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Cosmic Ray Dose Rates in Urban Environment -Case studies in Nagoya, Japan-

Susumu Minato
Radiation Earth Science Laboratory

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Abstract

In order to examine precisely how cosmic ray levels vary with the size, material and arrangement of surrounding building structures, measurements were carried out at several places in Nagoya City, i.e., a riverside promenade under bridges, general detached house, water tower, planetarium dome, railway station building and subway platforms. Bulk densities of the observed objects were evaluated using a simple model analysis, which revealed a wide variety of values depending on the structure.

1. Introduction

Cosmic rays observed at sea-level consist of hard (muon) and soft (electromagnetic shower) components. Although the soft component is almost absorbed within a few meters of water, the effective relaxation length of the hard component in water is about 20 m. Moreover, the hard component moves in an almost straight line. Accordingly, it should be possible to use cosmic rays to study objects several hundred times as large as those commonly investigated by usual X and gamma ray and/or neutron nondestructive testing.

In previous papers[1-3], cosmic ray observations were performed inside and outside architectural and civil engineering structures for exploring the possibility of cosmic ray nondestructive inspection as mentioned above. In this paper, additional observations are made as further feasibility research to examine the applicability to more complicated objects.

2. Materials and Method

A battery operated portable type 1” ϕ x2”NaI(Tl) scintillation counter was used in this study. A discrimination level was set at 5 MeV to exclude environmental gamma ray contribution. The calibration was made for 10-minute measurements with this instrument at platforms of subway stations by comparing with the dose rates obtained in 1987 at the corresponding platforms[2] in addition to several outdoor measurements. Figure 1 shows the result.

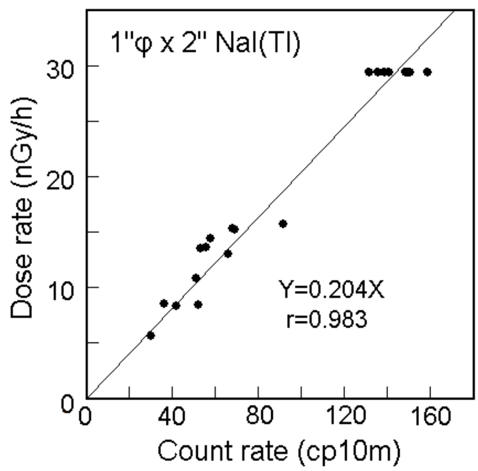

Figure 1. Calibration. The term r represents a correlation coefficient.

The intensity of cosmic rays transmitted through material is represented as a function of the shape and density of the material. We can, therefore, estimate the bulk density of a surrounding structure by analyzing the shape and the measured intensity data. Specifically, we assume that the cosmic rays penetrate rectilinearly and that the structure is a homogeneous and uniform body. Then, we express the intensity J at a point of interest as

$$J = \int_S F(\theta)G(\theta, \rho r)\frac{\cos\beta dS}{r^2}$$

Here, F(θ) is the incident intensity per unit solid angle with respect to zenith angle θ , G(θ , ρ r) the ratio of intensity after a distance r to F(θ), with r and ρ being the distance between the surface element dS and the point of interest and the bulk density, respectively, S the surface area of the structure, β the angle between the direction of incidence and normal incidence of the surface element dS, and cos β dS/r^2 the solid angle which area dS subtends to the point of interest. The terms θ , r and β are functions of the position of dS. The functions F(θ) and G(θ , ρ r) have already been given in Refs. 1 and 4 (See Appendix). Thus, the unknown parameter ρ can be obtained from the above equation.

3. Results and Discussion

3.1 Riverside Promenade under Bridges

Figure 2 shows the result of 10-minute measurements done at 89 points along a promenade. The raw data in the figure scatter widely. Considerable part of this scattering may be due mainly to statistical variability caused by counting error.

