MEMOIRS OF THE COLLEGE OF SCIENCE, University of Kyoto, Series A,
Vol. XXVIII, No. 3, Article 3, 1957

ON SOME RELATIONS BETWEEN ATMOSPHERIC IONS AND NATURAL RADIOACTIVITY

BY

Sigeru OKABE

(*Received July 30, 1957*)

ABSTRACT

The relations of atmospheric ions to atmospheric radioactive substances and to ground radioactivity were investigated by a direct measuring method. Namely, the height distribution of alpha-particles in the air near the ground surface was measured by a newly devised nuclear plate method, and the density of alpha-particles in the lower layer of the atmospheric ions to atmospheric radioactive substances was studied by an ion counter and an induction collector. The correlation between atmospheric ions and ground radioactivity in the spa was also studied and both correlations were ascertained to a certain degree and will be discussed here in some detail.

1. Introduction

It is commonly accepted that, in the lower layer of the atmosphere, the radiation of the radioactive substances that are contained in the air and in the uppermost stratum of the earth's crust is the principal source of atmospheric ion formation. This is an important fact in our research, as it determines to some extent the behaviour of the electric potential gradient and the conduction current at the point close to the ground surface. Recently, Cotton (**1**) studied these relations by means of a special ionization chamber. However, the relation between atmospheric ion and natural radioactivity has hitherto been treated only by a theoretical presumption based on some experimental data, and certainly no direct measurement of these correlations has ever been carried out. Therefore, it is considered to be important to make a suitable observation to ascertain the adaptability of the theoretical treatment and also study the reliability of the above-described correlations. And moreover, from these observations, some developments in this research field are anticipated. For instance, the abnormal intense radioactivity on the ground surface in the neighbourhood of hot springs (**2**) and the variation of atmospheric radioactivity connected with an earthquake (**3**), which were already reported in this Memoir by the present writer, may more clearly be interpreted in connection with atmospheric ions. Concomitantly, the work by Ito (**4**) intending to clarify the luminous phenomena from the side of correlation of earthquake with ground- and air-radioactivity, is considered to be, anew, highly appreciated. In this paper, the results obtained by some direct measurements to study the relation between atmospheric ions and ground- or air-radioactivity, are reported in some detail.

2. Distribution of alpha-particles in the atmosphere

As the alpha-particle is the main ionization source of atmospheric ions, and moreover the distribution of radioactive elements in the air is also ascertainable by alpha-particles, measurement of the distribution of alpha-particles is considered to be highly important in the investigation of the relation between natural radioactivity and atmospheric ions. But, no practical, detailed measurement has yet been carried out on these problems, though there are some theoretical calculations by Priebsch (**5**) and the finding by Hess (**7**) based on the theory of Schmidt (**6**) and Priebsch. There are some possible methods to measure directly alpha-particles in the air. Namely, a method of measuring alpha-particles in the air directly by using a scintillation counter, a method of using some vacuum large ionization chamber into which is introduced a sample of air containing radioactive elements, a method of using a nuclear plate as a detector of alpha-particles, and others, are practicable ones. After comparing the advantages of these different methods, the nuclear-plate method was employed in preference to the others, in the present research. Throughout the following investigation, a newly devised nuclear plate camera with some accessories was utilized; and the distribution of alpha-particles in the air as observed with this equipment will be described. Observation was then carried out by means of the newly devised nuclear-plate camera with its accessories, and consequently, distribution of alpha-particles was studied.

2.1 Apparatus and method of measurement

Most of the radioactive substances in the air are Radon, Thoron, and their decay products (**8**) (**3**), and the artificial radioactive products as developed to the present are quantitatively negligible compared with natural ones. As an example, a part of the results of a continuous measurement of atmospheric radioactive substances conducted at a point one meter above the ground surface on the playground of Tottori University, in Tottori city, is shown in Fig. 1, and a comparatively large irregular variation is clearly observed. Cotton (**1**) describes in his report that this sort of variation is related to the turbulent exchange in the air adjacent to the ground surface. However, it is rightly interpreted from the observational result previously obtained by the writer (**3**) that this variation is mainly related to the difference of Radon content in different air masses. Moreover, it was found from the present observation by a nuclear plate method that the number of tracks observed of alpha-particles is extremely small, namely, being 1 track/cc/scores of hours. For these reasons, these sorts of observations should be continued over a fairly long period to avoid statistical errors and to obtain adequate proof.

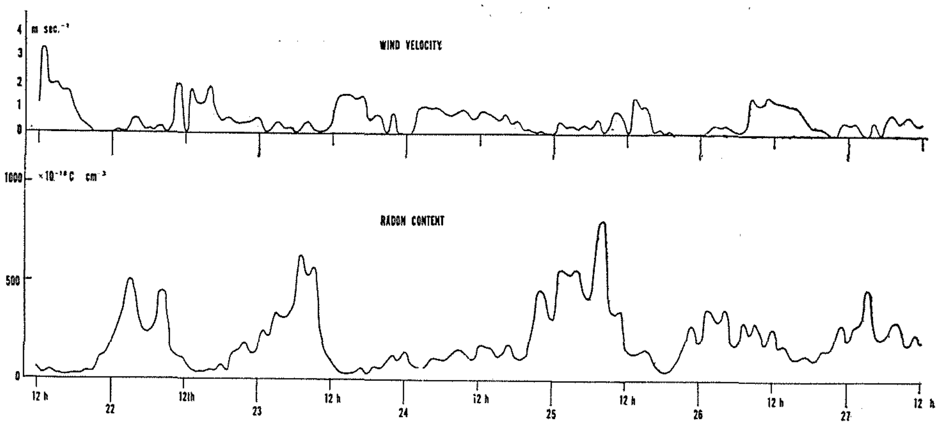

Fig. 1. Atmospheric radon content and wind velocity (July, 1956).

The apparatus and its practical manipulation in measurement are briefly described as follows: six camera-boxes, each size being $13 \times 12 \times 6$ cm, are jointed together into a single unit and the camera cover is loaded with six nuclear plates in its interior, the end of the air-introducing rubber tube on one side of each camera being kept at a suitable height, while the tube on the other side is connected to an aspirator-pump. An adjusting valve for keeping the air flow of same amount, and a light-interception plate are fixed at the connection point of rubber tube and camera box as schematically shown in an arrangement-diagram of Fig. 2. The power of the aspirator-pump is adjusted to 180 L/hour to prevent the disturbance of air at the pipe entrance, and the pump-motor is so arranged as to be operated by battery for portable purposes. First,

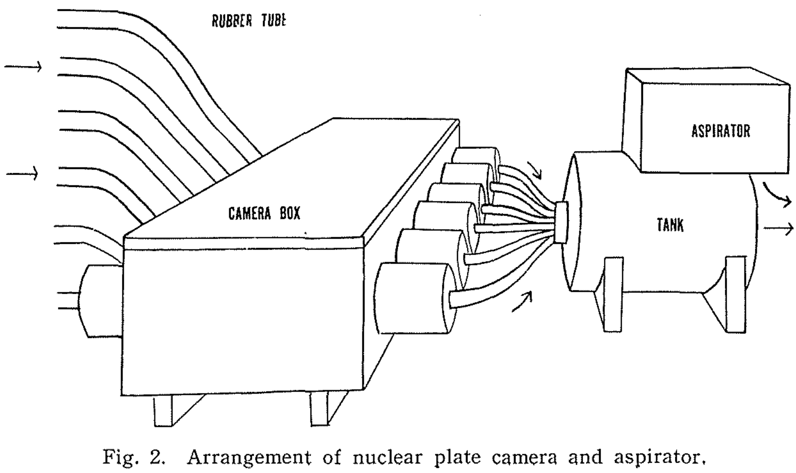

Fig. 2. Arrangement of nuclear plate camera and aspirator.

the camera was loaded with a nuclear plate, each rubber tube was supported at a suitable height, and then the aspirator-pump was operated for a period of 3~10 hours. The exposed nuclear plates were then developed as soon as possible after exposure. The number of alpha-particle tracks on 100 numbers of field of view by $\times$400-microscope were counted and the radius of each field was found to be 230 μ. (see Fig. 3) The nuclear plates "Sakura" were chiefly employed in the present observation, its emulsion thickness being 50 μ. In practical measurement, the effect caused by any disturbing radioactivity superposed upon the properly aimed radioactivity is appropriately corrected by comparing the exposed plate in the above-described treatment with the unexposed one.

