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Analysis of Environmental Gamma-Ray Intensity Increase Due to Precipitation Using EGS4 Monte Carlo Simulation Code

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The EGS4 (Electron Gamma Shower, Version 4) Monte Carlo simulation code is used to calculate the conversion factors of the radon daughter quantity accumulated on the ground surface to the environmental gamma radiation dose rate with considering the actual geographical conditions. When the precipitation rate is low, the time variation of the environmental gamma radiation dose rate estimated from the measured radon daughter content of precipitation and the amount of precipitation by using these conversion factors corresponds fairly well with the measured increase of it. It is confirmed that this method is useful for removing the effect of precipitation from the observed fluctuation of the environmental gamma-ray intensity and rising the reliability of the practical monitoring of it.

INTRODUCTION

It is well known that the precipitation causes the temporal increases of environmental gamma-ray intensity near the ground surface by several to several tens percents of its normal level (1-4). These large increases of it are the serious disturbances to the gamma radiation monitoring carried out around the nuclear facilities. They are due to the gamma-rays emitted from the radon daughters which are brought from the upper air and accumulated on the ground surface by the scavenging effect of precipitation. In this century, the direct measurements of the radon daughter content of precipitation were carried out by many researchers (5-9). However, the periods of them were short and the results of them were scarcely compared with the time variation of environmental gamma-ray intensity. On the other hand, there are some studies that the radon daughter contents of precipitation were estimated from the time variation of the environmental gamma radiation dose rate and the precipitation rate, and were discussed about their relations with some meteorological conditions and etc (10-12). In these studies, the conversion factors of the radon daughter quantities accumulated on the ground surface to the increase of environmental gamma radiation dose rate were used. They were calculated by using the Monte Carlo simulation code with the assumption of the uniform distribution of radon daughters on the infinite plain of ground surface (13).

One of the present authors, with his collaborators, made the continuous measurements of radon daughter content of precipitation in the manual method (14,15). And the time variation of the quantity of radon daughters accumulated on the ground surface, that was estimated from the results obtained by the measurements mentioned above, was compared with the time variation of environmental gamma-ray intensity measured simultaneously with the radon daughter content of precipitation (16). Furthermore, the automatic measuring instrument of the radon daughter content of precipitation was developed and the continuous measurements of it have been carried out together with the environmental gamma-ray intensity (4).

The measuring point of the environmental gamma-ray intensity was, at the beginning, the open space. Therefore, the conversion factors of the radon daughter quantities accumulated on the ground surface to the increase of environmental gamma-ray intensity were calculated with the assumption that the radon daughters on the ground surface makes an infinite plain source. They were calculated by using the partially modified Monte Carlo simulation code that was used in the calculation of the effect of the atmospheric radon daughters to the environmental gamma-ray intensity (17). About five years ago, the measuring point of the environmental gamma-ray intensity was moved to the valley-like place where the high buildings were standing on both sides of north and south at a distance of 20 m each other. The conversion factors of the radon daughter quantities accumulated on the ground surface to the increase of environmental gamma radiation dose rate are newly calculated by using the EGS4 (Electron-Gamma Shower, Version 4) Monte Carlo simulation code that can treat the geographical conditions as the buildings and so on (18). In this paper, the relations are discussed between the time variation of the measured environmental gamma radiation dose rate and that estimated from the time variation of the measured radon daughter content of precipitation by using the conversion factors mentioned above with taking account of the effect of the buildings. This study is useful to improve the reliability of the practical monitoring system of the environmental gamma-ray intensity by removing the effect of the precipitation to the measured value of it.