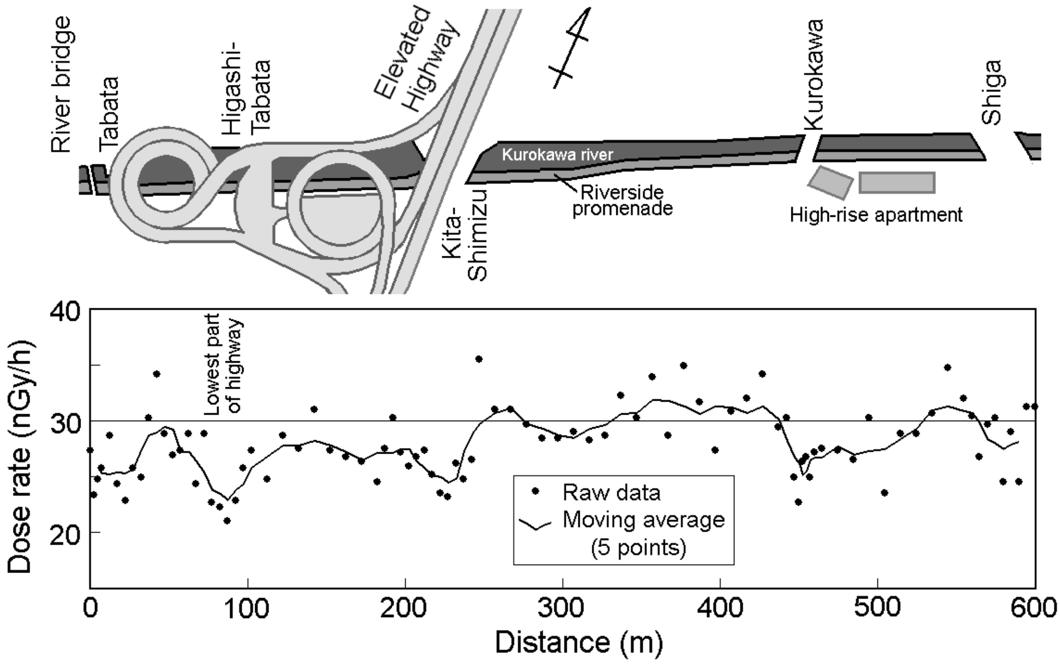

Figure 2. Variation with distance along the Kurokawa River, Sugimura-cho, Kita-ku,

A curve of 5-point moving average is also given in the figure. The dose rates under bridges tend to be low compared to the other points. It should be noted that the dose rates not only under the elevated highway but also near the high-rise apartment are also relatively low.

Sea-level dose rate values in the open air due to hard and soft components of cosmic rays are reported in Ref.3. The 11-year mean values reevaluated recently by the present author amount to 23.8 and 5.4 nGy/h, respectively, resulting in a total of 29.2 nGy/h. It is, therefore, obvious from Figure 2 that the bridges shield almost only soft component.

3.2 Detached House

Figure 3 shows an example of measurement made in a house made of light gauge steel. The dose rate in the figure is represented as an average and standard deviation for 10 times of 10-minute measurements. It is found from the data that this house shields only a part of soft component.

A bulk density of this house can be evaluated using a semi-theoretical formula[1,4] (See Appendix). Inputting the size and geometry of the house into the formula, we obtain a value of 0.145 g/cm^3 from the 1st floor dose rate, which leads to an overall weight of the house to be 53 tons.

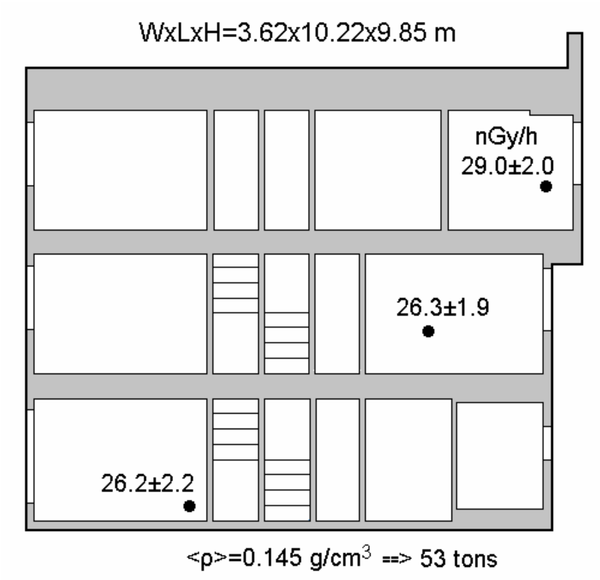

Figure 3. Dose rates inside a 3-story house, Yamaguchi-cho, Higashi-ku.

3.3 Water Tower

This cylindrical tower was built in 1937 and is now renovated as a facility for exercising drama and dancing. The appearance of the tower is shown in Figure 4. The size data of the tower are from Ref.5.