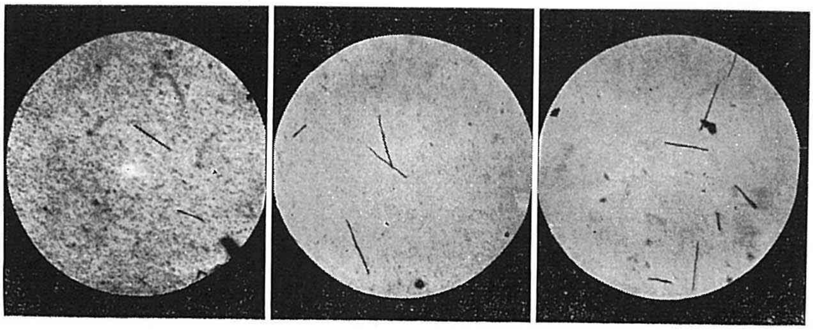

Fig. 3. Some examples of α-particle track observed by nuclear plate. ($\times$600)

2.2 Results

Considering the various conditions stated in the introduction, measurement was carried out at the plain, rice field, wood and spa, both in the daytime and at night. The results of observation are shown in Fig. 4, the ratio of each value obtained to the mean value is plotted for the benefit of comparing the relative distribution of alpha-particle with height. In Fig. 5, the sum of all data obtained during the 104 hours are shown without any consideration on any conditions concerning the observed place, weather, and other conditions; therefore it may safely be said that it shows the mean tendency of the distribution of alpha-particles. In this measurement some disturbing effects must be taken into consideration; such as the attachment of emanation, the inequality in the balance of radioactive equilibrium of the aspirated elements, and others. Moreover, as the number of tracks of alpha-particles which is registered on the nuclear plate shows some parts of total particles that are radiated in the camera box, it seems difficult to get an accurate, absolute value of height distribution of alpha-particles and radioactive elements by this method. From these reasons, the argument in the present research is reasonably restricted to the problem on relative correlation of intensity of alpha-particles with height.

In this measurement it was found that the sample air needs about 20 seconds to pass through the rubber tube, and therefore, considering the decay process of the radioactive substances, the results obtained should be interpreted as the intensity of alpha-particles measured at any level showing in reality a level higher than the height of the rubber tube-end. These level corrections are tentatively calculated after the theoretical treatment of Priebsch (5), and are as follows; for example, the height above the ground surface of 10 cm is corrected as 20 cm, 55 cm as 100 cm, 95 cm as 150 cm, and 200 cm as 310 cm respectively. But these corrections themselves need to be examined, because, the theoretical results by Priebsch and Hess of the alpha-particle distribution at the ground level, for example, are twice as large as those at the height of one meter, and are not in agreement with the practical measurement, as shown in Figs. 4 and 5. Though it is difficult, under such circumstances as above described, to obtain a definite conclusion concerning the height distribution of the emanation, it may possibly be said, from the present measurement, that the distribution-intensity of alpha-particles is comparatively

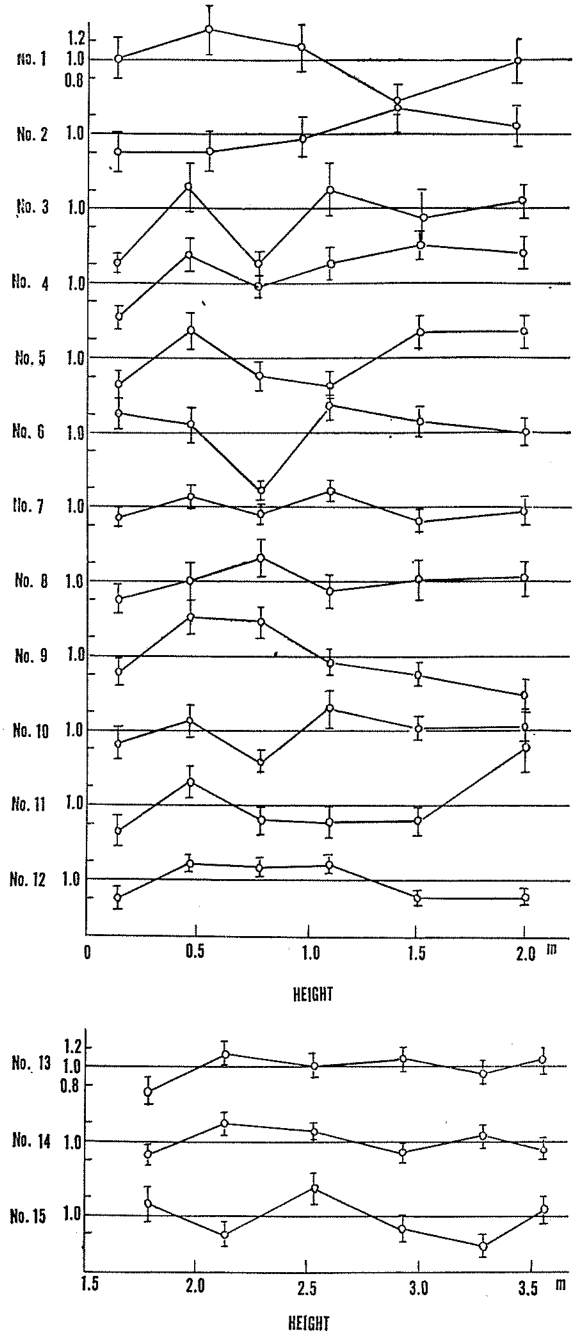

Fig. 4. Ratio of distribution of alpha-particles. Nos. 1, 4, 5: at play ground; No. 2: at valley of cypress; No. 3: at spa; Nos. 6, 7, 10, 11, 12, 13, 14, 15: at rice field; Nos. 8, 9: at bamboo grove.

small at the ground level, and large at 0.5 meter-height, and, from the level of 1.0 m up to 4.0 m, a certain fluctuation is observed with a range of less than 20% of the value at 1.0 meter-height.

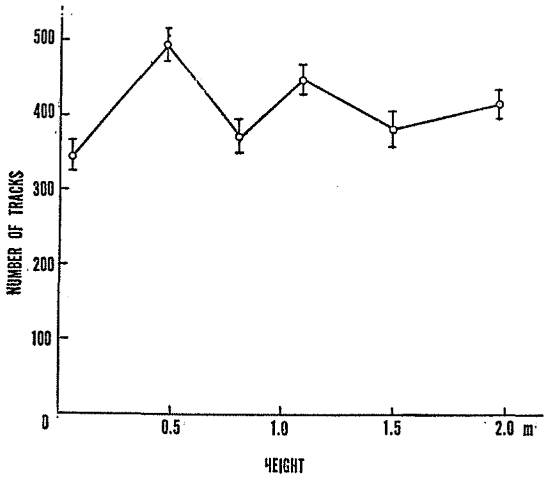

Fig. 5. Height distribution of alpha-particles.

