

2 学位論文概要

Studies on Factors Associated with the Variations of Environmental Radiation Dose

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Air-absorbed radiation doses, continuously measured around a nuclear power station, were analyzed in order to clarify the relationships between the variations of environmental radiation and the environmental factors peculiar to cold and snowy area along the coast of the Sea of Japan. First, the increase in doses was confirmed to be derived from the precipitation originated from a high flux density of gamma-rays due to the decay products of ^{222}Rn . While the decrease was attributable to the shielding effect of a part of gamma-rays, especially from ^{40}K and ^{208}Tl in a soil surface covered by the snow layers. Second, the vertical profile of environmental doses was practically established above the ground. The mean dose rates in the winter increased unexpectedly according to a quadratic curve in upper region. Based on the observed results, the increasing tendency can most likely be attributed to bremsstrahlung X-rays generated from thunderclouds. It was assumed that this study was the first observation of an increasing radiation dose with height associated with winter thunderstorms. Third, it became evident that the sensitivity of a radiophotoluminescence glass dosimeter decreased by about 3-5% in the winter season, when mean temperature was relatively low, below 6.3°C. Finally, Monte Carlo calculations of terrestrial gamma-rays were carried out to simulate the observed doses above the ground.

Keywords : environmental radiation; natural radioactive nuclides; winter thunderstorm; bremsstrahlung; radiophotoluminescence glass dosimeter; Monte Carlo method; terrestrial gamma-rays.

1. Introduction

Around nuclear facilities, such as power reactors, fuel fabrication plants, spent fuel reprocessing plants and radioactive waste storage site, the local governments take the initiative in operating the environmental radiation monitoring programs. The fundamental objective of monitoring is to ensure the health and safety of the public around the nuclear facilities and to confirm that the environmental radiation doses are below the dose limit for the public.

To estimate accurately the facility-related component from the observed radiation dose, it is important to understand the factors associated with the variations of environmental radiation dose.

The sources of environmental radiation are subdivided into natural and artificial ones. Natural radiations consist mainly of cosmic rays, terrestrial gamma-rays and radiation from atmospheric radon progeny. Artificial sources of radiation originate in fall-out nuclides, radioactive waste gas, skyshine from nuclear facilities and

some other sources of industrial and medical usage. Moreover, bremsstrahlung generated by winter thunderstorms is peculiar to coastal district of Niigata and Hokuriku region in Japan. These sources are not uniformly distributed in the whole environment and radiations emitted from these sources have quite different ranges in their values and energy.

In this study, air-absorbed doses continuously measured around the light water reactors located at both Kashiwazaki city and Kariwa town were analyzed in order to clarify the relationships between the variations of environmental radiation and the environmental factors peculiar to cold and snowy area along the coast of the Sea of Japan.

2. Factors associated with the variations of environmental gamma-ray spectra in snowy area

The Kashiwazaki Kariwa nuclear power station commenced operation in September 1985. Since two years before, the Niigata Prefectural Government has

been carrying out the environmental radiation monitoring around the nuclear power station. Nine monitoring stations have been established within a radius of 10km from the center of nuclear power station, and five of them have been established within about 3km radii at almost regular intervals, and others at the densely populated area (Fig. 1).

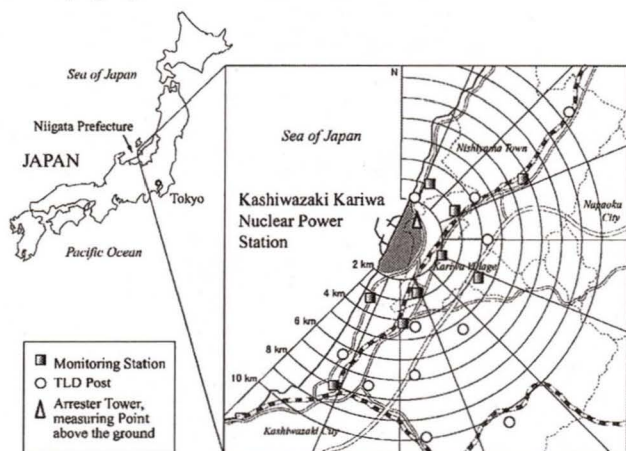


Fig. 1. Locations of gamma-ray measuring point.

Two kinds of detectors, consisting of NaI(Tl) scintillation detector (NaI) and pressurized ionization chamber (IC), have been used for the continuous measurements. From the former, in addition to the dose rate which was evaluated from the pulse height value by G(E) function method, the gamma-ray spectra could also be obtained as output pulse-height distributions every one hour, for the sake of the identification of the nuclides that affected the increase in dose rate.

The practical gamma-energy spectrum incident to the detector was obtained from the pulse-height distribution using the unfolding method with 22×22 response matrix proposed by Minato. The resultant variations were examined in each energy band as a function of time series. The variations were compared on the basis of apparent concentrations of natural radioactive nuclides in the soil, which were calculated from the gamma-ray energy spectrum.

In this chapter, the variations in the spectra, dependent on the precipitation and snow, were investigated.

It is well known that the environmental dose rate rises whenever the precipitation occurred around the monitoring site. This has been recognized to be derived mainly from the decay products of ^{222}Rn contained in the precipitation, which covers on the ground to form infinite plane source (Fig. 2). The same phenomena have been often encountered in the Kashiwazaki-Kariwa area since the environmental radiation monitoring was started. The increases in doses in the precipitation also show the

seasonal variations, which may be affected by different precipitation owing to various kinds of air mass origins. The increments derived from the precipitation owing to the continental air mass are higher than that owing to the maritime air mass. Also, the lower dose rate has been found in the winter season, since gamma-ray from the ground is partially shielded with thick snow.

