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TIME VARIATION OF THE ATMOSPHERIC RADON-CONTENT NEAR THE GROUND SURFACE WITH RELATION TO SOME GEOPHYSICAL PHENOMENA

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ABSTRACT

The daily variation of atmospheric Radon-content near the surface of the ground was observed in Tottori for one year and the effect of wind direction, wind velocity, atmospheric pressure, atmospheric temperature, and rain fall on Radon-contents of atmosphere were investigated. And from these data, the influence of local earthquakes occurring in the vicinity of Tottori on the increase of atmospheric Radon-content is discussed in some detail and their correlation was fairly well ascertained.

1. Introduction

The discovery of radioactive substances in the atmosphere was made by Elster and Geitel (**1**), who gave a physical explanation by it for the weak conductivity of the air. After them, many measurements of radioactive substances in the atmosphere have been made at various places in the world. These investigations have made it clear that the chief radioactive substances in the atmosphere are Radon, Thoron and their decay products, and they have a close relationship with the meteorological elements and the position of observatory. The fact that the mean Radon-content in the atmosphere near the ground surface over the continents amounts to about $100 \sim 2000 \times 10^{-18}$ C cm^{-3} and over the oceans to about $1 \sim 2 \times 10^{-18}$ C cm^{-3}(**2**), shows that the origin of Radon is continental, and this suggests that the Radon-content in the atmosphere may have some relation with any geophysical phenomena originating from the change of state of the ground, for example, in case of the occurrence of earthquakes or the displacement of active faults. Taking meteorological and seismological factors into consideration, a series of measurements of the atmospheric Radon-content were made at the site of 2 m above the ground surface once a day for a period of one year from March, 1955 to February, 1956 at the play ground of Tottori University in Tottori. The details of the experiments and the results will be presented in the following.

2. Method of measurement

In measuring the radioactive elements in the atmosphere, Radon is preferably adopted as the object of measurement, for it has a relatively long half-life, this condition being considered to be the most suitable in the present investigation for detecting any correlation between the time variation of atmospheric radioactivity and geophysical phenomena. There are three possible methods of measuring the radioactive elements in the atmosphere; one is in removing the emanations from the air by absorption and condensation, and measuring them in an ionization chamber, or only using an ionization chamber of large volume for measurement (e. g. 13~45 liters by Vancour (**3**)). Since the above-mentioned "enrichment method" is comparatively difficult for daily measurement, and also since, in the large ionization chamber method, only small part of the atmospheric Radon is measured, these methods were not employed. The second method utilizes the property of some radioactive decay products which carry a positive electrical charge. These products are deposited on negatively charged collectors, where their ionization effect can be examined. This technique is termed the "induction method". The experimental technique of the induction method is simpler than that of emanometry, but quantitatively less reliable. The third method consists in the deposition of radioactive matter from a given amount of air by point discharge, as suggested by Sella (**4**). The same method in a modernised arrangement was used recently by Wilkening (**5**). In these circumstances the "induction method" was preferably used for the present investigation after improving both the method and instrument so as to increase quantitative reliability.

(*a*) *Arrangement of the induction method*

According to Eckmann (**6**), the RaA atoms are positively charged immediately after their formation. Furthermore, the other by-products also carry, at least in part, electric charges. Consequently, if they did not soon lose a large part of their charge by interaction with the ions in the atmosphere, they would be collected on a negatively charged body. The general type of a practical technique for carrying out such measurements is that in which a wire is kept at a high negative electric potential, exposed for several hours, and then wound on a spool and examined in an ionization chamber. Concerning this method, Gerdien (**7**) and Bauer (**8**) tried some improvements and introduced the aspiration process for collection.

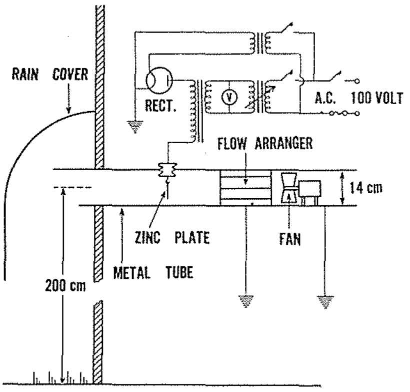

Fig. 1. Measuring arrangement.