3. The relation between atmospheric small ion and radioactive elements in the air

The diurnal variations in atmospheric radioactivity have been investigated at many locations throughout the world since the first observations in the early 1900. Also the continuous observations on the rate of ionization have been carried out at some stations, and the curves of their diurnal variations have been expected to show the same form. But, since the process of formation and destruction of small ions is too complicated, the relation between atmospheric radioactivity and atmospheric ions have not yet been investigated. Namely, the process of combination of small ions with condensation nuclei, the mingling with the ions formed at other places, the recombination with those of opposite signs, and other conditions are very complicated. However, it is quite interesting and essential in the research branch of atmospheric electricity to study whether or not there exists a certain correlation between atmospheric small ions and atmospheric radioactivity in the open field.

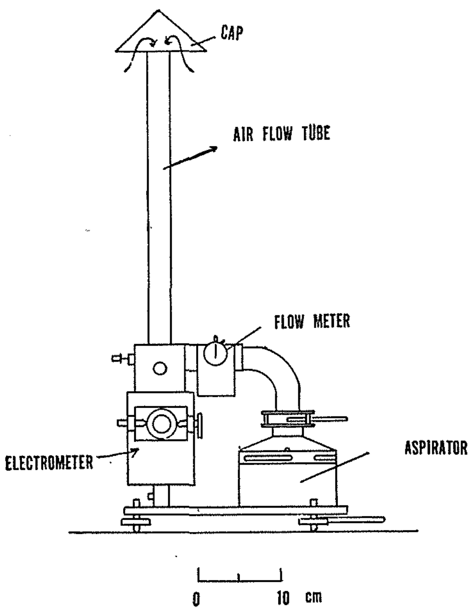

Fig. 6. Ebert ion counter with Wulf electrometer, No. 6191.

3.1 Apparatus and some considerations

(a) Apparatus for ion measurement

For the measurement of atmospheric small ions, a portable ion counter has been used, its construction is shown in Fig. 6. The essential features are, as seen in the figure, the air flow tube, the

Wulf-type bifilar electrometer, the anemometer connected at the base of the air flow tube, and the cylinder at the right-hand side of the electrometer in which is contained a spring-driven air flow fan. The cap on the top of air flow tube is equipped with a screen through which the air is inhaled into the counter.

The method of measurement is as follows: the fiber of bifilar electrometer was charged by a dry cell of 90 volts, operating the aspirator for five minutes, and then the number N of an anemometer was read. From the reading difference of division $(V_0 - V_t)$ of the electrometer, V_0 and V_t being the scale readings at the time of initial charge and at any time (t) after the initial charge respectively, the charged electricity in the central collector is given by an expression in the formula

$$E = \frac{16.18 \times (V_0 - V_t)}{N \times 1.16 \times 10^3 \times 300} \cdot \quad \text{(c.g.s. esu)} \qquad (1)$$

Supposing that each small ion has an elementary charge, the number of ions in the aspirated air, is given as follows:

$$n = E/4.8 \times 10^{-10}.$$

In some observations a vinyl pipe of 2 meters' length and 2 cm radius was connected to the air flow tube, for collecting the sample air at a higher level. In this case, not only the mass of inflowing air is decreased by the resistance of the vinyl tube, but an excess attachment of the ions to the inner wall of the tube is feared. Fig. 7 shows the result which was obtained by operating an ion counter attached to the vinyl pipe, when X-rays of known intensity were radiated to several different points on the vinyl pipe. But the existing condition of naturally small ions is so complicated that any regularity in the decrease in height cannot be expected in this case. Therefore the formula (1) cannot be applied in these cases and it is safely understood that the observed value shows only a relative correlation.

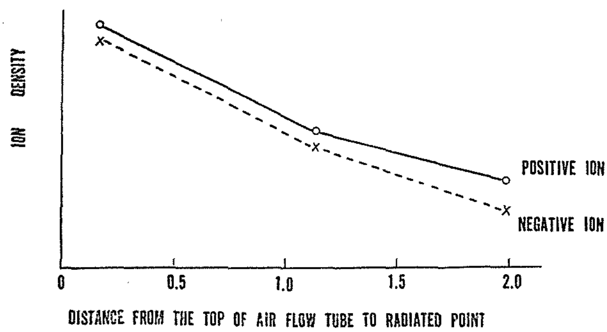

Fig. 7. Decrease of the flowing ions when vinyl pipe is connected.

(b) Collecting apparatus of atmospheric radioactive elements

The filter paper method is a well-known method for collecting atmospheric radioactive elements, but it has poor efficiency compared with the other two methods which will be described here (8) (9). Namely, the improved induction-method, and the corona-discharge method were employed in the present measurement. For the purpose of comparing the corona-discharge method with the induction method, the former was investigated with high voltage, 12 KV, similarly used by Wikening (**10**). It is ascertained by this experiment that the efficiency of the two methods for collecting atmospheric radioactive elements is nearly equal, and though the induction method can be expected to collect RaA and ThA, the corona-discharge method, on the contrary, cannot catch the positive charged elements. For instance, in studying the typical decay-curves plotted from the deposits of the two methods, the corona-discharge method shows considerably less uniformity in its shape compared with the curves of the induction method. Consequently, the improved induction method is more advantageously adopted than that of corona-discharge for the present research.

As the details of the improved induction method were already reported by the writer in this Memoir (**3**), only a simple description will be given here. Air of 2.0 m^3/minute is aspirated through the air tube of a 14 cm radius, and the metal plate charged with the negative high voltage of 11 KV, is hung in the centre of the tube; then the atmospheric radioactive elements and their decay products will be caught to that metal plate. After a 30-minute hanging of the metal plate, it is measured with the Lauritsen electrometer. The value of measurement expressed as d.p.m. (scale division per minute) shows the mean value of change in scale-division per 10 minutes in the present observations. The efficiency of this measurement was about 3% as examined with a known quantity of Radon. The amount of Thoron and its decay products are assumed to be comparative to that of the atmospheric Radon content.

(c) The effect of the electric field

At the location of the ion counter, it is considered that the apparatus is grounded through the body of the observer and a stand, and then the intensity of the electric potential gradient may be large at the top of the air flow tube. The influence of the electric field on the efficiency of the ion counter will be examined. Fig. 6 shows the arrangement used for this research. The area of the electrode plates which are used to make an artificial electric field is 3×2 m, and they are separated 1 meter apart from each other, X-ray being used as an ion source in this case. According to the results of measurement, as shown in Figs. 8 and 9, it may be said that the influence of the electric field is negligible so far

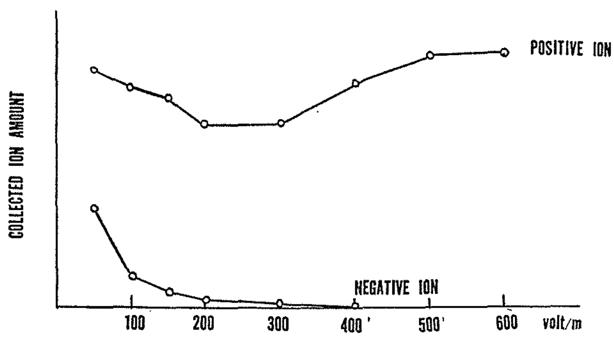

Fig. 8. Effect of the artificial negative electric field.

as the measurement of positive ions is concerned, because, in a normal condition, the potential gradient is about negative 100 volt/m. And as it is considered that the small ions which are made by X-rays have larger mobility than out-door small ions, the above-mentioned effect becomes increasingly negligible. Consequently, the measurement of the electric field was not made in these observations, but the observations were carried out at as unobstructed a place as possible to avoid any change of electric field influenced by some object as has been mentioned by Ishikawa (**12**).