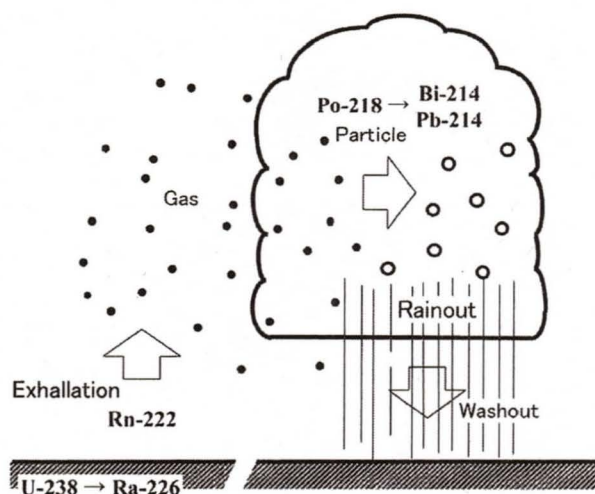


Fig. 2. Removal process of atmospheric radon progeny by clouds and precipitation.

Figure 3a shows a pulse-height distribution spectrum in the precipitation, in comparison with that before the precipitation, and 3b shows the energy spectrum converted by applying the unfolding method to the pulse-height spectra. There appears to be some clear increments of peaks assignable to natural radioactive nuclides of ^{222}Rn progeny in the precipitation. Main constituents to produce high dose rate were identified to be ^{214}Bi and ^{214}Pb of the U series, while the peaks due to ^{40}K and ^{208}Tl of the Th series offer a negligibly small contribution.

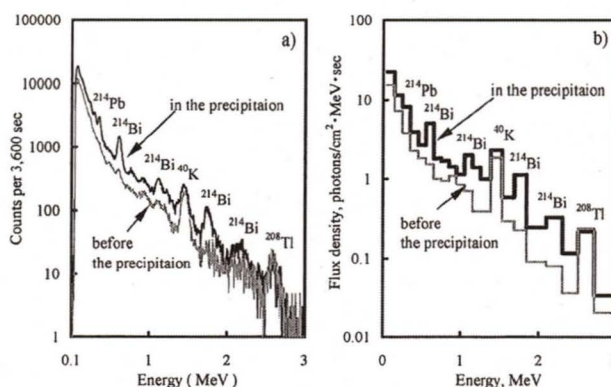


Fig. 3. Pulse-height distribution spectra (a) and converted energy spectra (b) by applying the unfolding method, in and before the precipitation.

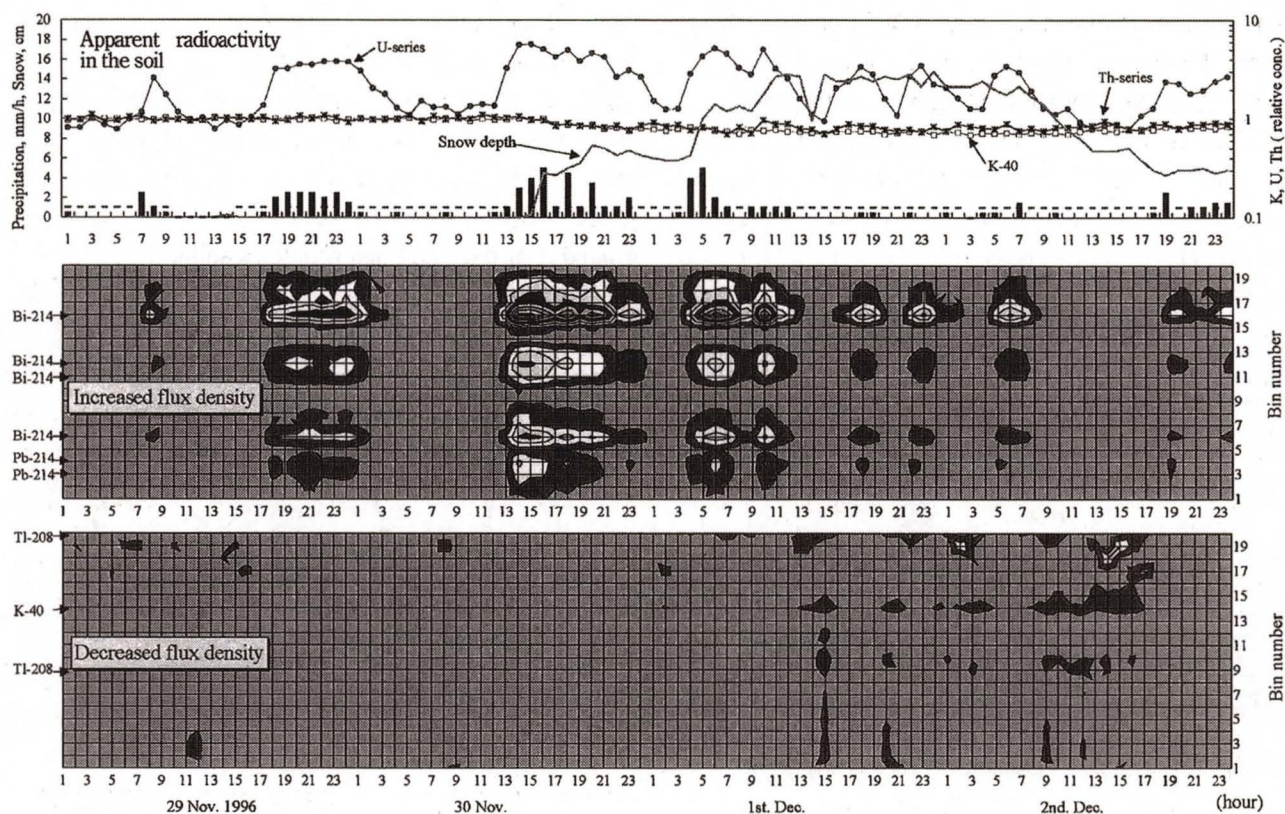


Fig. 4. Contour diagrams of energy spectra during a snowy period at Kariwa monitoring station: In the upper diagram, relatively increased flux density is shown as the contour lines beyond unity value in intervals of 0.5. On the other hand, contour lines are described under unity value in intervals of 0.2 in the bottom diagram.