In the present investigation the following induction method was adopted, its arrangement being shown in Fig. 1, and the practical technique is briefly described as follows: the aspiration tube is set at the height of 2 m above the ground surface; the velocity of air aspiration is adjusted to 2 m/sec; a piece of metal plate of zinc ($4.5\times6\,\mathrm{cm}^2$) is hung for 30 minutes in the aspirator tube, and it is kept at an electric negative potential of about 11 K.V. After the metal plate has acquired a certain amount of radioactivity, it is measured with a Lauritsen electrometer, the value of which is expressed as d.p.m. (scale-division per minute) and shows the mean value of change in scale-division per 10 minutes in the present observations. Both the velocity of air aspiration and the plate's electric negative voltage were so arranged as to gain the most favourable conditions for the present study, after numerous careful tests. By the above described arrangement, the weak point of the induction method (the uncertainty of measured air mass), is greatly mitigated, and it is certainly serviceable for the present study on time variation of air Radon. Since the Lauritsen electrometer (**9**) is well known, the description of its details will be omitted here.

(*b*) *Comparison with actual value*

It is said that the induction method supplies only relative values which, when obtained under similar working conditions, are more or less comparable with one another. However Eve (**10**) has obtained reliable quantitative results by exposing the collecting wire in a large closed vessel, $16\,\mathrm{m}^3$ in volume, and compares the resultant activity with that obtained under the condition of a known quantity of Radon in the same vessel.

In the present case, a method was applied to get a reliable actual Radon-content. A known quantity of Radon, which has reached equilibrium with its decay products, is sent into the aspirator. It is measured by the above-described induction method, and the division of Lauritsen electrometer is compared with a known quantity of introduced Radon. Then from the result obtained, a division of 1.0 d.p.m. on the Lauritsen electrometer is approximately equal to $141\times10^{-18}\,\mathrm{C\,cm}^{-3}$. But in this report, the content of Radon is generally shown by d.p.m. units except for special cases.

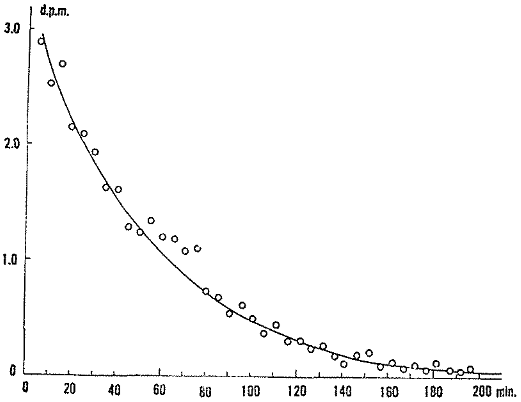

Fig. 2. Decay curve of Type I.

(*c*) *Decay of collected radioactive elements*

From the observation of the decay curve of induced decay products, collected elements can be analysed. The data of decay curves, which were obtained from prelimi-

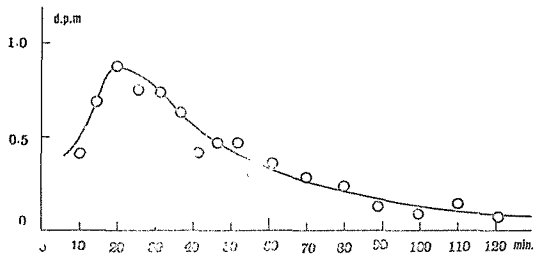

Fig. 3. Decay curve of Type II.

nary observations conducted at Tottori from December 1952 to January 1954, and Misasa (a place of radioactive hot springs) from September 1952 to June 1953, can be classified into two representative types, which are shown in Figs. 2 and 3. The analysis of a curve of the type as that in Fig. 2 by means of the ordinary procedure for examining the graph represented by means of a semilogarithm shows that the collected elements are RaA, RaB and RaC, while a curve of the type as in Fig. 3 shows that the same elements are contained, but in this case RaB and RaC have not reached a radioactive equilibrium with RaA. In conclusion, it has been made clear that the radioactive elements collected on the surface of a metal plate are only decay products of Radon.

The appearance percentage of the two types of curves mentioned above are respectively 10 : 1 at Tottori and 3 : 1 in Misasa. The high ratio of Misasa is considered to be attributable to its local characteristic of having many radioactive hot springs, each spring containing 100～300 mache Radon. In carrying out these observations, it was planned to measure the air Radon every noon in routine work and to denote the mean value of division of the first 10 minutes in the decay curve as the Radon value of that day.

3. Variation of the atmospheric Radon-content

The daily observation by the method described above was made during the one year period from March 1955 to February 1956 at the play ground in the Tottori University to study the relation of atmospheric Radon-content with the meteorological elements. Some relations obtained from these observations will be discussed in this section.