Figure 4. Water Tower, Inabaji-cho, Nakamura-ku

Figure 5 shows the measured result. A bulk density is evaluated to be 0.55 g/cm^3, which corresponds to about 7400 tons. The surrounding columnar pillars were ignored in the bulk density calculation.

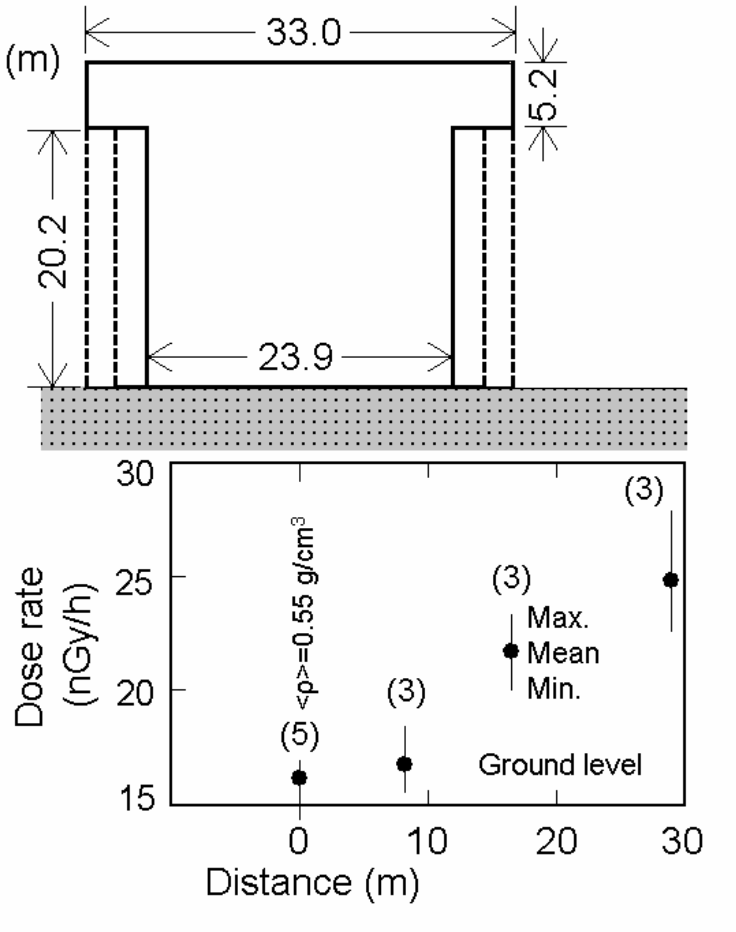

Figure 5. Variation with distance at Water Tower. The parentheses represent the number of measurement times.

A weight per floor space of about 2.1 tons/m^2 is generally used for reinforced concrete structures[6]. Using this value, a weight including the surrounding columnar pillars is calculated to be about 9000 tons, while it amounts to about 5600 tons for the case of excluding the pillars. The cosmic ray evaluated weight lies between the both values.

3.4 Planetarium Dome

The appearance of the dome and nearby buildings belonging to the Nagoya City Science Museum is shown in Figure 6, which is the biggest planetarium dome in the world[7] at present. The size data are from Ref.7. Figure 7 shows the measured result.

It would be easy to evaluate the bulk density of the dome if we could use an ideal spherical model. As is seen from the figure, however, it is difficult to evaluate the bulk density of the dome alone from the ground level data because of the existence of the adjacent two buildings. It is expected that the influence of the adjacent buildings become relatively less if we measure inside the dome. The data taken at the 5th floor of this dome are also shown in Figure 7. The bulk density can be evaluated using a semi-spherical model, i.e., a spherical segment shape partly cut off at the 5th floor plane. A bulk density for the part upper than the 5th floor of this dome is evaluated from model calculation to be 0.075 g/cm^3, which corresponds to around 1900 tons. For reference, the weight of the entire dome is reported to be 4000 tons[7].

Figure 6. Planetarium Dome of the Nagoya City Science Museum, Sakae, Naka-ku.