The observed data at Kariwa monitoring station during a snowy period, from 29th November 1996 to 2nd December 1996, are demonstrated in Fig. 4. The flux density and the apparent activity intensities of ^{40}K , U series, Th series in the soil are shown at the relative values normalized to mean values on 26th November when no precipitation was recorded.

As illustrated in the upper diagram, the energy spectrum during rainy period certainly shows the tendency to increase the flux density in the bins belonging to ^{214}Bi (bin number 6,11,12,16) and ^{214}Pb (bin number 3,4). This result strongly supports that the progeny of ^{222}Rn contained in the precipitation are responsible for the increases in the gamma-ray flux density incident on the monitoring detector.

However, from the bottom diagram, it is interesting to note that the flux density decreases with a snowfall, especially in the bins containing ^{40}K (bin number 14) and ^{208}Tl (bin number 9,20). This is also positively seen in the line graph, in which the apparent decrease in the concentrations of ^{40}K and Th series radionuclides in the soil occurred. This was considered to be due to the shielding of a part of gamma-rays emitted from ^{40}K and Th series nuclides distributed in the soil by the snow cover layer.

Furthermore, the lowest values in the flux density of ^{40}K and ^{208}Tl observed when the snow depth covered the earth was not always at the maximum. The following reasons are taken into account to explain the experimental results: (1) the scattered radiation of gamma-rays from U series nuclides, distributed in the snow surface, tend to increase the flux density in the bins of ^{40}K and ^{208}Tl during a snowfall period, and (2) the decrease in peak, due to shielding effect by the snow shows the time lag from a peak of snow depth. This time lag was presumably derived from the fact that the increase of snow depth at the beginning produces porous snow layers. However, the consolidation of the snow layers must cause the high density of snow layer with the time lag.

In the case of U series nuclides, the shielding effect of the snow cover layer was not so prominent as compared to ^{40}K and Th series nuclides, although the precipitation after the snowfall can provide appreciably additional gamma-ray source.

3. Vertical profile of the environmental gamma-ray in snowy area: Possibility of bremsstrahlung X-ray generation by winter thunderstorms

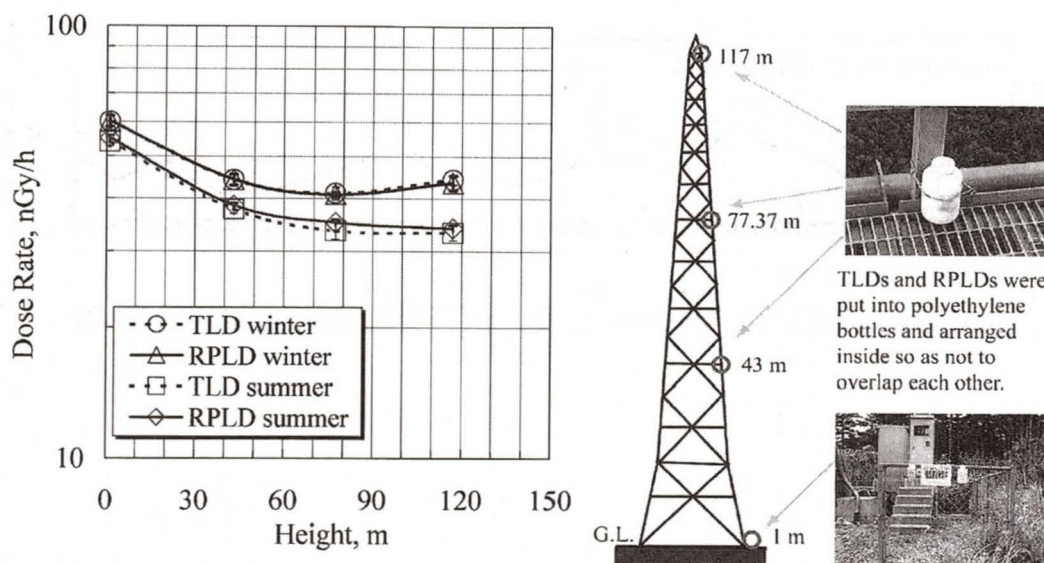


Fig. 5. Variations of mean dose rates with height above the ground at the arrester tower.

Winter thunderstorms often occur on the west coast of Japan, and it has been suggested that gamma-ray dose may increase occasionally during thunderstorms.

In Kashiwazaki Kariwa area, it has been repeatedly observed that the dose rates measured around the nuclear power station transiently increased under the winter thunderstorms, since October 1983, when the continuous measurements have been established. Taking into account the pattern of the variation in dose rate and the operational condition of the nuclear power station, it seems that these dose enhancements were not caused by the radiation emitted directly from the facility or by the contribution of artificial radionuclides released. It has been a problem to be solved for a long time what is the cause.