(*a*) *Diurnal variation of Radon-content of the atmosphere*

Becker (**11**) and Maček (**12**) reported that the diurnal curves certainly show a single period with a maximum during the night and a minimum during the afternoon. Measurements conducted in Tottori show somewhat different results from those obtained by Becker and Maček having some time lag, as shown in Fig. 4. In this figure, the curve of Radon-content seems to correspond to the diurnal variation of temperature, except during the time of a rain fall. Its reason is supposed to be that the rate of exhalation of radioactive gas from the soil is affected by the temperature, dryness of the soil, surface ground moisture, and wind force. In general the temperature has a close relationship with the above-mentioned effects; for example, in the daytime there being no dew and the temperature being high, by the diffusion and suction effect of the wind upon the ground capillaries, Radon is brought into the atmosphere and transported to greater heights by vertical convection, and then the Radon-content in the lower air becomes small. And moreover, the Radon-content may be affected by a change in electric field, as Radon decay products carry positive charges. But in the present observation the measurement of electric field was not made, and its effect remained unsolved.

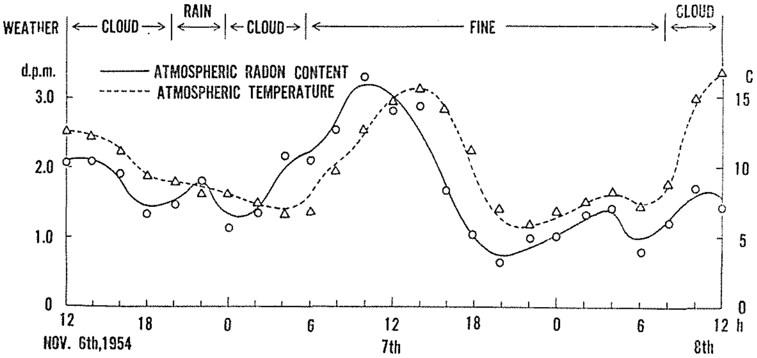

Fig. 4. Diurnal variation of atmospheric Radon-content observed at Tottori.

(*b*) *Relations to direction of the wind*

It is expected that the Radon-contents of the atmosphere become large in land wind and small in maritime wind, when they are measured at Tottori which is close to the Japan sea. In this section the relation between the direction of the wind and the mean value of Radon-content will be discussed. On such phenomena as the hysteresis of the wind, i. e. the classification of winds from Siberia or from Korea, or the effect of deep snow, for example, no consideration is given here. The data during the observation year classified according to the direction of wind are averaged for each direction and their "standard value" are shown in Table 1. The meaning of "standard value" is as follows: the reliability of each mean value of Table 1 is not equal, because the number of data of each wind direction is not the same and, moreover, there may be some uncertainty as to the wind direction. To avoid these defects, by giving the weight of accuracy of 1.0 for the mean value of a wind direction and weight of 0.5 for the both mean values for adjoining direction, a weighted mean value of three adjoining directions is assigned for "standard value". Thus the "standard value" is supposed to show smoother and more reliable data than the ordinary mean value, and be more suitable for future treatment, as shown in Fig. 5 which shows the mean and standard values for each wind direction. It is also to be

Table 1. Atmospheric Radon-content correlated with the wind directions.

Wind direction	Mean value (d.p.m.)	Number of data	Standard value (d.p.m.)
N	0.71	18	0.75
NNE	0.67	20	0.79
NE	1.11	40	1.06
ENE	1.38	14	1.19
E	0.92	6	1.17
ESE	1.46	14	1.44
SE	1.93	22	1.83
SSE	2.01	8	1.79
S	1.24	25	1.42
SSW	1.18	12	1.22
SW	1.29	9	1.14
WSW	0.81	20	0.91
W	0.73	15	0.67
WNW	0.41	5	0.54
NW	0.58	17	0.62
NNW	0.90	31	0.77

Remarks.

When direction of the wind observed at 9 and 12 o'clock differed so large from each other, these data are omitted here.

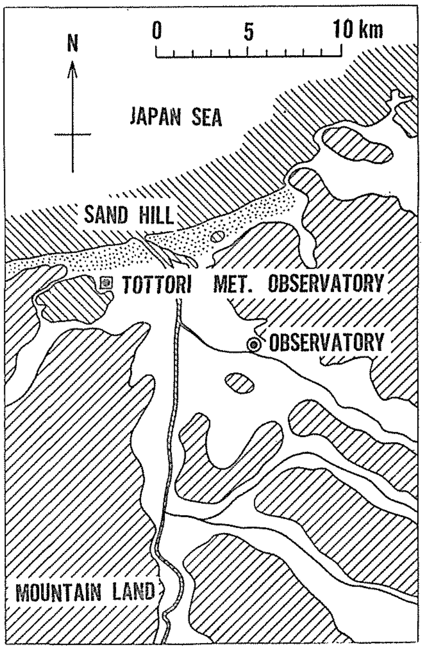

Fig. 6. Position of the Observatory and its surroundings.