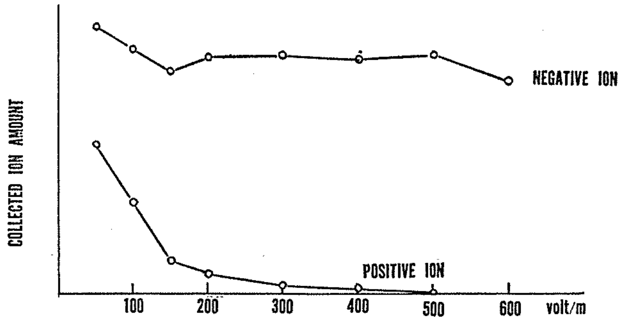

Fig. 9. Effect of the artificial positive electric field.

3.2 Measurement and results

(a) On the electrode effect

Hogg (**13**) and other researchers have reported that the potential gradient on a day of fair weather decreases with height in an area of few meters above the ground surface owing to a depletion of the negative ions in that area. This is the so-called electrode effect. The phenomenon is explained by the negative ions drift away from the earth due to the action of the electric field, and the concentration of the negative ions becomes small at the point close to the surface.

The influence of this phenomenon on the relation between atmospheric ions and radioactivity, in other words, on the relation between the height of the aspiration tube and the type of ions concerned, was studied in the present measurement, by connecting the vinyl pipe to the top of the air flow tube. According to ten preliminary observations, in cases where wind velocity ranged from 0 to 2 m/sec, no influence of electrode effect was observed as shown in Fig. 10 and Figs. 13, 14, 15, and also, with regard to the amount of positive or negative ions no difference was observed, as shown in Figs. 11, and 12. But so far as these observations are concerned, atmospheric radioactive substances and ions seem to have some correlation, and

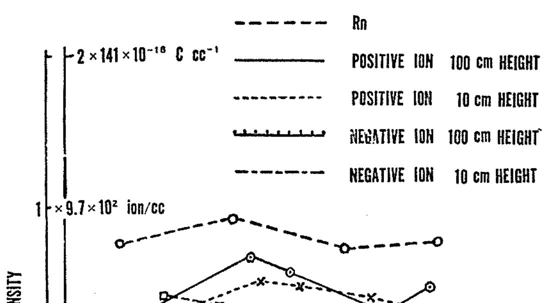

Fig. 10. Height distribution and time variation of ions.

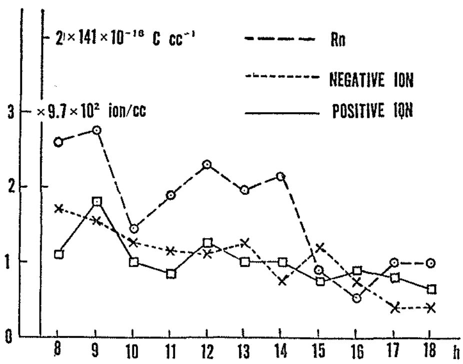

Fig. 11. Time variation of ions.

these results are fairly reasonable. From the above-mentioned reason, positive small ions are expected to be chiefly observed in the present case. Considering these phenomena of Fig. 10, the height of the cap of the air flow tube of the ion counter is profitably arranged at the level of 1∼1.5 meters.

(b) Results of the measurements

The measurement concerned was carried out at the play ground of Tottori University, and its condition are described in another report by the writer (**3**).

It is to be remarked that the data on rainy days are very scanty because the portable ion counter cannot be operated during rain. To investigate the results of Cotton (**1**), each datum was correspondingly compensated to the wind velocity observed at that time. In all of these measurements those data on which significant diural effects were observed are selected and explained here. The intensity of atmospheric radioactivity means the radioactivity of the substances which have been deposited on the collector-plate for the induction method during an interval of 30 minutes. The ion counter was operated for five minutes during the observation. The main wind directions are shown in Figs. 12∼19. Fig. 12 shows the special data on September 9, 1956, when Typhoon No. 12 was passing near the place of observation. In this figure, no general nature of the diurnal variation, and no correlation between the

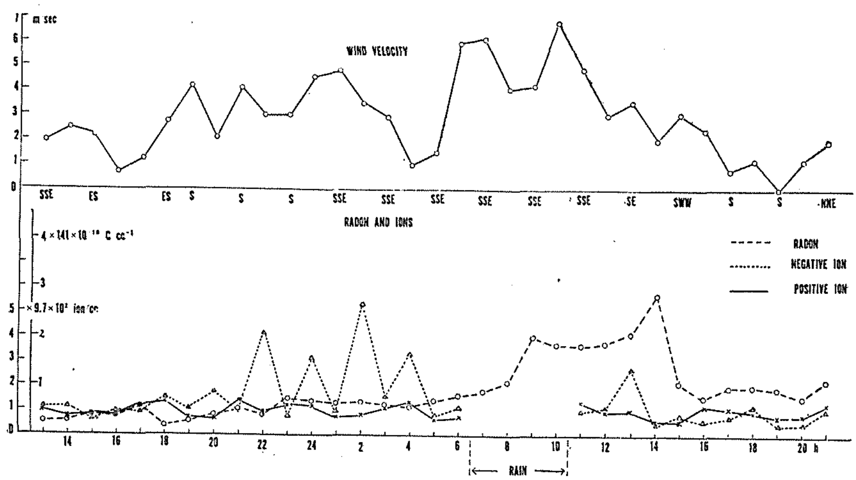

Fig. 12. Diurnal variation of ion, Radon and wind velocity on September 9∼10, 1956.

atmospheric ions and radioactivity can be detected, consequently the argument by (**1**), namely the relation between wind velocity and atmospheric radioactivity is not demonstrated from the data in Fig. 12. Fig. 13 shows the data on November 18, 1956, as an illustration of data on a calm cloudy day. In it a certain correlation between atmospheric ions and radioactivity is detected especially in the data of 10 cm height from the ground surface. Any definite relation of wind velocity to Radon cannot be observed here, too. Fig. 14 shows the data on November 21, 1956, when the mean cloud

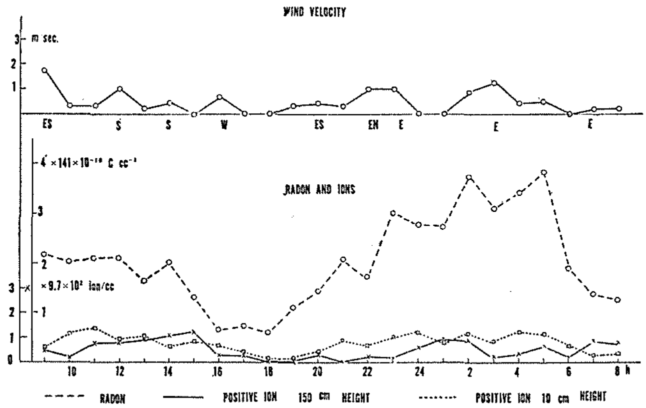

Fig. 13. Diurnal variation of ion, Radon and wind velocity on November 18~19, 1956.

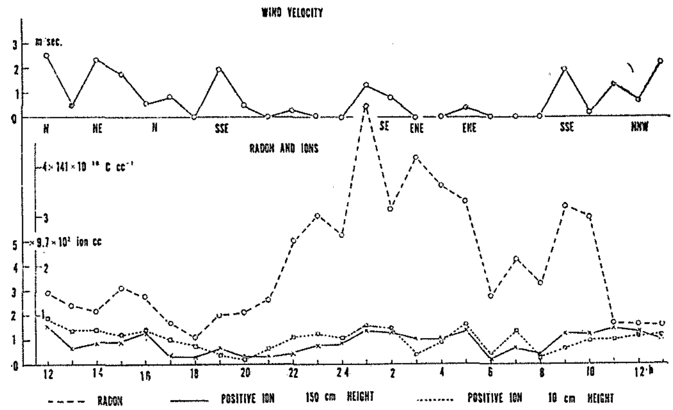

Fig. 14. Diurnal variation of ion, Radon and wind velocity on November 21~22, 1956.