In order to elucidate the origin of these dose enhancements, the vertical profile of environmental gamma-ray was investigated. Measurements have been performed above the ground on the arrester tower located approximately 85m above sea level at the site of the Kashiwazaki Kariwa nuclear power station (Fig. 1). The arrester tower is 121.5m in height and at a distance of 720m from the nearest reactor.

Cumulative doses have been measured using the radiophotoluminescence glass dosimeter (RPLD) as well as the thermoluminescence dosimeter (TLD). All RPLDs and TLDs used were employed in the same batches respectively. Three TLDs and RPLDs were put into polyethylene bottles and arranged inside so as not to overlap each other, and set up at a height of 1, 43, 77, and 117m above the ground (Fig. 5). Monitoring periods were from 3rd July 2001 to 18 October 2001 (hereafter "Summer" period) and from 18 October 2001 to 16 April 2002 (hereafter "Winter" period). The results were

converted to mean dose rates.

Figure 5 shows the vertical profile of the mean dose rates in summer and winter seasons measured by both TLD and RPLD. The dose rates from TLD agree with those from RPLD within the measurement error at each height in both seasons.

As shown in Fig. 5, the vertical profile of upper region is in the reverse attenuation in winter. It seems that the rising trend with height is caused by some external radiation such as; (1) cosmic rays, (2) skyshine radiation caused by the gamma-ray emitted directly from the nuclear power facility, and (3) bremsstrahlung X-ray generated by winter thunderstorms.

According to the previous measurement result of vertical profile, there is not significant difference between cosmic ray intensity at sea level and that at an altitude of about 150-200m. Therefore, cosmic rays are not responsible to the rising trend with height in winter period, even if cosmic ray intensity in winter was larger than that in summer.

In the boiling water reactor like the Kashiwazaki Kariwa nuclear power station, the water is boiled inside the reactor core, and the steam passes through directly the turbine generator. As a result, exposure to skyshine radiation, caused by the high-energy gamma-rays from ^{16}N (2.74MeV: 1%, 6.13MeV: 69%, 7.12MeV: 5%) in the steam at turbine buildings, can occur along a line-of-sight path.

From the operation report of the nuclear power station, the rates of operation at nearest reactors were lower in winter period than those in summer. Although the intensity of skyshine radiation is directly proportional to the reactor power, the reverse attenuation phenomenon seems to be enhanced in summer period than in winter.

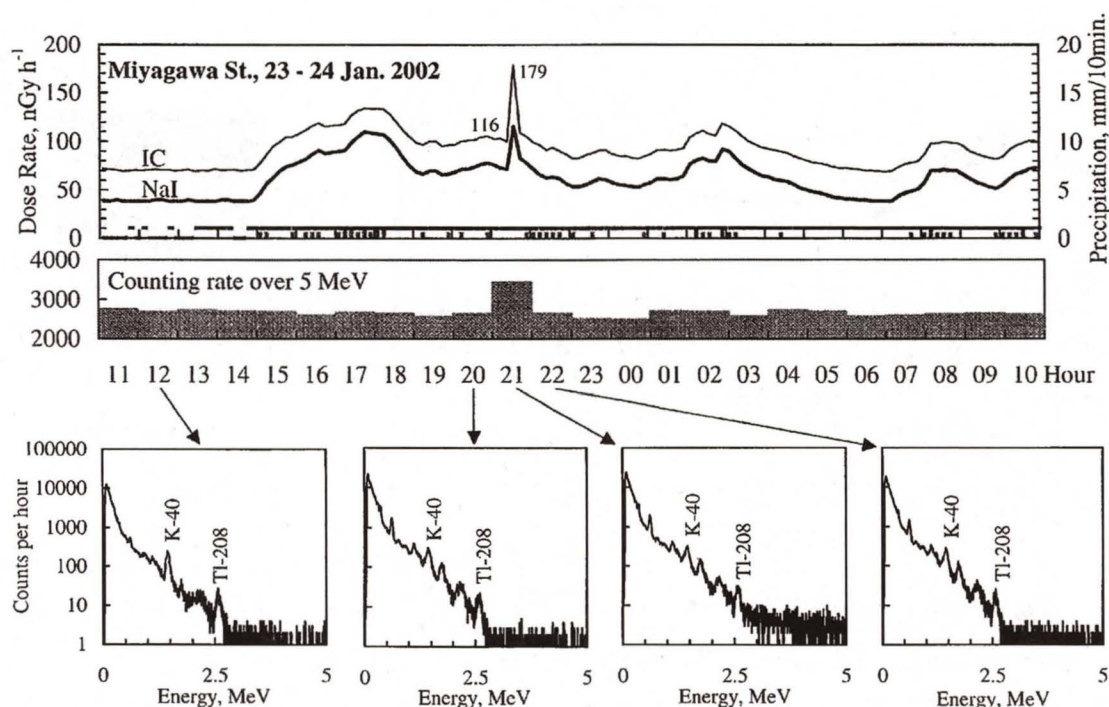


Fig. 6. Variations of dose rates, counting rate and pulse-height spectra in the thunderstorm period.

Therefore, it is considered that skyshine radiation is not responsible for reverse attenuation in winter.

In winter, cold and dry air from Siberia obtains heat and moisture from Tsushima Warm Current, and cumulonimbus develops over the Sea of Japan near Honshu Island. These clouds often develop to thunderclouds. As well as the Hokuriku coast, Kashiwazaki Kariwa district is one of the most active regions of the winter thunderstorms in Japan.