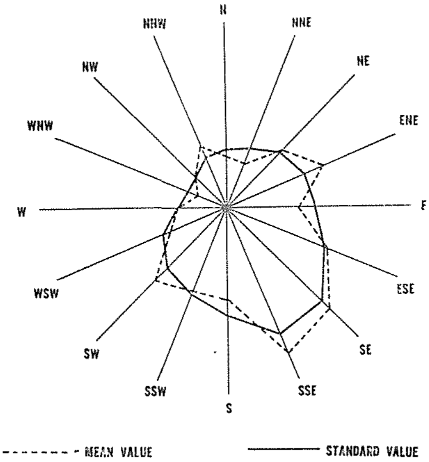

Fig. 5. Value of atmospheric Radon-content for each direction of wind at Tottori.

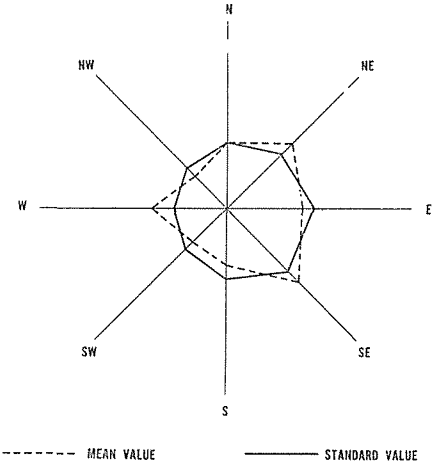

Fig. 7. Value of atmospheric Radon-content for each wind direction at Misasa.

remarked that the direction of the wind of that day was decided by referring to the data of wind direction observed at 9 and 12 o'clock in Tottori Meteorological Observatory and when direction of the wind at both times differed so greatly from each other, the latter was employed. For the convenience of reference the position of the observation station and the Tottori Meteorological Observatory, and their surroundings are shown in Fig. 6. The value assigned for the north-west wind representing air masses of maritime origin shows small Radon-content in contrast to the south-east wind whose standard value is exceedingly large. The standard values of each wind direction observed at Misasa from September 1952 to May 1953 are shown in Fig. 7. As the observation place of the Misasa Middle School at Misasa is situated to the north-west of the radioactive hot springs, the standard value observed at Misasa is considered to be greatly influenced by the effect of Radon exhaled from the hot springs and their neighbourhood. Concerning the reliability of the difference of the standard value above obtained in case of Tottori, the significance of the difference between those for the north-wind and south-wind was examined by stochastics and the reality of existence was recognized with great certainty in the significant level of 0.1%.

(*c*) *Relation to precipitation*

Maćek (**12**) reported that the precipitation, particularly that of long duration, decreases the Radon-content; this can easily be explained by a decrease of exhalation due to the clogging of the ground capillaries and in addition, the absorption of Radon by rain drops. In the present observation the data on their relation are listed in Table 2,

Table 2. Correlation between precipitation and atmospheric Radon-content.

Precipitation (mm) / Radon cont.	3	8	13	18	23	28	33	38	43	48
0.2										
0.5	1	5	4		1					
0.8	2	3	4		1	1	1			1
1.1	4	3	1							1
1.4	3	2								
1.7	1				1			1		
2.0		1		1						
2.3	1	1		1						
2.6	2									
2.9		2								
—										
—										
5.6			1							

$r \fallingdotseq -0.09$ (correlation coefficient)
Value of "Radon-content" is the ratio to each standard value.

in which the correlation of precipitation during the 24 hours before the time of Radon observation and atmospheric Radon-content is tabulated. In this case, correlation coefficient of -0.09, and significant level of 60% by stochastic calculation, tells us that their correlation may safely be neglected in the present treatment.

(*d*) *Relation to atmospheric temperature*

The seasonal variation seems to run generally parallel to the temperature curve as, for example, in the case of Messerschmidt (**13**), but there are some exceptions as in the case of the observation at Innsbruck, where the atmospheric Radon is highest in the cold season. In the present treatment, those data are selected which are between 1015 mb and 1020 mb atmospheric pressure in order to avoid the effect of atmospheric pressure, and the relation between atmospheric Radon-content and atmospheric temperature is investigated. The data are listed in Table 3, and the correlation coefficient calculated is 0.06 in this case. For the test of significance of correlation, the significant level of 70% is derived from stochastic calculation which permits a safe neglect of effect by atmospheric temperature upon the variation of atmospheric Radon in the present treatment.