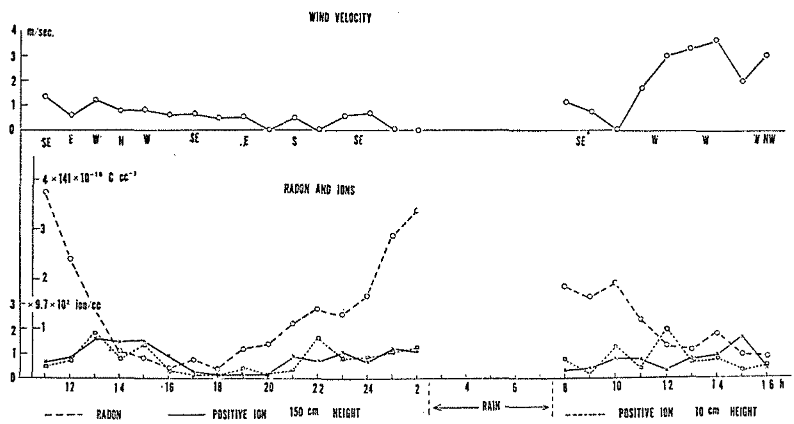

Fig. 15. Diurnal variation of ion, Radon and wind velocity on November 28~29, 1956.

quantity is half and the weather is fine. The correlation between ions and radioactivity seems to exist in some degree in this figure, being clearly observed particularly at about 18 h and 6 h, while, on the other hand, the relation of wind velocity to Radon is neither observed here, nor in Fig. 12.

Fig. 15 shows the data on November 28 and 29, 1956, when it rained from 2h to 8h on the 29th. It exemplifies the data observed before and after the rain. From the graph of 11h to 16h on the 28th and 9h–11h on the 29th, no correlation is observed. The relation of wind velocity to Radon is also negative in this case.

Fig. 16 shows the data on April 7, 1957, when the cloud quantity was 0 and fine weather lasted for about three days. The chart's curve is similar to that in Figs. 13 and 14 and, the correlation of ions to Radon is most clearly observed. Fig. 17 shows the data on April 13, 1957, when the cloud quantity was 0. Here, the correlation of wind velocity to Radon is fairly good, but the correlation of Radon content to ions is rather less; especially in the variation at 19h–22h and 7h–9h. Fig. 18 shows the data on April 26, 1957, when it had been raining heavily for three days just before the beginning of the observation. The play ground was covered with a sheet of water throughout the 26th; therefore, the ions which are generated at the ground surface by alpha-particles and beta-particles, are considered to have been greatly decreased. In this figure, the maximum atmospheric ions seem to be partially correlated with the Radon content, and

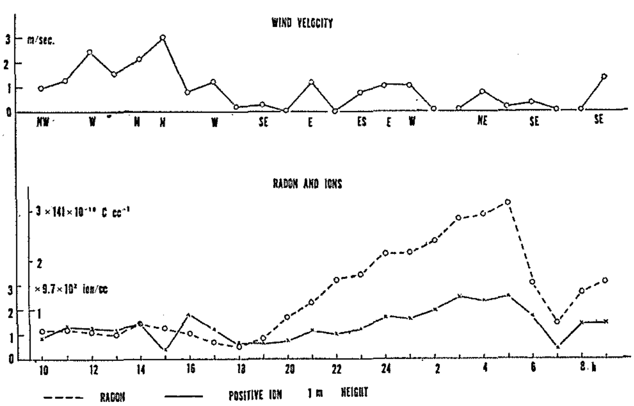

Fig. 16. Diurnal variation of ion, Radon and wind velocity on April 7~8, 1957.

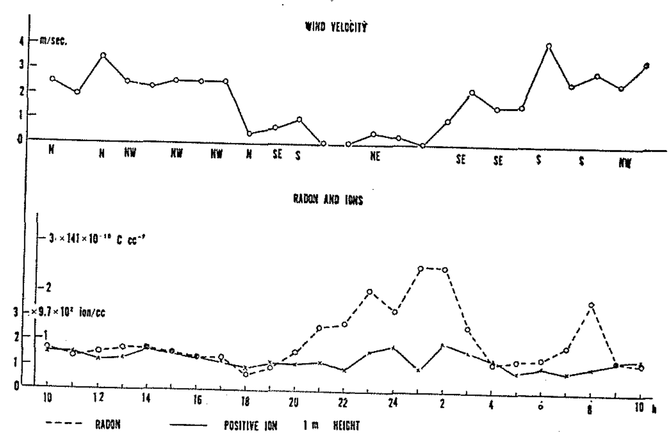

Fig. 17. Diurnal variation of ion, Radon and wind velocity on April 13~14, 1957.

its reason may possibly be attributable to the extinction of disturbing effect caused by ground activity which was greatly reduced by the cover of water sheet on the ground. Fig. 19 shows the data on May 9, 1957, when the cloud quantity was 0. It is an illustration of the atmospheric radioactive substances during the daytime which are considerably larger as in Fig. 13.

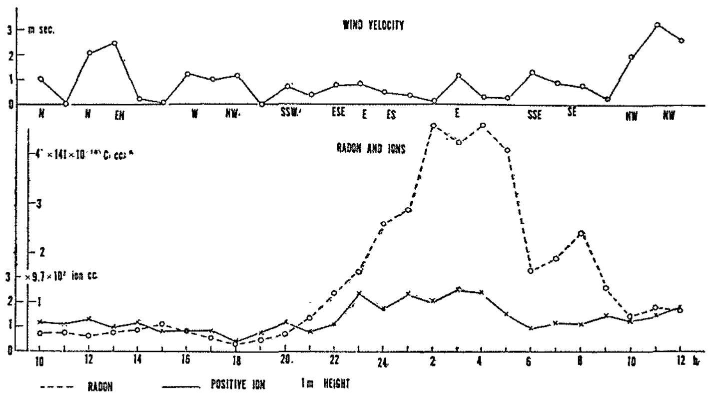

Fig. 18. Diurnal variation of ion, Radon and wind velocity on April 26~27 1957.

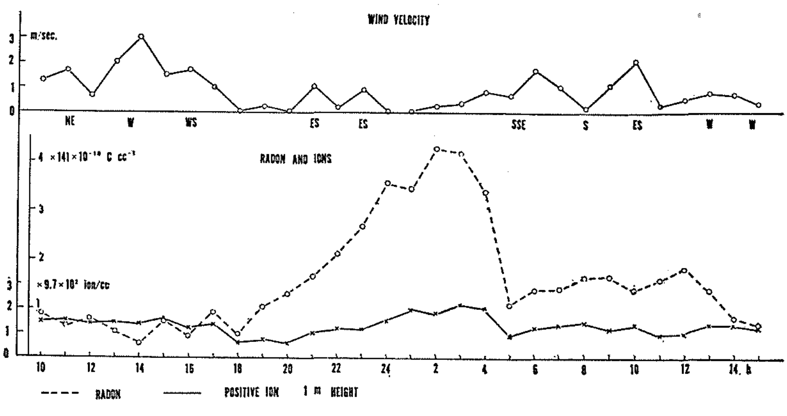

Fig. 19. Diuanal variation of ion, Radon and wind velocity on May 9~10, 1957.