In that winter, many thunderstorms occurred and dose rates increased occasionally at monitoring stations. The rise appeared not only in IC detectors, which may be affected by some electronic noise, but in NaI detectors.

On the evening of 23 January 2002, there was a thunderstorm lasting until the reactor power, the reverse attenuation phenomenon seems to be enhanced in summer period than in winter. dawn, during which there was much lightning activity in this area accompanied by snow. At 21:40 JST on 23 January, dose rates of both IC and NaI in two monitoring stations (Katsuyama and Miyagawa) at a distance of about 2km from the arrester tower increased transiently at the same time. Figure 6 shows the variations of dose rate, counting rate of gamma-ray energy over 5MeV and pulse-height spectra of Miyagawa station in this period. Around that time, cloud-to-ground and cloud-to-cloud discharges were detected by the LPATS (Lightning Positioning and Tracking System) around the nuclear power station.

The NaI(Tl) scintillation detector is connected to a multi channel analyser (MCA) with 1,000 channels in the

energy range up to 5MeV, and the MCA stores the pulse height distribution at one hour intervals. In Fig. 6, only two peaks from ^{40}K and ^{208}Tl appear clearly in the pulse-height spectrum before the precipitation (see the spectrum at 12:00). After the beginning of precipitation, several peaks from ^{214}Bi and ^{214}Pb of short-lived radon progeny became visible (20:00, 22:00). Then, at 21:00 when dose rates increased transiently, the counting rate of incident photons in the energy range under 5MeV increased unusually. It is shown more clearly as the net pulse-height spectrum in Fig. 7, which is obtained by subtracting the background spectrum from enhanced spectrum including the time that the dose rate increase occurred.

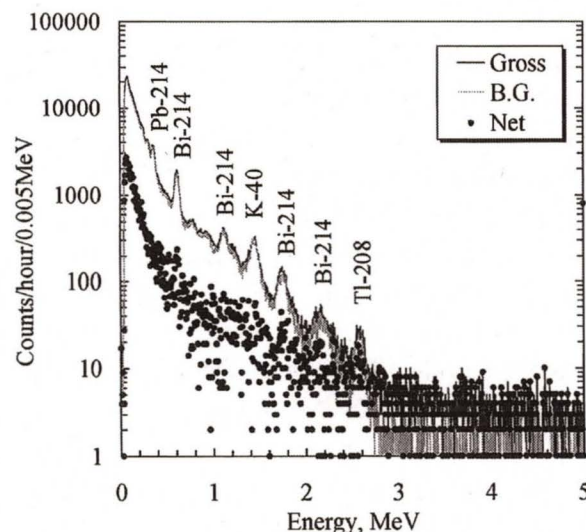


Fig. 7. Contribution of dose increase to the pulse-height spectrum.

If the increase in dose rate at 21:00 were due to radon progeny, peaks from ^{214}Bi and ^{214}Pb should be observed in the net pulse-height spectrum. However, there are no respectable peaks in net spectrum. Therefore, it seems that the increase dose not caused by radon progeny.

The counting rate over 5MeV also shows the increment at a period of time corresponded to dose rate enhancement. Thus, it is suggested that the dose rate enhancement under the winter thunderstorms is caused by bremsstrahlung generated by energetic charged particles, such as electrons, because the counting rate increased continuously with energy up to several MeV.

According to the previous Monte Carlo calculation of the behaviour of electrons and photons in the model thundercloud, the dose enhancement supported to be caused by the occurrence of the electron acceleration in a thunderstorm electric field and the following generation of a large number of bremsstrahlung photons in the sky of several hundred meters high.

It is reasonable that the vertical profile of the average dose rate in winter is in reverse attenuation with height in upper region.

From Fig. 5, dose increases at 117m above the ground, which measured by TLD and RPLD exposed during winter period were a few nGy/h in seasonal average or a few or tens μGy per 180 days in cumulative value. On the other hand, transiently increased doses at 1.5m above the ground obtained from NaI(Tl) and IC detector were tens nGy/h in 10 minutes value or several nGy per 10 minutes in cumulative value. Namely, cumulative doses observed from TLD and RPLD were 3 or 4 orders of magnitude larger than these from NaI(Tl) and IC detector. Thus, there was a large quantitative difference between the dose increment at the top of the tower and that on a nearby monitoring station. It may be caused by following reasons: (1) Pulse counting losses may have suddenly increased due to the dead time of the detector and MCA systems following the incident of photon burst; (2) Exposure at 1.5m is expected to be much smaller than that at 117m, since the flux density of photons emitted from high altitude attenuates in inverse proportion to the square of distance; (3) There is the possibility that many other events occurred to expose to bremsstrahlung X-ray at 117m and were not detectable due to attenuation at monitoring station on the ground.

Until now, the transient increases of dose rate have been observed only in winter season, not in summer. This may be explained as follows. Winter thunderstorms have qualitatively similar charge distributions to summer convective storms but the charging layers must be lower

in altitude, the main negative charge being 1 and 3km in contrast to be 5 and 8km in summer. If bremsstrahlung photons are emitted downward at an altitude of several kilometers, as would occur in summer conditions, dose increases on the ground would be very difficult to detect due to attenuation.

The mechanism of bremsstrahlung generation under the winter thunderstorms has not yet been perfectly clarified. However, it may be the first time to observe the reverse attenuation phenomenon of environmental radiation dose associated with winter thunderstorms. Although it is a rare event, further investigation must be carried out not only observation but also theoretical approach on generation of bremsstrahlung X-ray in winter thunderstorms.