MEASUREMENTS

The continuous measurement of the radon daughter content of precipitation is, at present, carried out by the automatic measuring instrument equipped with the well-type NaI(Tl) scintillator (4). It is able to measure the content of them in every 15 minutes together with the amount of precipitation. The sequence of operation of this instrument are as follows: 1) The precipitation is collected in the funnel of 30 cm diameter made of polyethylene. 2) The collected precipitation is led to the glass cell set in the well of the scintillator by opening the electromagnetic valve at every 15 min. When the collected precipitation is more than 10 cc, which is equivalent to 0.14 mm/15min precipitation rate, the excess water overflows to outside at the inlet of the cell and just 10 cc water is automatically taken into the glass cell as the sample water. While the precipitation rate measure with the rainfall intensity recorder is less than 0.14 mm/15min, the water sample is less than 10 cc. In this case, the effect due to the difference in the geometrical conditions of the measurement is corrected. 3) After 1 min from sampling, the gamma-rays from the water sample are counted by the scintillator for 5 min. 4) When the counting has finished, the water sample in the glass cell is aspirated by the pump and drained out by opening the electromagnetic valve. These processes are repeated at every 15 min automatically. The amount of precipitation is measured with the rainfall intensity recorder which generate one output pulse per 0.0083 mm precipitation.

The counting rate and the dose rate of environmental gamma radiation are simultaneously measured by the monitoring system equipped with the NaI(Tl) scintillation counter. The dose rate is obtained by using the DBM (Discrimination Bias Modulation) unit (19). This unit has the lower discrimination of which level shows the time variation with the suitable function taking into account of the variations of both the counting efficiency of NaI(Tl) scintillator and the flux-to-dose conversion factor according to the gamma-ray energy. This monitoring system is similar with those used widely around the nuclear facilities in Japan.

SIMULATION

In the case of the open area, the radon daughters accumulated on the ground surface are assumed to make an infinite plain source. The conversion factors of the radon daughter quantities accumulated on the ground surface to the increase of environmental gamma radiation dose rate are calculated by using the partially modified Monte Carlo simulation code that was developed and used in the calculation of the effect of the atmospheric radon daughters to the environmental gamma radiation (17). In the Monte Carlo computation program used practically, the gamma-rays are treated to be emitted from the point source due to the radon daughters on the ground surface and to be detected by the infinite plain detector. The detector plane is 3 m height above the ground surface because the NaI(Tl) scintillator used in this study is set at this height. The cut-off energy of the gamma-rays is set to be 50 keV because the lower discrimination level of the monitoring system corresponds usually to this energy. In each history, the gamma-ray is traced completely even when it goes into the soil because the contribution of the back-scattered gamma-ray is not so small. The number of histories of these simulations is 100,000 for both RaB (Pb-214) and RaC (Bi-214), which are the gamma-ray emitter. The conversion factors obtained in these simulations agree well with the published data (13).

In the present case that the buildings are standing near the measuring point of the environmental gamma-ray intensity, the radon daughters accumulated on the ground surface are distributed in a finite area. Some of the gamma-rays emitted by them penetrate into the concrete of the buildings and are scattered. Therefore, the Monte Carlo simulation code used in the case of the infinite plain source no longer can be used. To estimate the conversion factors of the radon daughter quantities accumulated on the ground surface to the increase of environmental gamma radiation dose rate in this case, the EGS4 (Electron-Gamma Shower, Version 4) Monte Carlo simulation code is used (18). The EGS4 is developed for the simulation of the coupled transport of electrons and photons in an arbitrary geometry. In this study, the geometrical conditions considered are as follows: 1) The building of 13 m height and 20 m width is standing at the distance of 10 m southward from the measuring point. 2) The other building of 25 m height and 50 m width is standing at the 10 m distance northward from it. 3) The radon daughters accumulated on the ground surface are distributed uniformly in the area between the buildings over the 600 m length in the east-west direction. 4) The detector is set at the 3 m height above the ground surface as mentioned before. 5) The detector region is set the 1 m × 1 m × 1 m box of air. Although the detector used practically in this study is small in the several cm diameter and height, the large space detector region is set so as to rise the efficiency of detection in these simulations. The deposited energy in the detector region is obtained as the results of these simulations and the absorbed dose rate in air is derived from it. Therefore, the dimension of the detector region scarcely disturbs the final results. The number of histories in these simulations is 2,000,000,000 which is close to the upper limit of the integer used in the computer of 32 bit. The cut-off energy of the gamma-rays is set to be 50 keV as mentioned before.