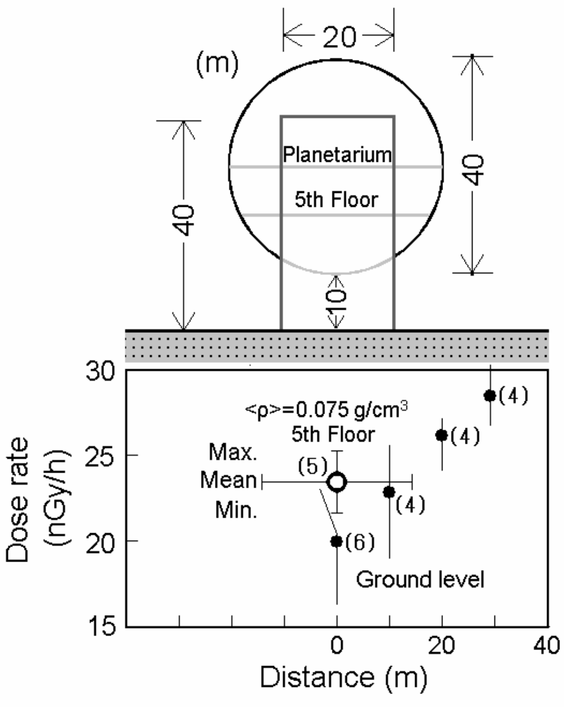

Figure 7. Variation with distance at the Planetarium Dome. The parentheses represent the number of measurement times

3.5 JR Nagoya Station

A traverse line along which cosmic ray dose rates were measured is shown in Figure 8. The measurements were done at ground level and levels of 10, 15 and 20 meters underground. Figure 9 shows the result. The statistical variability seems to be somewhat great because of one-time measurement for every point, as experienced in the Kurokawa river measurements (see section 3.1).

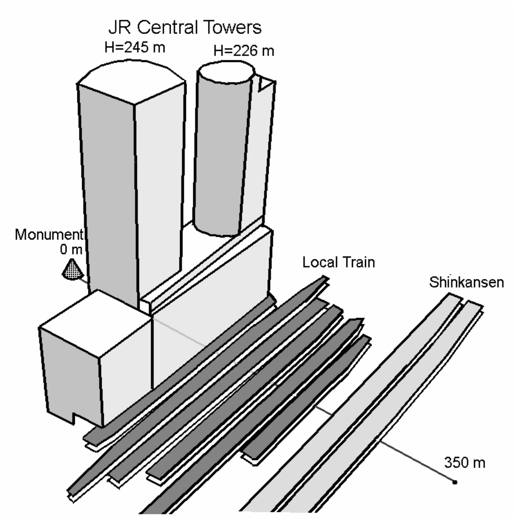

Figure 8. JR Nagoya Station, Meieki, Nakamura-ku.