4. Sensitivity dependence of the radiophotoluminescence glass dosimeter on environmental temperatures

In recent years, RPLD has been recognized to possess good characteristics such as repeated readout capabilities, excellent batch uniformity in sensitivity and long-term stability against fading. In order to apply RPLD to routine environmental monitoring in cold and snowy area, cumulative doses using RPLDs have been measured simultaneously in comparison with TLDs at the same monitoring points.

In this chapter, the difference between the results obtained by RPLD and TLD is discussed mainly with respect to the dependence on the ambient temperature.

For the investigations the RPLD model SC-1 (silver activated metaphosphate glass) and the RPL readout system model FGD-202 (Asahi Techno Glass Co., Ltd.) as well the TLD model UD-200S ($\text{CaSO}_4:\text{Tm}$) and the TLD reader model UD-512P (Matsushita Electric Apparatus Co., Ltd.) were used. All RPLDs and TLDs used were employed in the same batches respectively. The instruments were set up in a room of constant temperature of 22 - 23°C and constant humidity of about 55 rel.%.

The TLD reader was calibrated for every measurement using fixed dosage positions of ^{137}Cs source. On the other hand, RPLD readout system has been kept in sufficient accuracy by means of a built-in calibration glass, which was calibrated once a year.

Twenty-four monitoring points have been selected around the nuclear power station. Three RPLDs and TLDs were put into boxes made of vinyl chloride at a height of 1 - 1.5m above the ground, at each monitoring

point. Monitoring periods were every three months from the first quarter (April to June) of 1999 to the 4th quarter (January to March) of 2000, and the results were converted into cumulative doses per 91 days.

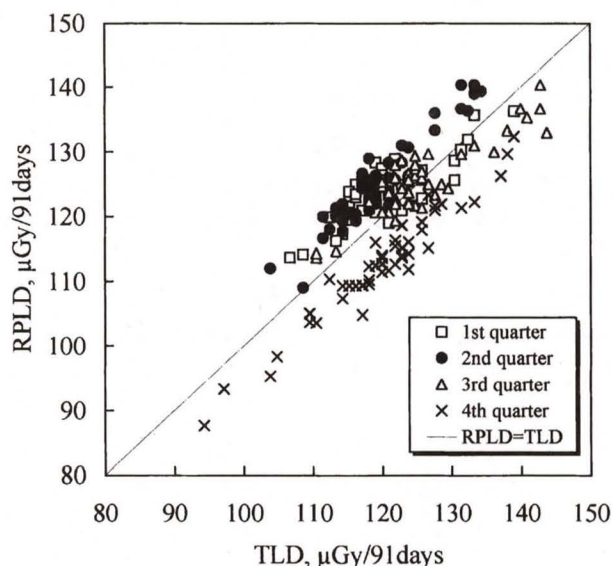


Fig. 8. Correlation between the measurement results of RPLD and TLD observed at 24 monitoring points.

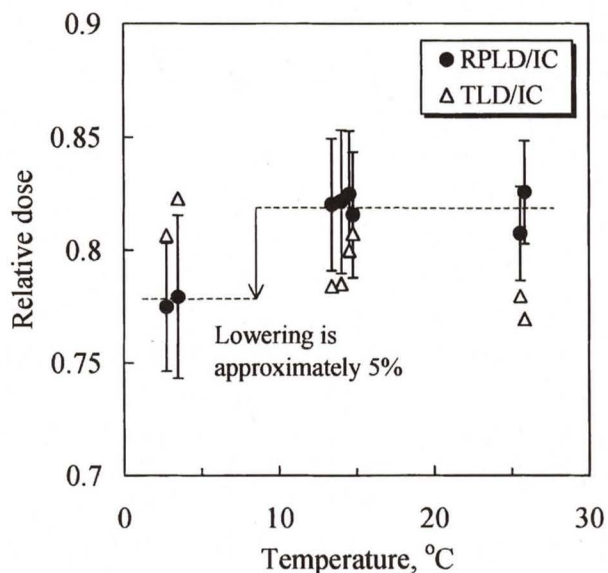


Fig. 9. Sensitivity changes in the average values of RPLD and TLD at 7 monitoring points as a function of the ambient temperature.

According to Fig. 8, there was almost good correlation between the results of RPLD and those of TLD. However, in the second quarter (summer), the TLD-values tend to become lower than the RPLD-ones at all points, and on the contrary, RPLDs give lower values than TLDs at all points in the fourth quarter (winter).

In seven of twenty-four monitoring points, the dose

rates have been measured continuously besides RPLDs and TLDs monitoring. The ambient temperature has been measured at two out of them. Both NaI(Tl) and IC detectors have been stabilized against the ambient temperature change by electronic devices.

The ratios of the cumulative doses obtained by RPLD and TLD to those of IC are defined as relative doses in order to describe the temperature effect on sensitivity, and are plotted against each ambient temperature. As shown in Fig. 9, the relative doses of RPLD have approximately 5% lower values in the 4th quarter (winter season), when mean temperatures come down below 4°C. On the other hand, in the other quarters, when mean temperatures vary in the 13 - 26°C range, the results have almost same values. In the case of TLD, including gradual or inevitable loss due to fading effect, the relative doses decrease with the rise of mean ambient temperature. These results are considered to be derived from the temperature dependence of dosimeter sensitivity. However, the mechanisms may be quite different in each other. The TLD is dependent on thermal fading, while the RPLD, which caused desensitization, is affected by some reaction mechanisms on low temperature.