Table 3. Correlation between at mospheric temperature and atmospheric Radon-content.

atom. temp. (C°) / atom. Rn cont.	1	4	7	10	13	16	19	22	25
0.2							4		
0.5	1			1	2	3	6		
0.8			1	3	4	2	3	3	
1.1		1		1	1	4	1	3	2
1.4					1			2	1
1.7	1	1	1		1			1	
2.0				1		1			
2.3				1					
2.6									2

$r=0.06$

Value of "Radon-content" is the ratio to each standard value.

(*e*) *Relation to atmospheric pressure*

According to Maćek (**12**), Kosmath (**14**) and Priebsch (**15**), falling pressure increases the Radon-content and rising pressure decreases it, as is to be expected from the atmospheric influence upon the exhalation, whereas Smyth (**16**) denied these relations. In this section the data of April, May, June and July which seem to show comparatively large variations of atmospheric pressure are selected and listed in Table 4. The correlation coefficient in this case becomes -0.20, and the significant level, calculated for test of significance, of correlation is 5%, which means a negative low correlation.

Table 4. Correlation between atmospheric pressure and atmospheric Radon-content.

atom. press. (mb) / atom. Rn cont.	998	1001	1004	1007	1010	1013	1016	1019	1022	1025	1028
0.2			2			1					
0.5	1	1		3	6	2	6	2			2
0.8	1		3	2	13	6	3	4	5	2	1
1.1		2	3	3	10	8	3	2		2	
1.4		1		1		5	2				
1.7		1	1	2	1		1				
2.0			2			1	1				
2.3		1									
2.6					1						
2.9					1						
3.2				1							

$r = -0.20$
Value of "Radon-content" is the ratio to each standard value.

(*f*) *Difference of Radon-content due to observation places*

According to the large number of data collected by Israël (2), the mean Radon-content of the atmosphere near the surface of the continents amounts to about in the range of $100 \sim 2000 \times 10^{-18}$ C cm^{-3}.

This difference of Radon-content seems to be reduced to the local characteristics of the observatory, for instance to their meteorological type, geographical position, etc. It is well known that the exhalation rate of Radon from the ground surface on the fault line is large. Concerning the local character of atmospheric Radon-content, some observations for comparison at the play ground of the Tottori University, and at the ground of the Misasa middle school were made, their results being tabulated in Table 5. The Radon-content at Misasa seems larger than that at Tottori, and the cause may be attributable to the circumstances that Misasa is the place of radioactive hot springs and, moreover, more distant from the sea shore compared with Tottori.

Table 5. Difference of atmospheric Radon-content observed at Tottori and Misasa.

Place and time	Number of data	$\times$C $10^{-18}cm^{-3}$		
		Mean	Max.	Min.
Tottori, Nov. 1952- Feb. 1953	81	119	362	23.9
Misasa, Nov. 1952- Feb. 1953	49	146	478	25.5

(*g*) *Relation to wind velocity*

It is expected that the exhalation of the Radon may have some relation with wind velocity, because it is connected with suction effect of the wind. On some groups of data, which are classified according to the direction of wind, 40 examples of NE wind, 31 examples of NNW wind, 25 examples of S wind, and 22 examples of SE wind, the correlation coefficients were calculated. Tables 6, 7, 8, and 9 show respectively the correlation of wind velocity and atmospheric Radon-content. The correlation coefficients are as follows; NE: −0.05, NNW: 0.017, S: −0.085 and SE: −0.348. The correlation coefficients of these are too small to be discussed, and these results are considered to reveal that the diffusion effect of the wind may be equal to the suction effect of the wind. For reference, the mean value of wind velocity and frequency of wind direction which are observed in Tottori, are shown respectively in Figs. 8 and 9.

Table 6. Correlation between wind velocity and atmospheric Radon-content in case of NE wind direction.

Rn cont. (d.p.10 m) / wind velocity (m/sec.)	2	5	8	11	14	17	20	22	25	28
1										
2		2		1	1					
3		3	2	3	2	1		1	1	1
4		2	1		2	1				
5		1	2	1		1				
6		2	1	2	1	1				
7				1	1					
8				2						
9										

$r = -0.05$

Table 7. Correlation between wind velocity and atmosperic Radon-content in case of NNW wind direction.