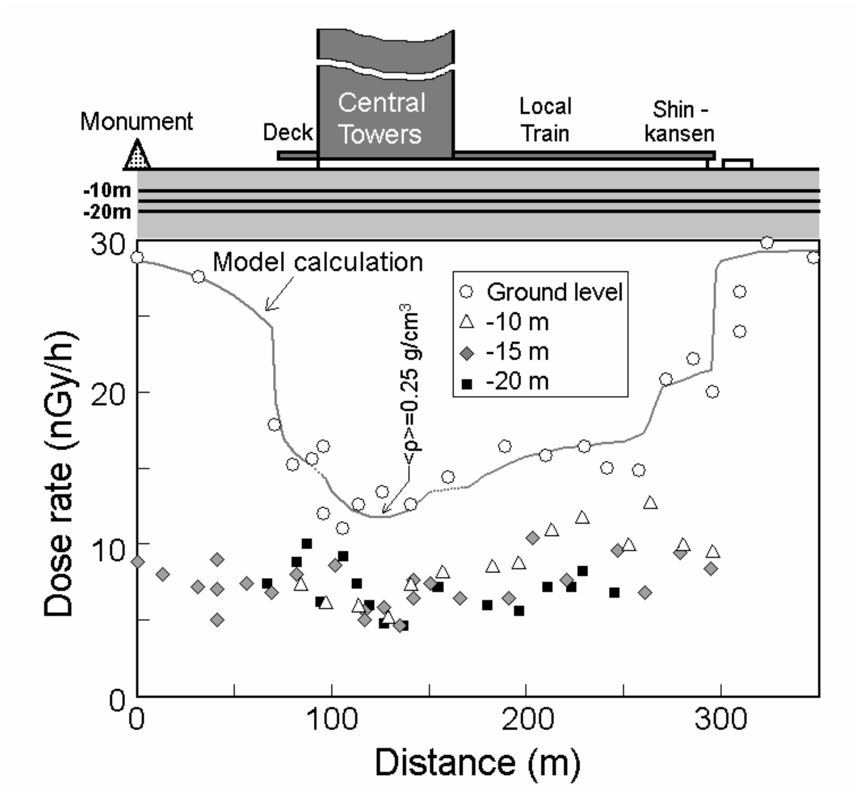

Figure 9. Variation with distance at JR Nagoya Station.

Table 1. Size data of Nagoya Station used in the model calculation

	Width (m)	Length (m)	Height (m)	Density (g/cm^3)
JR Central Towers	70	150	100	0.25
Deck	20	100	1.5	2.5
Floor-Deck	20	100	5	
Local train platform	104	200	2.5	2.5
Shinkansen platform	32	200	1	2.5
Floor-Platform	136	200	5	

As far as the ground level measurements are concerned, a model calculation can be made to obtain a bulk density of the station building. In contrast, the modelling for the levels underground is quite difficult, since the passages of the underground area are too complicated three-dimensionally to simulate. The best-fitted parameters to the observed data for the ground level are given in Table 1. Quite a small building on the right-hand side adjacent to the Shinkansen platform is not taken into account in the model.

A bulk density is evaluated to be 0.25 g/cm^3 at the center of the JR Central Towers.

3.6 Subway Network

Subway measurements were performed at all the station platforms[2] in 1987. The number of stations in Nagoya City was 60 at that time. Thereafter, the network has been extended up to 87 stations. In this section, the data for newly built stations are presented in addition to the old data.

Figure 10 shows the Nagoya subway network and a three-dimensional representation of observed dose rates. In the figure, markedly high values (around 30 nGy/h) are corresponding to 4 ground level platforms (3 stations of Higashiyama line and 1 station of Tsurumai line).

The Sakuradori and Kamiiida lines were dug under the older lines. Therefore, the dose rate levels there reveal lower than those measured at the older lines.

The method for evaluating bulk densities described so far in this paper is effective for not-so-massive materials like buildings on the ground. For the deeper positions like subway platforms, Miyake's semi-empirical formula[8] is more appropriate (See Appendix). The range we should use in the evaluation[9] is shown in Figure A-2 in Appendix.