(c) Conclusion and discussion

The process of ion formation is balanced by the process of ion destruction. The equation of ion balance was studied by Gish (**14**), and, under a suitable assumption, it is written as

$$q = 2\eta nN,$$

where q is the formation of small ions (expressed in ion pairs per cc per sec), η is the combination coefficient, n is the concentration of small ions (in ions per cc) and

N is the concentration of large ions. Therefore, if changes in q are neglected, the value of n is inversely proportional to N. The relation has been confirmed by several experiments, and it is an important condition which must be considered at present. The average value of ionization of the atmosphere, at one meter above the earth's surface, has been estimated lately by Hess (**15**) at about 7.3 ion pairs per cc par sec. The detail is as follows; 1.76 ion pairs generated by alpha-particles; 0.40 ion pairs by beta-particles; 3.15 ion pairs by gamma-rays; 1.76 ion pairs by cosmic radiation. According to this, the value of ionization by the atmospheric radioactive substances, may be estimated to be about 2 ion pairs. On the other hand, Hess (**19**) reports that, if the mean coefficient A of eddy diffusion at a point between 10 and 100 cm above the ground is assumed to be $0.5\,\text{cm}^{-1}\,\text{g sec}^{-1}$, the contribution of small ions produced by alpha-particles near the ground to the total ion content at one meter from the ground (about 200～600 small ions per cm^3) may be generally rather small (about 5–10 per cent). Therefore, the rate of ionization of the atmospheric source can be written as:

$$(1-0.1)\times\frac{2}{7.3}\cong 0.25\,.$$

This rate may change with the variation of the atmospheric conditions. In addition to this, it must be considered that a part of the measured small ions have travelled, being reduced along the path from other places to observation point, under the effect of electric field, eddy diffusion and density of neutral condensation nuclei. The process of collision of a small ion with a neutral condensation nucleus is also important.

From the above-mentioned consideration, the rate of atmospheric ions that are originated from atmospheric radioactive substances, seems to be about 20–10 per cent.

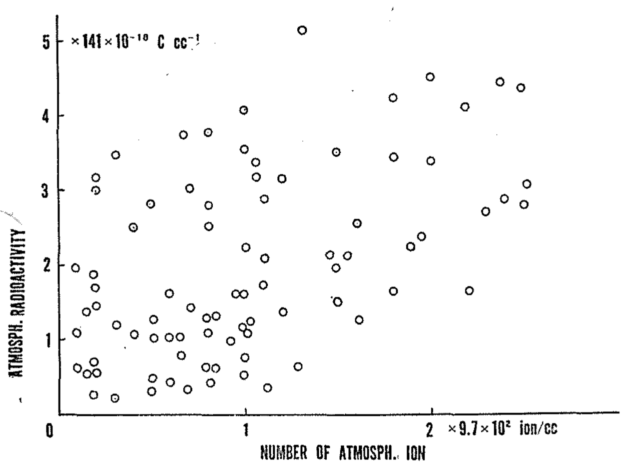

Fig. 20. Relation between atmospheric radioactivity and number of atmospheric ion at night.

Conversely, according to the observation in this research which was carried out during August 1956～May 1957, the relation between atmospheric ions and atmospheric radioactive substances is vague, as is shown in Figs. 11～18. Namely, the times when the atmospheric radioactivity and atmospheric ions show minimum values seem to coincide with one another in most cases, while the maximum value of positive small ion density at midnight is almost equal to the value during the daytime, in spite of the fact that the atmospheric radioactivity at midnight is about 5~10 times as large as that in the daytime. But, when the nighttime and daytime data are classified and arranged in a proper order, as shown in Figs. 20~23, the correlation seems to be fairly better at nighttime. Fig. 22 shows that 0~80% of atmospheric ions at night originates from atmospheric radioactive substances under the condition of Fig. 19. This phenomenon cannot be explained only by Austausch effect, and the correlation is considered to be certainly accidental.

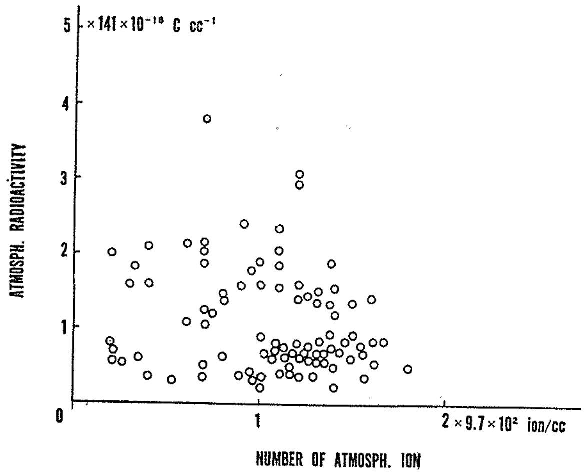

Fig. 21. Relation between atmospheric radioactivity and number of atmospheric ion at daytime.

Therefore, in consideration of this correlation, the possibility of appearance of the luminous phenomena which were often reported as following a destructive earthquake being explained by the increased atmospheric ions originated from the atmospheric radioactive substances following an earthquake, is concluded to be rather questionable.

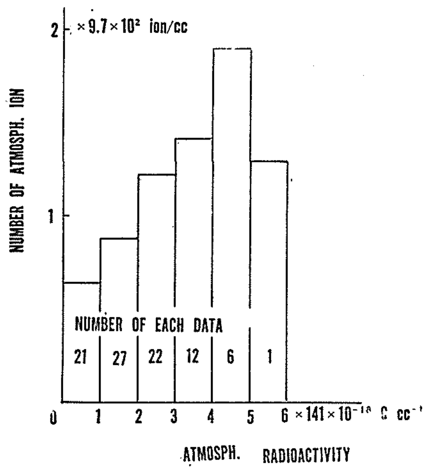

Fig. 22. Relation between atmospheric radioactive substances and ion density at night.

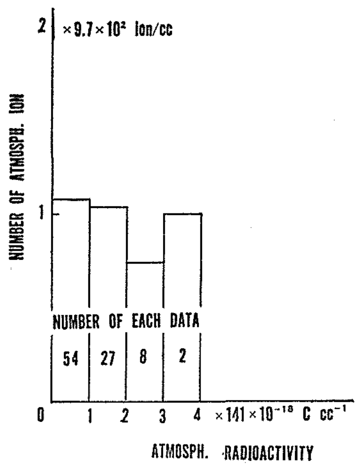

Fig. 23. Relation between atmospheric radioactive substances and ion density at daytime.

4. Relation between atmospheric positive small ions and ground radioactivity

The intensity of radioactivity on the ground surface is generally explained mainly to be influenced by the soil at that point, and especially, marked by the existence of the faults or hot springs.

Recently, Giletti (**17**) carried out some researches on the Radon leakage from radioactive minerals and Hatsuda (**18**) carried out researches on the intense radioactivity at the fault, and also the present writer investigated the intense radioactivity at the spa (**1**). Also, the writer has recently reported some correlation between electric potential gradient and the intensity of ground radioactivity at a spa (**19**). An abnormal space-charge density at the spa is, as a natural consequence, expected from these results. Therefore, the existence of a correlation between atmospheric small ions and ground radioactivity is also reasonably expected. Such correlation will be studied at several places.

4.1 Apparatus and method of observation

(a) Measurement of ground surface radioactivity

For the measurement of ground surface radioactivity a portable Geiger-Müller counter set called 2S–Pl was used, which was reconstructed so as to make it possible to connect two G–M counter tubes at the same time to meet the requirement of the present investigation. The details of this method of measurement were already described in another report by the writer (**2**), and will be mentioned briefly here. The natural counts of the 2S–Pl, which connect two G–M counters, are about 60~80 c.p.m., the counters being operated by dry cells. The end-window type counter which was used here, has a mica-window of 2 mg/cm^2, and is covered with 90 mg/cm^2 aluminium plate. The counter is supported 15 cm above the ground surface by a suitable stand. With this apparatus gamma-rays and a part of beta-rays are measurable, but it is assumed here that all radioactive radiation from the ground surface is proportional to the reading of the recorder.