Rn cont. (d.p.10 m) / wind velocity (m/sec.)	2	5	8	11	14	17	20	22
1								
2		1	1					1
3		3	2	1	1			
4	1	1	5	2				
5		1	3		1		1	
6		1	1			1		
7				1				
8		1						
9					1			

$r = 0.017$

Table 8. Correlation between wind velocity and atmospheric Radon-content in case of S wind direction.

Rn cont. (d.p.10 m) / wind velocity (m/sec.)	2	5	8	11	14	17	20	22	25
1									
2									
3				1	1	1			
4		1	1	1	1				1
5		1			1	2	1		
6		2	2	1	1	3			
7									
8							1		
9									
10				1					
11									
12									
13									
14									
15									
16				1					

$r = -0.085$

Table 9. Correlation between wind velocity and atmospheric Radon-content in case of SE wind direction.

wind velocity (m/sec.) \ Rn cont. (d.p.10 m)	2	5	8	11	14	17	20	22	25	28	31	34	…	48
1						1	1							1
2				2		1	1		1		1			
3				3	1			1		1		1		
4				2			1		1					
5					1									
6					1									

$r = -0.348$

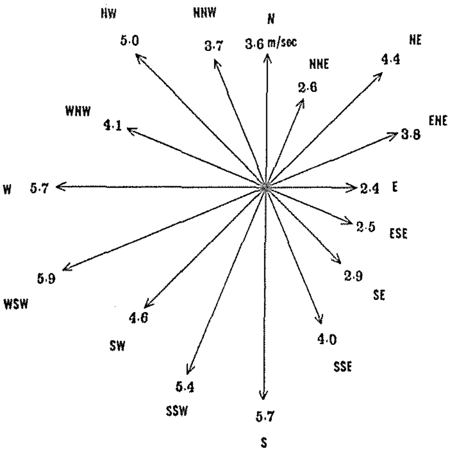

Fig. 8. Mean value of wind velocity for each wind direction at Tottori.

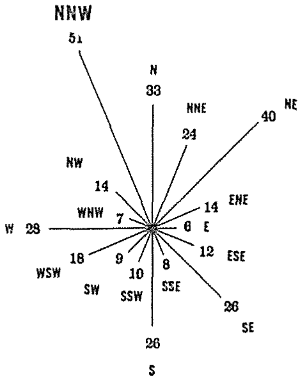

Fig. 9. Frequency of wind for each direction at Tottori.

4. On the relations between atmospheric Radon-content and earthquakes

Considering that the atmospheric Radon is mainly exhaled from the ground surface, it is considered to be worth discussing whether there exists or not any relation between the variation of atmospheric Radon-content and the occurrence of earthquakes, especially of local shocks near Tottori. For the purpose of detecting some influences of an earthquake upon Radon-content, raw materials observed must be corrected for all other conceivable effects other than earthquakes. Fortunately in the present case, the effects of the wind direction is the only thing that needs some consideration, and the relation to atmospheric pressure is not taken up here, for its correlation coefficient is comparatively small. Thus, in the following sections, all data are expressed in their ratio to the standard value for each wind direction, and it is generally considered that the effect of wind direction may be corrected by this process. For instance, the measured value of 1.5 scale division per minute in case of north-wind is calculated as 2.0 by dividing it with the standard value of 0.75 in N-wind in Table 2 and similarly when south-east wind is blowing, it becomes 0.82. Namely in the former case the measured value of Radon is interpreted as anomalously large, and in the latter case it is an ordinary value in this wind direction.

(*a*) *On the atmospheric Radon-content measured before and after the earthquake*

In this section all data of Radon-content during one year are investigated in regard to the relation with the earthquake. In Table 10, the distribution of the observed intensity of atmospheric Radon-content normalised by the standard value is classifiedly tabulated referring to the number of days before and after the earthquake occurrence. The earthquakes listed in the table are a total of 61 earthquakes which were observed during the period of present investigation with the seismometer of the Imamura type at the

Table 10. Atmospheric Radon-content observed before and after the occurrence of earthquake.