To elucidate the phenomenon of sensitivity decrease, gamma-ray irradiation experiments were carried out under different room temperatures and exposure times. From these experiments, the amount of desensitization of RPLD is 3 - 4% below 6.3°C, in comparison with a negligible contribution above 8°C. On the basis of this research, RPLD seems to have sufficient availability for environmental monitoring in certain temperature regions. Nevertheless, it is necessary to keep in mind the sensitivity decrease of RPLD by about 5%, whenever it is used in cold areas in winter.

5. Monte Carlo calculation of terrestrial gamma-rays

Theoretical calculation to simulate the behavior of environmental gamma-ray has been expected to provide one of the most effective methods of analyzing the pathways of external radiation dose.

In this chapter, air-absorbed doses per unit source density were calculated above the ground using Monte Carlo code "EGS4" (Electron Gamma Shower Version 4) by assuming terrestrial gamma-ray from natural radio nuclides uniformly distributed in soil, then the calculated results were compared with the vertical profile of the environmental radiation dose described in chapter 3.

The calculations were carried out by extending the radius of the annular source region at each 10m, where the width and the thickness of each annular region were fixed to 10 and 0.5m respectively. The geometry size of the soil-air system is so large that calculations were performed with 5,000,000 histories per one trial, and the Marsaglia-Zaman random number generator was adopted so as not to cause the same sequence of random numbers. Air-absorbed doses per unit source density at 14 heights up to 120m above the ground were calculated for about 40 gamma-rays emitted from U-series, Th-series and ^{40}K . Table 1 shows the list of terrestrial gamma-rays considered in the calculation.

Table 1. List of terrestrial gamma-rays considered in the calculation.

	Nuclide	Energy	Emi.Prob.		Nuclide	Energy	Emi.Prob.
U-series	Ra-226	0.1862	0.0330	Th-series	Ra-224	0.2410	0.0390
	Bi-214	0.6093	0.4610		Bi-212	0.7273	0.0630
		0.6655	0.0156		Pb-212	0.2386	0.4310
		0.7684	0.0491			0.3001	0.0330
		0.9341	0.0319		Ac-228	0.1291	0.0260
		1.1203	0.1500			0.2095	0.0430
		1.2381	0.0595			0.2702	0.0360
		1.3777	0.0405			0.3284	0.0310
		1.4080	0.0248			0.3387	0.1200
		1.5092	0.0219			0.4633	0.0460
		1.7296	0.0298			0.7553	0.0100
		1.7645	0.1580			0.7718	0.0160
		1.8474	0.0210			0.7950	0.0440
		2.2042	0.0459			0.8356	0.0170
		2.4478	0.0141			0.9112	0.2700
	Pb-214	0.2419	0.0760			0.9644	0.0470
Potassium		0.2952	0.1890			0.9688	0.1600
		0.3520	0.3670			1.5883	0.0350
	K-40	1.4608	0.1067		Tl-208	0.2774	0.0680
						0.5107	0.2160
						0.5831	0.8600
						0.7631	0.0164
						0.8604	0.1200
						2.6145	0.9980

The gamma-ray flux from cylinder-slab source is the sum of the contributions from every annular regions included in that cylinder-slab.

Following the trial calculation of a monoenergetic radiation (^{208}Tl , 2.615MeV) as the source radius and the source thickness increase, the contributions to the total flux are saturated approximately at 500m in radius and 0.5m thick. Therefore, following calculations were carried out on the cylinder-slab source with 500m in radius and 0.5m thick.

To determine the volume source strength, soil was sampled at Katsuyama monitoring station and just under the arrester tower. Assuming radioactive equilibriums of U-series and Th series, the concentrations of ^{238}U , ^{232}Th and ^{40}K were determined from measurements using a pure Ge detector in our laboratory.

The calculated dose rate of terrestrial gamma-rays originated from natural radionuclides dropped faster with height than measured dose rates using RPLD and TLD,

without cosmic ray and self-dose contributions. It suggests that other sources, for example atmospheric radon progeny, have significant contributions to the environmental radiation doses in upper region. In addition, calculated results of collided flux for upper region may be underestimated within the applied history numbers, since the geometry size is enormously larger than the flight distances of electrons and photons from natural radionuclides and their detection probabilities are very small. This is the future problem to be solved.

6. Summary and conclusions

The relationships between the variations of environmental radiation doses and the environmental factors were investigated. The results obtained in this study is summarized as follows:

(1) From the variations in the environmental gamma-ray spectra, the increase in doses was derived from the precipitation originated from high flux density of gamma-ray from ^{214}Bi and ^{214}Pb , which are decay products of ^{222}Rn . The increments derived from the precipitation owing to the continental air mass are higher than that owing to the maritime air mass. However, during the snowy period, the decrease in the dose rates was attributable to the shielding of a part of gamma-rays from the natural radioactive nuclides, especially ^{40}K and ^{208}Tl , from the soil surface covered by the snow layers.

(2) The vertical profile of environmental gamma-ray was established at the points from 1m to 117m above the ground. The mean dose rate decreases with height above the ground in summer, however, in winter, it is in the reverse attenuation in upper region. According to the pulse height spectra at monitoring stations and to the result of the previous Monte Carlo calculation of the behavior of electrons and photons in the model thundercloud, it is considered that the rising trend of doses in upper region might be caused by bremsstrahlung X-rays generated by winter thunderstorms at high altitude of sky. It may be observed for the first time that the reverse attenuation phenomenon of environmental radiation dose associated with winter thunderstorms. As there are rare events, such kind of investigation must be further carried out not only observation but also theoretical approach on generation of bremsstrahlung X-ray in winter thunderstorms.