ESTIMATION OF INCREASE OF GAMMA RADIATION DOSE RATE DUE TO PRECIPITATION

The increases of environmental gamma radiation dose rate due to the precipitation are estimated from the radon daughter quantities accumulated on the ground surface and the conversion factors mentioned above at every 15min. The radon daughter quantities accumulated on the ground surface are derived from the radon daughter content of precipitation and the amount of precipitation measured for every 15 min. The derivation process of them is as follows: 1) The amounts of radon daughters brought from the upper air to the ground surface by the precipitation for every 15 min are obtained from the product of the radon daughter content of precipitation and the amount of precipitation with the modification according to the successive disintegration of the radon family. 2) The survival quantities of them at each 15 min interval after that time are calculated by taking account of the successive disintegration of the radon family exactly. 3) The radon daughter quantities accumulated on the ground surface at every 15 min interval are obtained by the additions of the survival quantities of them calculated as mentioned above.

RESULTS AND DISCUSSION

In the case of the open area, the conversion factors of the radon daughter quantities accumulated on the ground surface to the environmental gamma radiation dose rate are calculated to be 7.19 (nGy/hr)/(Bq/cm^2) for RaB and 47.3 (nGy/hr)/(Bq/cm^2) for RaC, respectively. Figure 1 shows the example of the time variation of the environmental gamma radiation dose rate estimated by using this conversion factors and the radon daughter quantities accumulated on the ground surface in comparison with the measured increase of it in the case of the finite area mentioned before. The data shown in this figure are obtained during November 17 – 18, 1998. As shown in it, the estimated values of the increase of environmental gamma radiation dose rate are larger than the measured one. The contribution of the area covered with the buildings, if it is not covered with them, is very large as shown by the difference between them.

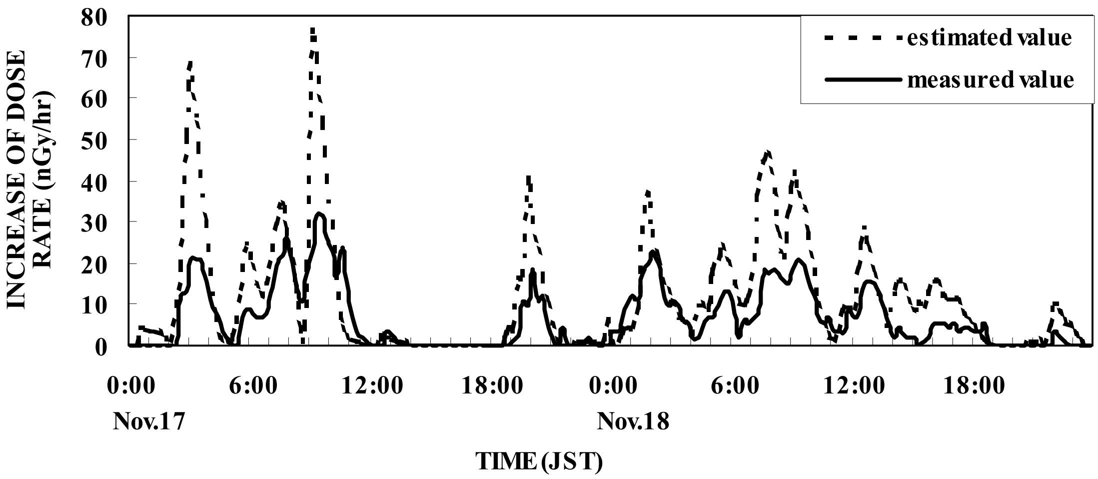

Figure 1 Time variations of the increase of environmental gamma radiation dose rate measured on November 17 - 18, 1998 in comparison with the estimated one with the assumption of the infinite plain source of radon daughters accumulated on the ground surface.