atom. Rn cont.	Below 0.9		1.0–1.5		More 1.6		More 2.0	
	Number of data (f)	f/e	Number of data (f)	f/e	Number of data (f)	f/e	Number of data (f)	f/e
−3 (3 days before)	34	1.0	19	1.0	10	1.0	5	1.0
−2 (2 days before)	37	1.1	14	0.7	10	1.1	8	1.6
−1 (1 day before)	32	1.0	21	1.1	10	1.0	6	1.2
0 (that day)	37	1.0	17	0.9	7	0.8	7	1.4
1 (1 day after)	30	0.9	17	0.9	12	1.3	9	1.8
2 (2 days after)	32	1.1	17	0.9	13	1.4	10	2.0
3 (3 days after)	30	0.9	18	1.0	13	1.3	7	1.4
4 (4 days after)	27	0.8	23	1.2	11	1.2	8	1.6
5 (5 days after)	30	0.9	20	1.1	10	1.1	8	1.6
6 (6 days after)	34	1.0	17	0.9	8	0.9	5	1.0
Expected number of days (e)	33		19		10		5	

Value of "Radon content" is the ratio to each standard value.

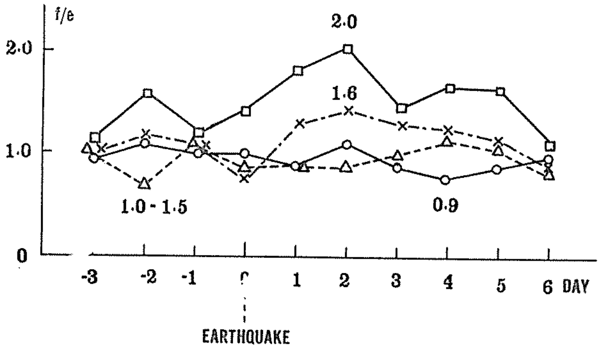

Fig. 10. Relation between the observed intensity of atmospheric Radonc-ontent and the number of days before and after the earthquake occurrence.

Tottori Meteorological Observatory, the free period and magnification of the seismograph being 4.0 sec 40 respectively. The distribution in Table 10 is shown in Fig. 10 in which the ordinate shows the ratio of the observed number to the expected number. Expected numbers are meant the number of days which are theoretically expected to appear and calculated from the frequency distribution of total data. According to Fig. 10 the days of large Radon-content are expected several days after an earthquake has occurred, and considering the process of Radon exhalation from soils and the half-life of Radon, this phenomenon is reasonably explained. To show it more clearly, the distribution of the data during the period of three days after the earthquake is shown in Table 11, according to which, most values larger than 3.0 are observed within three days after the earthquake, and even in the case of values over 2.50, 75% of them are observable in these days, and thus some relationship between Radon-content in the atmosphere and the earthquake occurrence seems to exist, as far as the above argument is concerned. But, by applying the test to ascertain the real existence of different character between two distributions of total data and data during three days after earthquake occurrence which are shown in the percentage columns of Table 11, the significant level of this view that there are some differences between the distribution of these two sets of data, is estimated as 90% by using the distribution of χ^4 of 4 free dimensions in stochastic calculation. Consequently, the prospect for the relation between the atmospheric Radon-content and the earthquake occurrence is calculated to be negative from the test of stochastics so far as all the earthquakes observed at Tottori are concerned.

Table 11. Atmospheric Radon-content observed during three days after the earthquake occurrence.

Rn cont.	Total data		Data in 3 days after the earthquake occurrence	
	Number of data	%	Number of data	%
0.2	15	24.9	7	26.2
0.5	75		33	
0.8	97	26.8	40	26.1
1.1	78	21.5	30	19.6
1.4	37	11.0	13	8.5
1.7	22	16.8	8	19.8
2.0	13		6	
2.3	4		3	
2.6	8		4	
2.9	5		4	
3.2	2		1	
3.5	2		1	
3.8	1		1	
4.1				
4.4	1			
—				
5.6				
5.9	1		1	
6.2	1		1	
Total	362		153	

Value of "Radon-content" is the ratio to each standard value.

(b) Relation between atmospheric Radon-content and local shocks

In the preceding section, the relation between the value of Radon and earthquake occurrence was not noticed from the standpoint of stochastics, though it seems to exist in appearance as shown in Fig. 10 and Table 11. In this section the same argument as described above will be applied only to the local shocks occurred near Tottori. It is expected that the relation between the atmospheric Radon-content and occurrence of local shocks can, if existing, be fairly well detected, since the intensity of atmospheric Radon-content is supposed to be greatly increased by exhalation from the ground surface near the observation station caused by the violent shaking of local shocks and, moreover, the increased Radon-content will reach the observation station with less absorption and diffusion into the large air mass. Table 12 shows those earthquakes which had their epicenters in Tottori prefecture, and these 14 earthquakes are treated as local shocks in the present case. Referring to the above 14 earthquakes the same procedure was applied as in the preceding

Table 12. Earthquakes which have their epicenters in Tottori Prefecture.