(3) It becomes evident that the sensitivity of RPLD decreases in the winter season, when the temperature is comparatively low. The amount of desensitization is 3 - 5% below 6.3°C, in comparison with a negligible

contribution above 8°C. On the basis of this research, RPLD seems to have sufficient availability for environmental monitoring in certain temperature regions. Nevertheless, it is necessary to keep in mind the sensitivity decrease of RPLD by about 5%, whenever it is used in cold areas in winter.

(4) Monte Carlo calculations of terrestrial gamma-rays were carried out by using the EGS4 code. From the results, calculated dose rates dropped faster with height than the observed ones that subtracted the cosmic ray and self-dose components from actually measured doses. It suggests that other sources, for example atmospheric radon progeny, have significant contributions to the environmental radiation doses in upper region.

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環境放射線の変動要因に関する研究

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環境放射線には、モニタリングの対象である原子力施設由来の放射線のほか、大地や大気中に含まれる天然放射性核種からの放射線、宇宙線、過去の核実験等により地球規模で拡散・沈着した人工放射性核種からの放射線等が含まれる。これらの放射線は、エネルギー範囲や方向分布が異なるとともに、放射線量が空間的・時間的に変化する等複雑な様相を示している。また、日本海側積雪寒冷地域においては、降水や積雪のほか、冬季雷など環境放射線の変動に寄与する特有の自然要因が存在し、施設寄与を評価するためには、これらの影響を明らかにしておくことが重要である。本研究は、原子力発電所周辺地域で測定した空気吸収線量データの解析を中心に、環境放射線の変動と日本海側積雪寒冷地域特有の環境要因との関連について考察した結果をまとめたものである。

原子力発電所周辺に設置したモニタリングステーションにおける空気吸収線量率及びガンマ線スペクトル連続測定データを、同時に観測した降水量及び積雪深との関係に着目して解析した。その結果、降水時の線量率上昇は主にウラン系列のラドン子孫核種であるビスマス-214と鉛-214からのガンマ線束の増加に由来するものであり、上昇量を一降水毎に分析することにより、冬季に多い大陸性気団の下での降水では大きく、夏季に多い海洋性気団の下では小さいことを示した。また、積雪時の線量率低下は、積雪層による地殻ガンマ線の遮蔽効果によるものであり、特にカリウム-40とトリウム系列のタリウム-208からのガンマ線束の減少が大きいことを示した。また、線量率最低値は積雪深最大時に対して時間的遅れを伴って発生するが、この理由は自重により積雪層が圧縮されるためであり、積雪水量最大時に対応しているものと考えられた。

実測例がほとんどない地上約百メートルまでの環境放射線の鉛直分布と季節変動を測定し、その結果を北陸から新潟までの日本海沿岸地域に特有の現象である冬季雷との関連を中心に解析した。原子力発電所構内の誘雷鉄塔上に高度別に積算線量計を設置して得た空気吸収線量率平均値は、夏期は高度とともに減少を示したのに対し、冬期は鉄塔上部で減少から増加に転じた。種々の要因を検討した結果、冬期間の鉄塔上部での線量増加現象は、雷雲で発生した制動X線の照射を受けたことによるものと結論づけた。冬季雷に起因すると考えられる地上付近での線量上昇を高度別に観測した事例は本研究が初めてである。

環境モニタリング用積算線量計として広く使用されてきた熱蛍光線量計 (TLD) に比べて、感度ばらつきが少なく熱フェーディングが殆ど無い等、その優れた特性から近年注目されるようになった蛍光ガラス線量計 (RPLD) に着目し、積雪寒冷地での環境モニタリングへの適用性を検討した。積雪寒冷地で RPLD を用いた環境放射線測定を行い、環境温度依存性について詳細に考察した事例はほとんど無い。2年間にわたり環境での TLD 及び電離箱検出器、NaI(Tl)シンチレーション検出器との比較測定を行い、室内での照射実験で検証した結果、平均気温 6.3℃以下の冬期の低温環境下では RPLD に 3-5%程度の感度低下が生ずることを示した。

モンテカルロ法による地殻ガンマ線の輸送計算を行い、実測した平均線量率の高度変化と比較した。その結果、地上百メートル程度までの上空の線量評価においては、大気中ラドン子孫核種からの放射線等地殻ガンマ線以外の寄与が無視できないことが分かった。

3 他誌発表

新潟県における放射能調査

笠原貢, 昆信芳, 丸田文之, 殿内重政, 加藤健二, 藤巻広司, 山崎興樹, 坂上央存, 田邊広和前年度に引き続き, 平成14年度に実施した文部科学省委託の環境放射能水準調査及び放射線監視交付金による原子力発電所周辺の環境放射線監視調査について, 調査結果の概要を報告した。

調査結果は次のとおりである。

1 全β放射能

定時降水等について測定したが, 各試料とも例年と同レベルであった。

2 空間線量率

柏崎刈羽原子力発電所周辺地域及び新潟市において測定したが, 各地点とも例年と同レベルであった。

3 核種分析

大気浮遊じん等について, ゲルマニウム半導体検出器により機器分析し, 海水等に ^{137}Cs を認めた。また, 放射化学分析により ^{90}Sr , ^3H , $^{239+240}\text{Pu}$ を認めた。これら検出された人工放射性核種は, いずれも例年と同レベルであった。

第45回環境放射能調査研究成果論文抄録集(平成14年度), 194(2003)。

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平成15年度日本物理学会新潟支部第32回例会, 新潟市, 日本歯科大学新潟歯学部, 平成15年12月6日(平成15年度日本物理学会新潟支部第32回例会ポスター発表予稿集, p.46, 2003)。