(b) Measurement of ions

For the measurement of atmospheric ions, a portable ion-counter that is described in 3.1 (a), was used, and the height of the air flow tube was adjusted just one meter above the ground surface.

4.2 Measurement and results

Measurement was carried out simultaneously with an ion counter and a G–M counter at the same point for a duration of five minutes. Those days were selected when wind velocity was less than one meter and the weather was fine, because the area of abnormal radioactivity was relatively small as it was necessary to avoid the effects from an electric field produced by clouds. In a locality measurement, 3$\sim$6 hours are needed.

Assuming that the diurnal variation in the measured area is equal, the effect of diurnal variation is avoided by correcting the data obtained at the different points, compared with the diurnal variations observed after every three observations at the same fixed point.

Certainly, this amendment is not considered to be perfect but it seems to be rather conclusive in the present treatment. A preliminary observation was carried out to decide which observation would show a better correlation, an observation at nighttime or daytime. For several tests above mentioned, it was decided that all observations should favourably be carried out in the daytime.

The corrected results of measurement are shown in Figs. 24～28, and the map of each place has already been printed in the other reports by the writer (**2**).

Fig. 24 shows the observation at the Iwai hot spring and a. b. c. ··· denote the measured points. The geological formation at Iwai hot spring is a complex of tertiary tuff, shale and sandstone, and the Radon content in the thermal water is 1 Mache. The ground radioactivity measured by G–M counter is about 70～90 c.p.m.. This measurement was carried out between 9h～13h, when there was no wind and the weather was fine. The correlation coefficient between the atmospheric small positive ion density and the ground radioactivity is calculated as $r=0.50$. To illustrate the reason why the measurement was carried out in the daytime, two cases of measurement conducted in the afternoon and at midnight should be mentioned here. The correlation coefficient in the afternoon when the wind velocity was rather large, was $r=0.43$, and that at night on the same day was $r=0.27$.

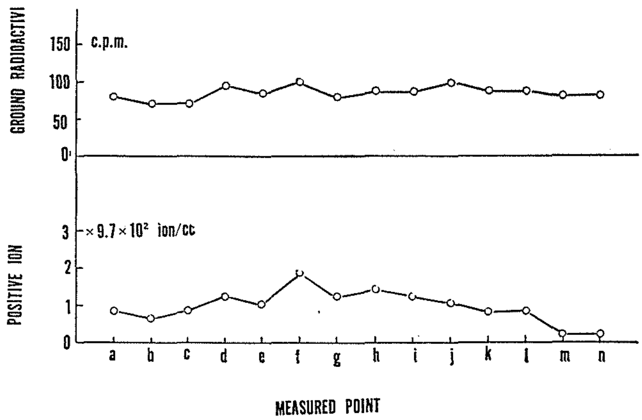

Fig. 24. Ground radioactivity and number of positive ion observed at Iwai hot spring.

Fig. 25 shows the observation at the Misasa hot spring. The bed rock of this area is porphyritic granite and it is intruded in spots by the fine grained granite, from where thermal water springs out. The Radon content of the thermal water is about 100 Mache and the Radium content of this region is large. The ground radioactivity measured by G–M counter is about 90～110 c.p.m.. The observation was carried

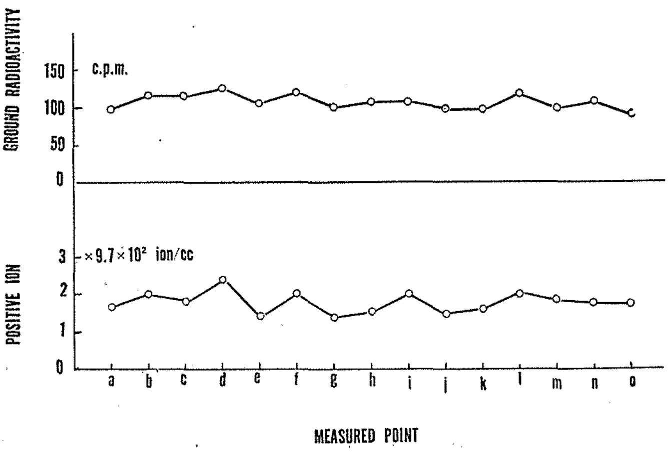

Fig. 25. Ground radioactivity and number of positive ion observed at Misasa hot spring.

out between 11 h and 15 h, when the wind velocity was almost 1 m/sec and the weather was fine. The correlation coefficient between atmospheric small positive ions and ground radioactivity is calculated as $r=0.65$. It is supposed that, if the wind velocity of that day had been smaller, the correlation might have become larger.

Fig. 26 shows the observation at the Hamamura hot spring. The bed rock of this region is formed by strongly radioactive granite and the ground surface is an alluvium area with alternating strata of clay-beds and gravel. This locality is surrounded by sand hills and rice fields. The Radon content in the thermal water is several Mache, and the ground radioactivity measured by G–M counter is about 70～100 c.p.m.. The measurement was carried out from 9 h to 14 h, when it was cloudy with no wind. The correlation coefficient between atmospheric small positive ions and ground radioactivity is calculated as $r=0.52$.

Fig. 27 shows the observation at the Togo hot spring. This locality is situated close to the southern part of the small Togo Lake, and its bed rock is granite covered

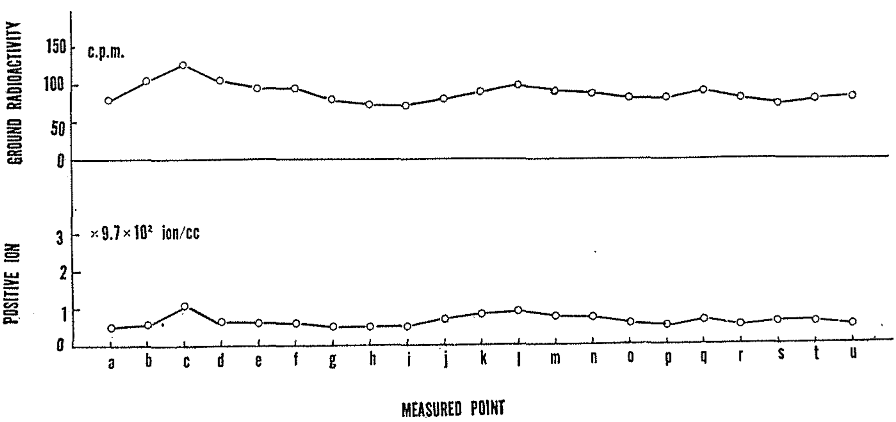

Fig. 26. Ground radioactivity and number of positive ion observed at Hamamura hot spring.

with a clay-bed and gravel. The Radon content of the thermal water is 2～18 Mache, and the ground radioactivity measured by a G-M counter is about 60～85 c.p.m.. This observation was carried out between 11 h and 15 h, when the weather was fine and the wind was blowing from the direction of the lake with a volocity of 1～2 m/sec. The correlation coefficient between atmospheric small positive ions and ground radioactivity is calculated as $r=0.62$.