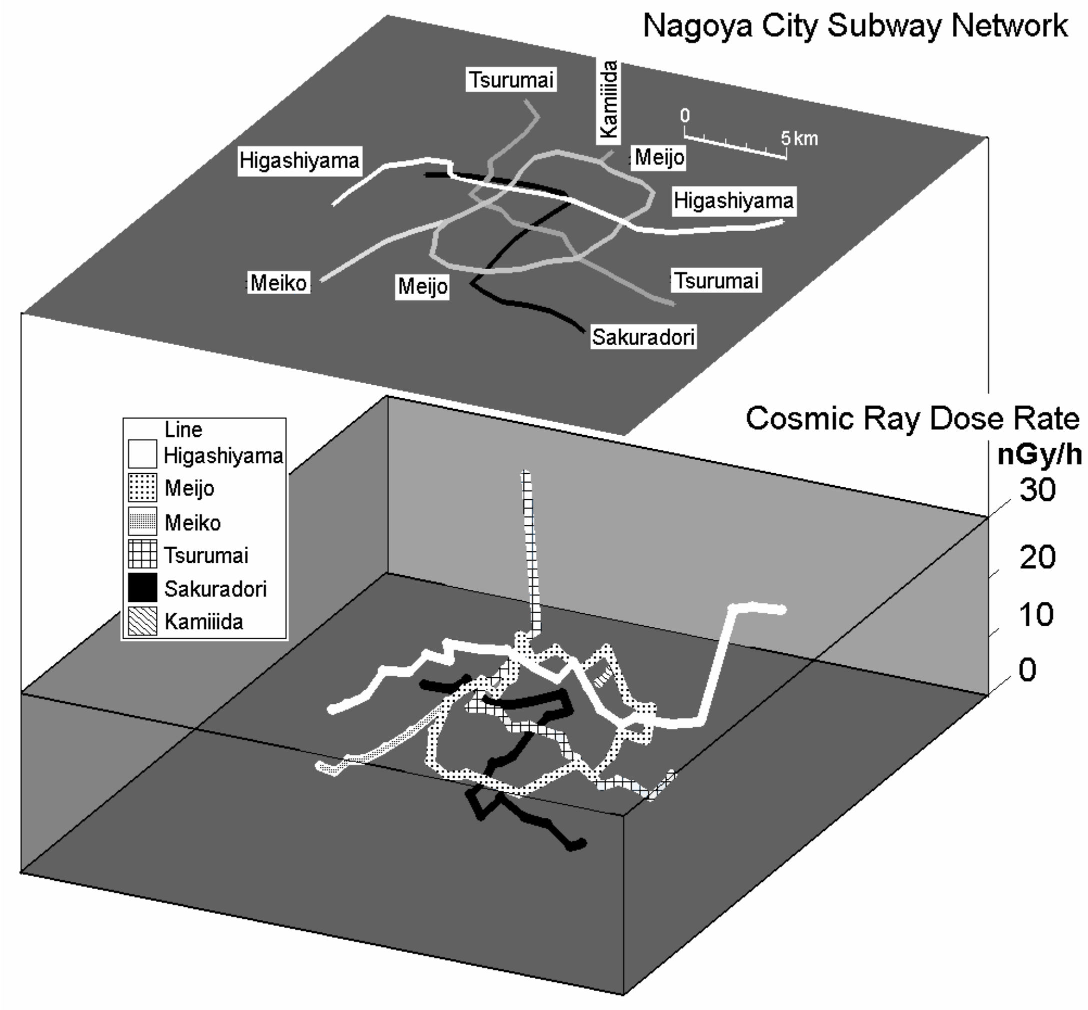

Figure 10. The Nagoya City Subway Network

Figure11 shows the relationship between cosmic ray level and platform depth. The data scatter markedly not only due to statistical variability but also depending on the degree of complicatedness of every station structure[2)]. However, the average dose rate for every line decreases almost linearly with increasing depth. A bulk density averaged over all the platforms of 1.26 g/cm^3 was obtained from the method mentioned above.

In order to examine whether or not the depth profile given in Figure 11 is general, let us check the other case. The Tokyo subway network has 285 stations. The cosmic ray levels have been measured in a part of the whole stations[10)]. Figure 12 shows the comparison of Nagoya data with observations made at 34 platforms in the Tokyo subway network. The both depth profiles are similar to each other. A calculation based on the above-mentioned formulas carried out assuming the bulk density of 1.26 g/cm^3 well represents the observed results.

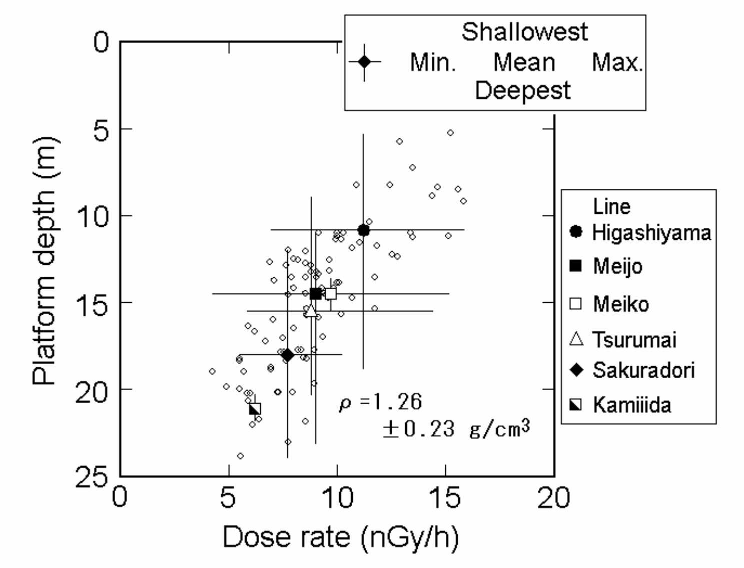

Figure 11. Variation with platform depth. Data for ground level platforms are excluded.