In the present simulation using the EGS4 for the finite area, the conversion factors of the radon daughter quantities accumulated on the ground surface to the environmental gamma radiation dose rate are calculated to be 3.03 (nGy/hr)/(Bq/cm^2) for RaB and 16.7 (nGy/hr)/(Bq/cm^2) for RaC, respectively. In these simulations, the geometrical conditions are as mentioned before. Figure 2 shows the same example of the comparison of the time variations between the measured increase of the environmental gamma radiation dose rate and the estimated one by using this conversion factors and the radon daughter quantities accumulated on the ground surface. The period shown in this figure is the same in Fig. 1. In this figure, the time variations of the amount of precipitation and the radon daughter content of precipitation are also shown. These data are measured directly and used to estimate the environmental gamma radiation dose rate due to the precipitation. As shown in this figure, both patterns of the time variations of estimated environmental gamma radiation dose rate and of measured increase of it are similar each other. The radon daughter content of precipitation has no correlation with the amount of precipitation. Therefore, for the removing the effect of precipitation to the environmental gamma-ray intensity in order to improve the reliability of its monitoring, the estimation of it is important by using the directly measured value of the amount of precipitation and the radon daughter content of precipitation.

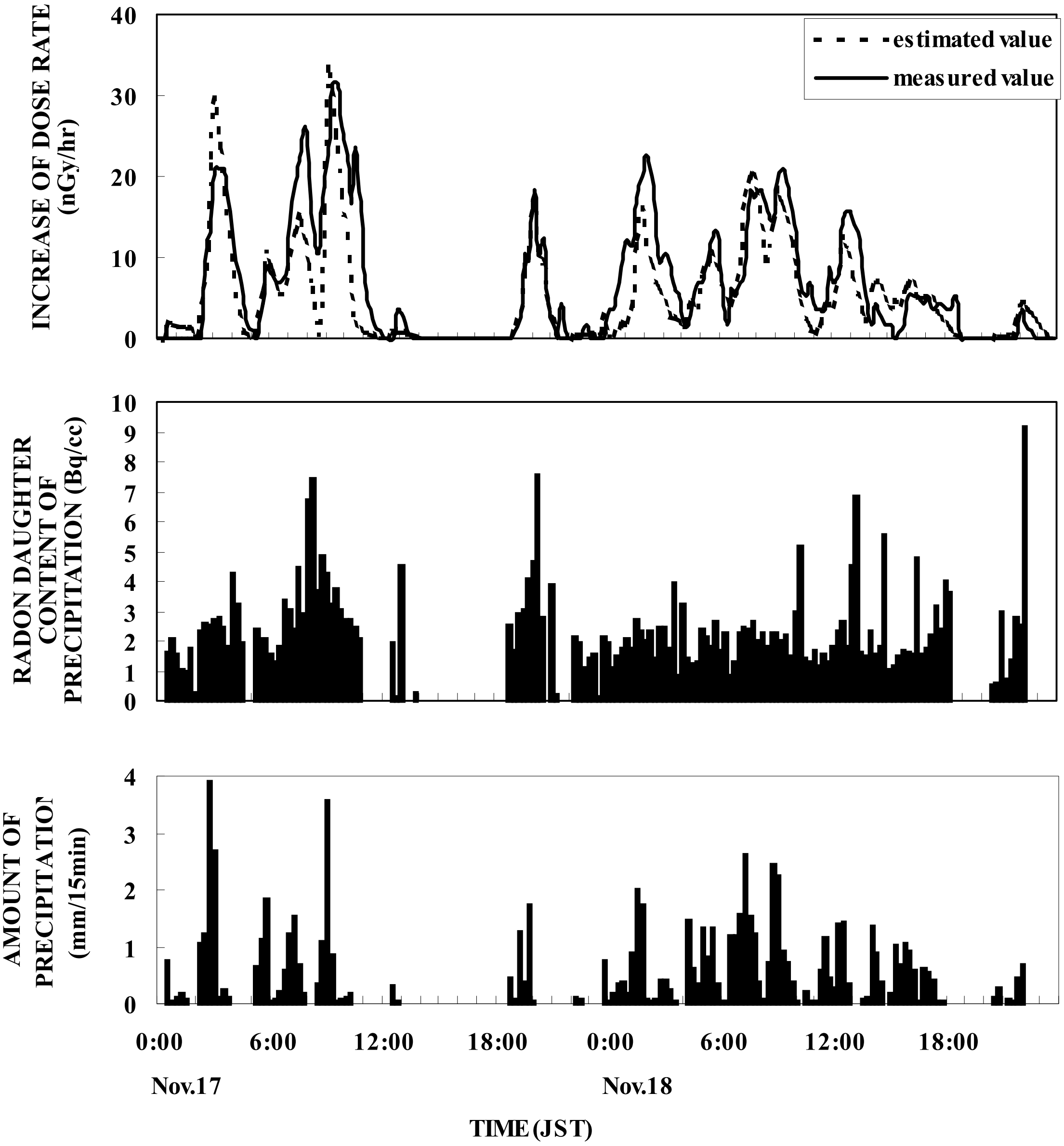

Figure 2 Time variations of the amount of precipitation, the radon daughter content of precipitation, and the increase of environmental gamma radiation dose rate measured on November 17 - 18, 1998 in comparison with the estimated one. The estimated values are obtained by assuming that the radon daughters accumulated on the ground surface make a finite plain source with considering the actual geographical conditions.

When the precipitation rate is not so high, as shown in Fig. 2, the estimated time variation of the environmental gamma radiation dose rate corresponds fairly well with the measured increase of it. However, the case that the measured increase of the environmental gamma radiation dose rate is sometimes much lower than the estimated one when the precipitation rate is high. The example of this case is shown in Fig. 3. The reason why this difference appears between the measured value and the estimated one is considered to be that the greater part of radon daughters brought to the ground surface is drained with the large quantity of rainwater.