Fig. 28 shows the neighbourhood of the Ikeda mineral spring which is situated

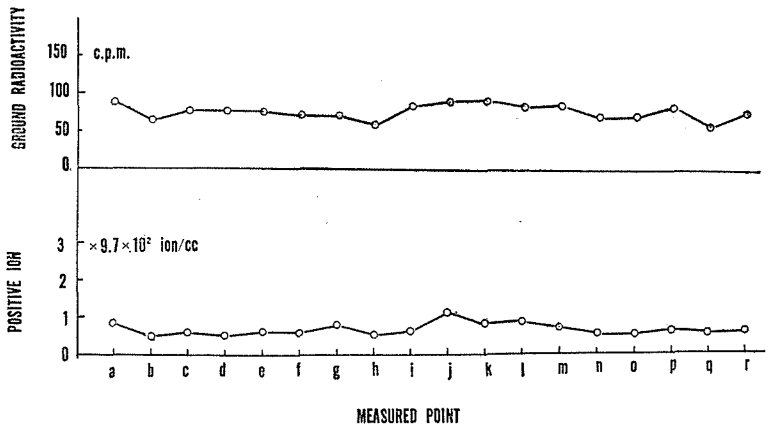

Fig. 27. Ground radioactivity and number of positive ion observed at Togo hot spring.

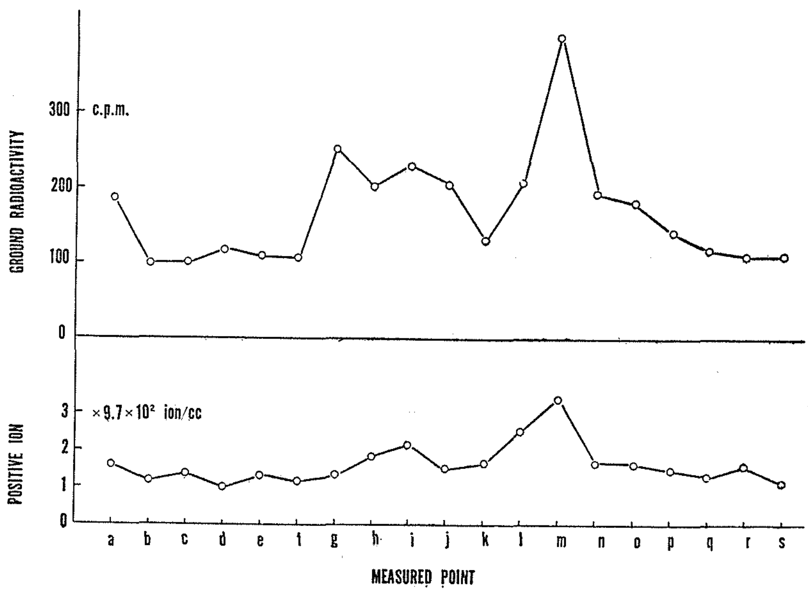

Fig. 28. Ground radioactivity and number of positive ion observed at Ikeda mineral spring.

at the foot of Mt. Sambe. The Radon content of the mineral water is 100～300 Mache and the content of Radium in the mineral water is as strong as 50×10^{-12} g/L.

The ground radioactivity measured by G–M counter shows 100～400 c.p.m.. The measurement was carried out from 9h to 16h when the weather was fine and the wind velocity was almost 1 m/sec. In the observation, some places were covered with a water sheet, and, in spite of a strong ground radioactivity at such places, the counts observed are mainly those of gamma-rays, as no ions would be ionized by alpha-particles and beta-particles at the ground surface by the interruption of the water sheet. For instance, point g was covered with water in the observation, and the correlation coefficient calculated becomes as large as $r=0.90$ if the g–point observation is excluded, and as small as $r=0.83$ when the g–point value is included.

Table 1

	Correlation coefficient	Ratio of mean ground radioactivity	Ratio of mean ion density
Iwai	0.50	1.00	0.56
Misasa	0.65	1.35	2.71
Hamamura	0.52	1.10	1.06
Togo	0.65	1.00	1.00
Ikeda	0.83 (0.90)	2.10	2.44
mean	0.62		

Table 1 shows briefly the results of these five observations. The mean value of correlation coefficient is fairly good. As already mentioned in §3, the rate of atmospheric ionization by cosmic-rays is about 25% and the contribution of atmospheric radioactive substances is estimated to be about 10～20%. Therefore, the contribution of ground radioactivity to the atmospheric ionization may be about 60%.

Moreover, a part of atmospheric radioactive substances is supplied from the ground surface at that point. The rate of contribution of the ground radioactivity will be larger, almost 70%. The effect of the ions moved by the wind may be small, as the mean life of small ions is short. These are the reason why the correlation coefficient of the present subject shows $r=0.62$. And this fact confirms the reports which were already made by the writer on the abnormal value of the electric potential gradient at a spa. (**19**).

5. Summary

Recently atmospheric natural radioactivity has been theoretically and practically studied as it has close connection with the atmospheric electricity and other natural phenomena. But the direct measurement of the distribution of atmospheric radio-

activity in the layer of atmosphere close to the ground, and of the relation between atmospheric ions and radioactivity, has not yet been carried out. In the present paper, some practical direct measurements on these phenomena were made, and the following results were obtained:

1) From the direct measurement by nuclear plate camera of distribution of alpha-particles in the air near the ground surface, it was found that the density of alpha-particles in the lower layer of air is small, contrary to the theoretical assumption of Hess. Consequently the application of the theory of eddy diffusion to these phenomena is considered to be inappropriate. The results obtained by the present direct measurement will certainly offer us an important knowledge on the atmospheric ion formation.

2) Measurement of the correlation between atmospheric ion and atmospheric radioactivity has been carried out in the field, and the correlation was ascertained to be conspicuously existing in the night, but not in the daytime. The ratio of atmospheric ions which are ionized by atmospheric radioactive substances to the total ions was calculated to be about 0～80%.

3) From the measurement of the correlation between the earth radiation and atmospheric ions in the field, the mean correlation coefficient was estimated to be 0.62. The percentages of ion formation by earth radiation and by atmospheric radioactivity are presumed to be 60～79% and 10～20% respectively.

Acknowledgment

The writer is greatly indebted to the kind guidance and pertinent advice given by Profs. E. Nishimura, K. Kimura and Y. Tamura, of Kyoto University and Dr. M. Kawano (of Elect. Labo.) throughout the present investigation.

REFERENCES

1. E. S. Cotton, J. Atmos. Terrest. Phys., **7** (1955), 90.
2. S. Okabe, Mem. Coll. Sci., Kyoto Univ., A. **28** (1956), 39.
3. S. Okabe, Mem. Coll. Sci., Kyoto Univ., A. **28** (1956), 99.
4. Y. Ito, Bull. Disaster Prev. Res. Inst., Kyoto Univ., **27** (1953).
5. J. Priebsch, Physik. ZS., **16** (1931), 622.
6. V. F. Hess and W. Schmidt, Physik. ZS., **19** (1918), 109.
7. V. F. Hess and G. A. O'Donnel, J. Geophys. Res., **56** (1951), 557.
8. E. Tasima and T. Doke, Kagaku, **26** (1956), 124 (in Japanese).
9. W. Anderson, W. V. May Neord and R. C. Turner, Nature, **174** (1954), 424.
10. M. H. Wilkening, Nucleonics, **10** (1952), 36.
11. C. C. Lauritsen and T. Lauritsen, Rev. Sci. Instr., **8** (1937), 438.
12. G. Ishikawa, M. Kadena and M. Kitamura, Journ. Geomag. Geoelec., **4** (1952), 1.
13. A. R. Hogg, Mem. Comm. Solar Observatory. Cambera, **7** (1939), 1.
14. O. H. Gish, *Terrestrial Magnetism and Electricity*, (New York, 1938), 182.
15. V. F. Hess, Arch. Met. Geophys. Biokl, A. **3** (1950), 56.

16. V. F. HESS and W. D. PARBINSON, Trans. AGV, **35** (1954), 869.
17. B. J. GILETTI and J. L. KULP, Am. Mineralogist, **40** (1955), 481.
18. Z. HATSUDA, Mem. Coll. Sci., Kyoto Univ., B. **21** (1954), 231.
19. S. OKABE, Liber. Arts J. Tottori Univ., No. **5** (1954), 10.