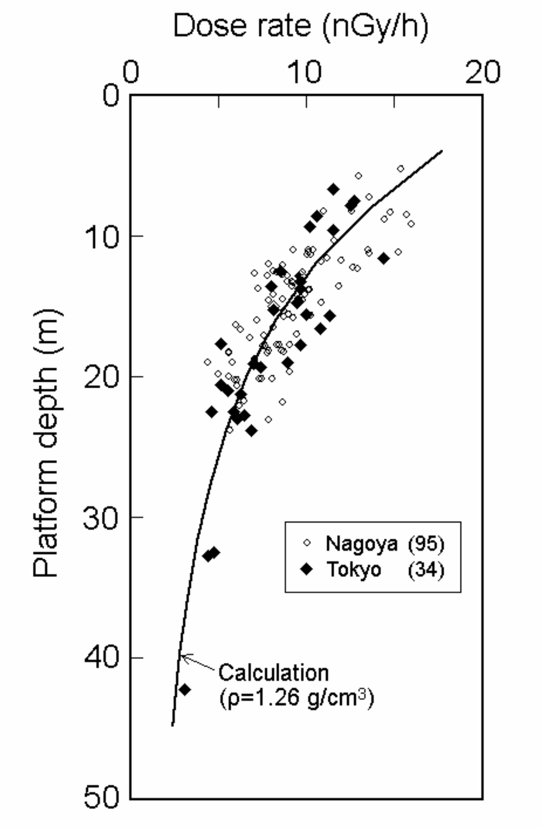

Figure 12. Variation with platform depth in Nagoya and Tokyo subway stations along with a calculated curve. Data for ground level platforms are excluded. The parentheses represent the number of observed platforms.

4. Conclusions

It was found through the case studies described in this paper that the cosmic ray level ranges from about 30 down to a few nGy/h in the urban environment. This kind of study must be effective for educating students. Namely, by measuring the cosmic ray levels at many points inside and outside their school buildings in science club activity, they would be able to understand the behavior of cosmic rays concretely. It may be also helpful in the graduation thesis of university students.

In the process of the present study, the bulk densities as well as weights of surrounding materials were evaluated. The application of this technique is possible to various fields. For example, it would be useful for estimating the weight of the waste when a very large scale structure is dismantled.

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Appendix Empirical Formula for Cosmic Ray Transport Underground

Depth (Vertical distance): h (hg cm^{-2})

① Formulas for cosmic ray flux and dose rate derived by Minato S (1992) Cosmic-ray transmitted images, Hoshasen, 19: 49-56. (in Japanese)

Muon (Hard component)

$$I_{\mu}(h,\theta) = I_{00}\cos^{n}\theta \cdot e^{-h/\Lambda(h)} \qquad (1)$$

Here, θ is the zenith angle in degrees, and

$$\Lambda(h) = A + Bh + Ch^2,$$
$$n = \alpha + \beta h.$$

For knock-on fluxes (not for dose rates),

$$electrons: \quad 0.1033 I_{\mu}(h,\theta) \quad (1-1),$$
$$photons: \quad 0.1894 I_{\mu}(h,\theta) \quad (1-2).$$

Table A-1 Constants used in equation (1)

		I_{00}	A	B	C	α	β
Flux	(cm^{-2} s^{-1} sr^{-1})	0.00723	17.61	0.1404	-7.069×10^{-5}	1.495	0.002018
Dose rate	(nGy h^{-1} sr^{-1})	9.270	20.56	0.1386	-6.365×10^{-5}	1.427	0.001963

Electromagnetic shower (Soft component)

$$I_S(h,\theta) = \frac{1 + Dh\sec\theta}{1 + Eh\sec\theta} I_{00}\cos^{3}\theta \cdot e^{-h\sec\theta/L} \qquad (2)$$

Table A-2 Constants used in equation (2)

	I_{00}	D	E	L
Flux				
Electron	0.00224	13	7	0.6495
Photon	0.0118	11	7	0.6530
Dose rate	3.38	11	7	0.7186

The above formula is valid down to 300 hg/cm^2.

② Formula for muon flux derived by Miyake S (1979) Cosmic ray research in the deep part under the ground, J. Phys. Soc. Japan, 34: 292-301 (in Japanese).

$$I_{\mu}(h,\theta) = \frac{A}{h+H}(h\sec\theta + a)^{-\alpha}\exp(-\beta h\sec\theta), \qquad (3)$$

$$where, \quad A = 174, \quad H = 400, \quad a = 11,$$

$$\alpha = 1.53, \quad \beta = 8.0\times10^{-4}$$

The accuracy of the above formula is worse near the ground surface as is seen in Figure A-1.