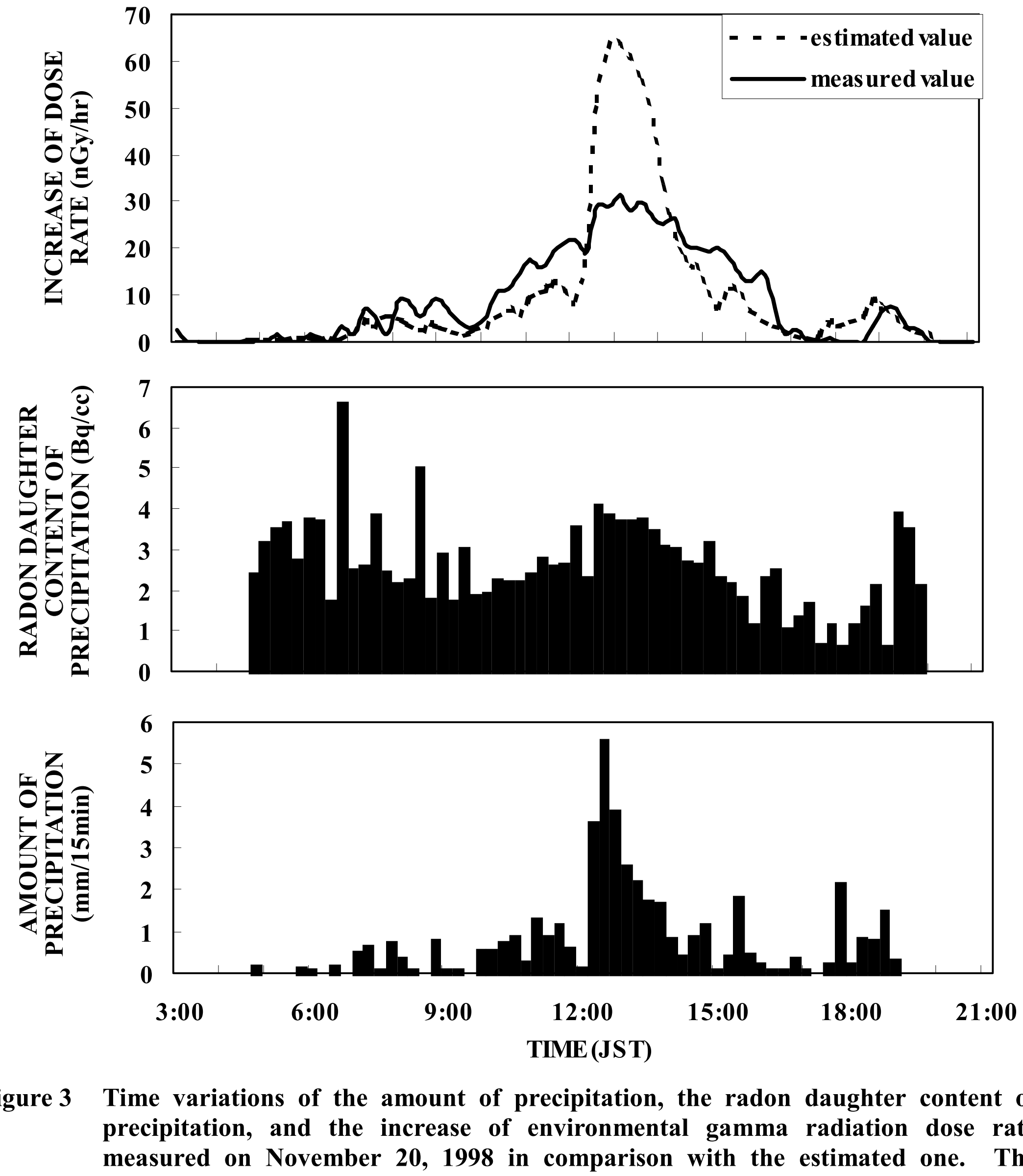

Figure 3 Time variations of the amount of precipitation, the radon daughter content of precipitation, and the increase of environmental gamma radiation dose rate measured on November 20, 1998 in comparison with the estimated one. The estimated values are obtained by assuming that the radon daughters accumulated on the ground surface make a finite plain source with considering the actual geographical conditions.

The measured increase of environmental gamma radiation dose rate is sometimes higher than the estimated one as shown in Fig. 2 and Fig. 3. The geometrical conditions in the present simulations using the EGS4 are considered to be incomplete for reflecting the actual geographical conditions, e.g., the effect of the radon daughters accumulated on the roofs of buildings, and so on.

When the precipitation rate is low, this method described above is confirmed to be useful for removing the effect of precipitation from the observed fluctuation of the environmental gamma-ray intensity and improving the reliability of the practical monitoring of it.

CONCLUSION

The continuous measurements of the radon daughter content of precipitation, the amount of precipitation and the environmental gamma radiation dose rate are carried out simultaneously for a long period. In order to analyze the effect of the precipitation to the environmental gamma radiation dose rate exactly, the quantity of radon daughters accumulated on the ground surface is derived from the measured radon daughter content of precipitation and the amount of precipitation by taking account of the successive disintegration of the radon family, and it is converted to the environmental gamma radiation dose rate. In the present study, the EGS4 Monte Carlo simulation code is used to obtain the conversion factors of the former to the latter. This simulation code can take account of the geographical conditions exactly. When the precipitation rate is low, the estimated environmental gamma radiation dose rate corresponds fairly well with the measured increase of it. It is confirmed that this method is useful for removing the effect of precipitation from the observed fluctuation of the environmental gamma-ray intensity and improving the reliability of the practical monitoring of it.

