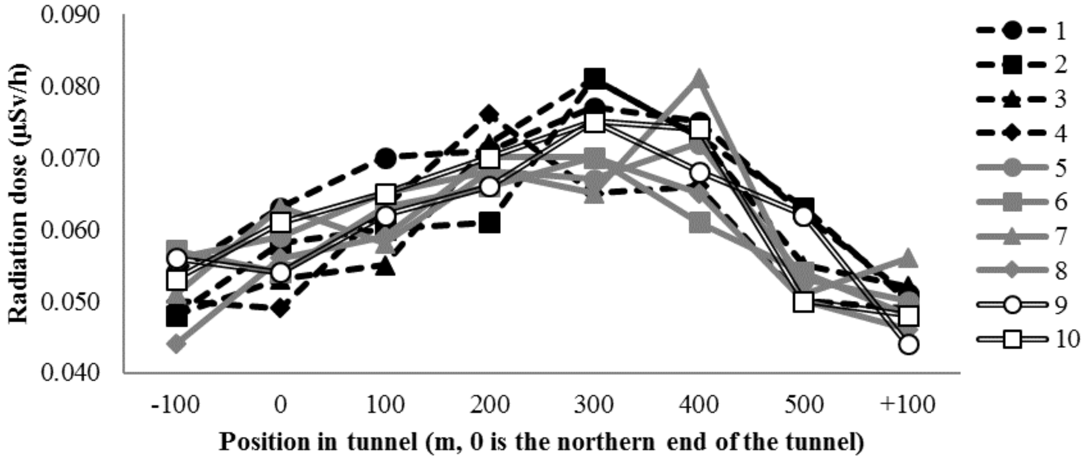

Figure No. 1: Radiation dose in tunnel B (east)

-100 and +100 indicate positions 100 m away from the north and south ends of the tunnel, respectively.

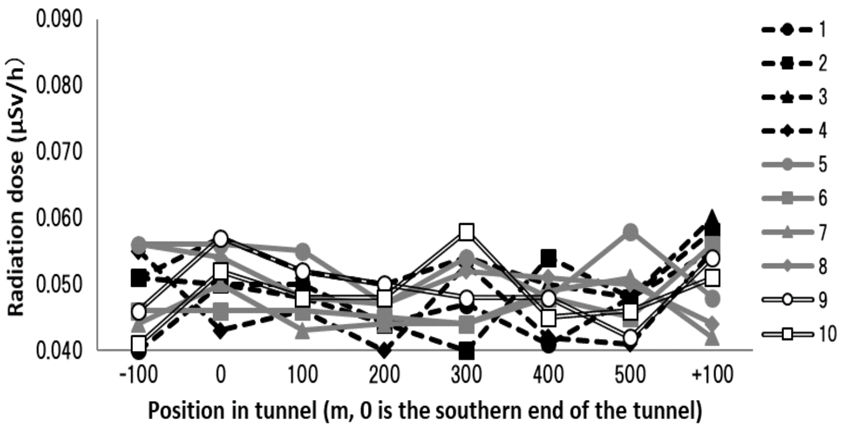

Figure No. 2: Radiation dose in tunnel B (west)

-100 and +100 indicate positions 100 m away from the south and north ends of the tunnel, respectively.

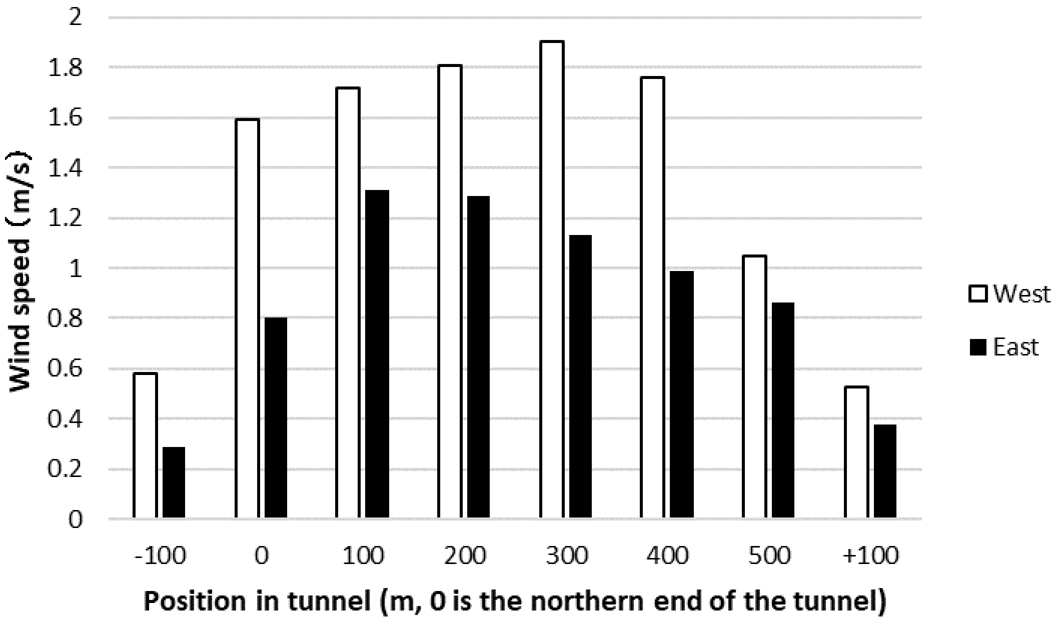

Figure No. 3: Wind speed in tunnel B

The annotation is the same as in Fig. 1.