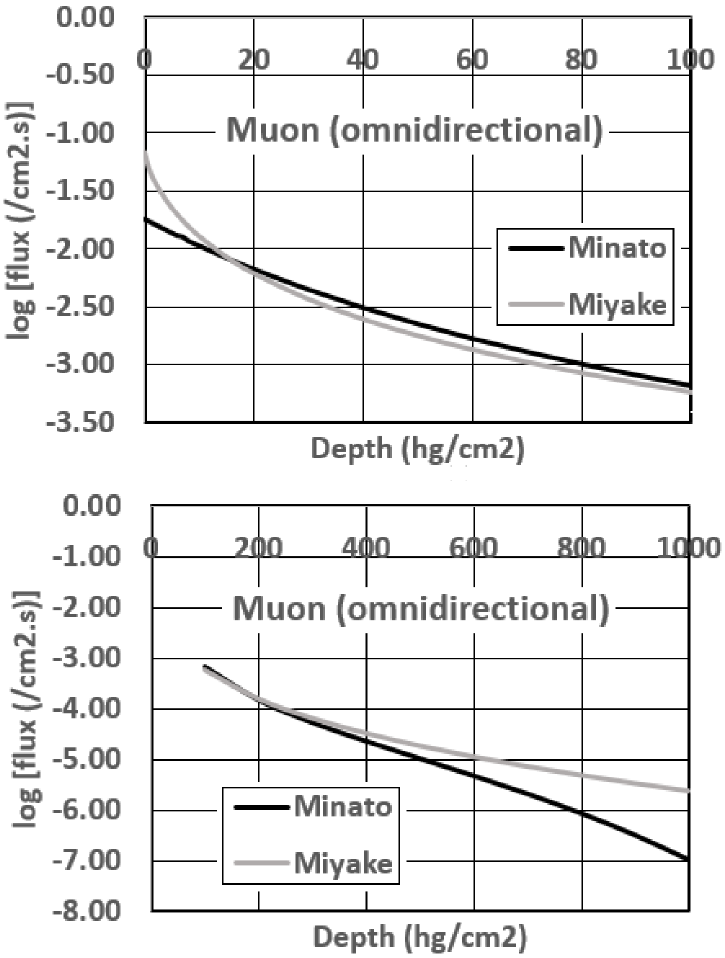

Fig. A-1 Muon fluxes calculated by the two formulas

From the two formulas, the ratio of dose rate to Miyake's muon flux is derived as

$$r = \begin{cases} 1253 + 7.81h - 0.0417h^2 & (40 < h \leq 100hg/cm^2) \\ 1527 + 1.35h - 0.00339h^2 & (100 < h \leq 200) \\ 1670 & (200 < h) \end{cases} \quad (4)$$

Accordingly, the ranges to be recommended for the above formulas is shown in Figure A-2, where the boundary is expressed by[9)]

$$L = 6.61e^{0.020\theta}$$

Here, θ is the zenith angle in degrees

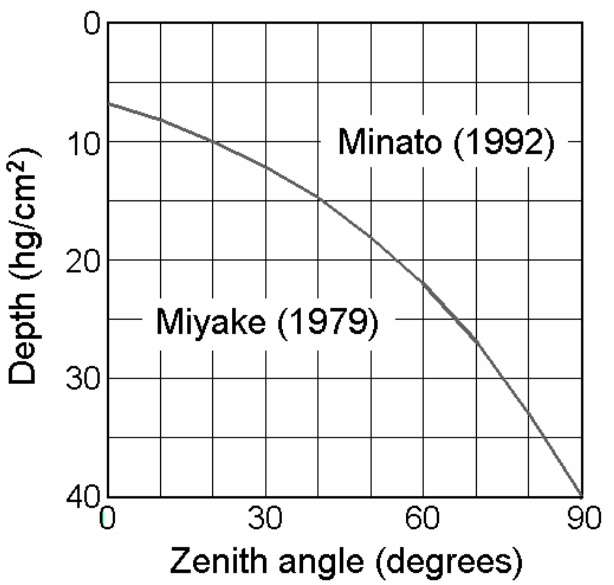

Fig. A-2 Recommended ranges underground