REFERENCES

1. R.R. Finck and B.R.R. Persson, *In Situ Ge(Li)-Spectrometric Measurements of Gamma Radiation from Radon Daughters Under Different Weather Conditions*, “Natural Radiation Environment Ⅲ”, CONF-780422, Vol.1, 357-369 (1980).
2. S. Minato, *Analysis of Time Variations in Natural Background Gamma Radiation Flux Density*, J. Nucl. Sci. Technol, 17(2), 461-469 (1980).
3. Katase, Y. Narahara, Y, Ishihara, K. Tanaka and H. Matsuyama, *Variation of Intensity of Environmental Gamma-Rays Measured with Ge(Li) Spectrometer*, J. Nucl. Sci. Technol., 19(11), 918-927 (1982).
4. T. Nishikawa, M. Aoki and S. Okabe, *Automatic Measuring Instrument for Radon Daughters Concentration of Precipitation*, J. Nucl. Sci. Technol., 23(11), 1001-1007 (1986).
5. C.T.R. Wilson, *On Radio-Active Rain*, Proc. Camb. Phil. Soc., 11, 428-430 (1902).
6. P.E. Damon and P.K. Kuroda, *On the Natural Radioactivity of Rainfall*, Trans. Am. Geophys. Union, 35(2), 208-216 (1954).
7. N. Bhandari and Rama, *Study of Atmospheric Washout Processes by Means of Radon Decay Products*, J. Geophys. Res., 68(13), 3823-3826 (1963).
8. Y. Ikebe, K. Aigyo and Y. Nakashima, *Measurements of Radioactivity of Rain Water* (in Japanese), Proc. Soc. Atmos. Electr. Japan, No.20, 33-38 (1978).
9. M. Takeyasu, K. Yamasaki, T. Tsujimoto, Y. Ogawa and I. Urabe, *Rn-222 Progeny in Precipitation*, “Proceedings of Asia Congress on Radiation Protection”, 618-621 (1993).
10. S. Minato, *Some Observations of the Variations in Natural Gamma Radiation Due to Rainfall*, “Natural Radiation Environment Ⅲ”, CONF-780422, Vol.1, 370-382 (1980).
11. H. Hayakawa, *Short-Lived Radon Daughter Deposition Activity on Ground Surface Carried by Rainfall*, Hoken Butsuri 22, 47-52 (1987).
12. K. Yoshioka, *The Seasonal Variation of Rainout Activity of Short-Lived Radon Daughters*, Radiat. Prot. Dosim., 45(1/4), 395-398 (1992).
13. S. Minato, *Monte Carlo Calculation of Gamma Radiation Field Due to Precipitation Washout of Radon Daughters from the Atmosphere to the Ground Surface*, Hoken Butsuri, 15(1), 19-24 (1980).
14. T. Nishikawa, M. Aoki and S. Okabe, *Time Variation of Radon Daughters Concentration in Snowfall*, RADIOISOTOPES, 33(5), 257-261 (1984).
15. T. Nishikawa, M. Aoki and S. Okabe, *Time Variation of ^{222}Rn Progeny Concentration in Rainwater*, Health Phys., 49(6), 1284-1289 (1985).
16. S. Okabe, T. Nishikawa and M. Aoki, *Effect of Radon Daughters in Atmosphere and Precipitation on the Change of Environmental Gamma Radiation* (in Japanese), “Atmospheric Radon Families and Environmental Radioactivity”, (Atomic Energy Society of Japan, Tokyo, Japan), 127-137 (1985).
17. T. Nishikawa, S. Okabe and M. Aoki, *Monte Carlo Calculation of Gamma-Ray Flux Density Due to Atmospheric Radon Daughters*, J. Nucl. Sci. Technol., 26(5), 525-529 (1989).
18. W.R. Nelson, H. Hirayama and D.W.O. Rogers, *The EGS4 Code System*, SLAC-Report-265, Stanford Linear Accelerator Center, Stanford, California, USA (1985).
19. H. Hayakawa, M. Ohnishi and H. Shimada, *Measuring Additional Dose Rate Contributed by Nuclear Plants*, Health Phys., 64(3), 306-310 (1993).