Date of earthquake occurrence	Intensity of earthquake	Epicenter
22h 14th May 1955	I	neighbourhood of Tottori city
15h 19th May	I	neighbourhood of Tottori city
20h 15th Jun.	I	neighbourhood of Chizu
22h 23th Jun.	II~III	upper stream district of Hino river
8h 26th Jun.	II	upper stream district of Hino river
4h 27th Jun.	0	upper stream district of Hino river
2h 30th Jun.	0	upper stream district of Hino river
20h 13th Oct.	III	center of Tottori prefecture
19h 14th Oct.	I	neighbourhood of Tottori city
19h 20th Oct.	I	neighbourhood of Tottori city
23h 18th Nov.	I	neighbourhood of Tottori city
13h 21th Nov.	I	neighbourhood of Tottori city
4h 1th Feb. 1956	I	neighbourhood of Tottori city
22h 24th Feb.	0	west part of Tottori prefecture

Table 13. Relation between the near earthquake and atmospheric Radon-content.

atom. Rn content	Data of 3 days after earthquake		Total data	
	Number of data	%	Number of date	%
0.2		8.2	15	24.9
0.5	3	27.0	75	
0.8	10	24.4	97	26.8
0.1	9	10.8	78	21.5
1.4	4		38	11.0
1.7	2	29.8	22	16.8
2.0	3		13	
2.3			4	
2.6	1		8	
2.9	1		5	
3.2			2	
3.5	1		2	
3.8	1		1	
4.1				
4.4			1	
—				
5.6	1			
5.9	1		1	
6.2	1		1	
Total	37		362	

Value of "Radon-content" is the ratio to each standard value.

section, the numerals being shown in Table 13. It seems also to show some influence of the earthquake upon Radon-content, and the test of difference of these two distributions was tried by making use of the distribution of χ^4 of 4 free dimensions. The significant level of this test shows 0.1%, i. e. it can certainly be said in this case that when an earthquake occurs near the observatory the Radon in the atmosphere increases. Next, some explanation must be found for the earthquakes which were not accompanied by the increase in Radon-content, namely, the earthquakes on May 14th and May 19th 1955. It may be attributable to the blowing wind from the sea in north direction during these days, because the air mass of maritime origin has low Radon-content, and the Radon exhaled by the shaking of the earthquake from sea side alluvium is of low value and, furthermore, the area which can contribute to Radon exhalation is very narrow in this case.

(*c*) *Relation between atmospheric Radon-content and intensity of earthquake*

The sixty one earthquakes recorded at the Tottori Meteorological Observatory are classified according to their intensity as well as their relation to the atmospheric Radon-content, which was measured during the three days after the earthquake, and they are shown in Table 14. Their correlation coefficient becomes 0.24 and according to the test of significance of correlation, this relation is slightly recognized, but with the significant level of 10%.

Table 14. Correlation between intensity of earthquake and atmospheric Radon-content.

Intensity of earthquake / atom. Rn content	0	I	II	III
0.2				
0.3	9			
0.8	9	3	2	
1.1	12	2	1	
1.4	11	2		1
1.7	2			
2.0	2	2		
2.3				
2.6	1			1
—				
3.8				
4.4		1		

r≒0.24

Value of "Radon-content" is the ratio to each standard value.

(*d*) *Effect of distant earthquakes traced by air currents*

As mentioned above, the relation between the atmospheric Radon-content and local shocks has been fairly well recognized. In this section we shall briefly discuss the effect of Radon exhaled by a distant earthquake and transported by favourable winds to Tottori from its epicentral region. Concerning the displacement of air mass, the air current in question is blowing near the ground surface, and it may receive much disturbance by the configuration of the ground, but here it is assumed that the air mass is displaced from the epicenter to Tottori retaining most of the Radon caused by the earthquake. For instance it is possible to move 260 km in 24 hours, presuming the wind velocity to be 3 m/sec. From this point of view, the effect in question was examined for some distant earthquakes, taking wind direction into consideration as deduced from the Far-East weather chart issued by the Central Meteorological Observatory. Fig. 11 shows the relation between the variation of Radon-content observed in Tottori and the direction of wind determined from the weather chart, when the earthquake occurred in Ibaraki Prefecture on June 15, 1955. This is an example of a case of the air mass which is supposed to be transported to Tottori from the epicentral region. Fig. 12 shows the case of an earthquake, occurring in the Tokushima district on August 14, 1955, and it is an example in which the movement of air from the epicentral region to Tottori is not expected.

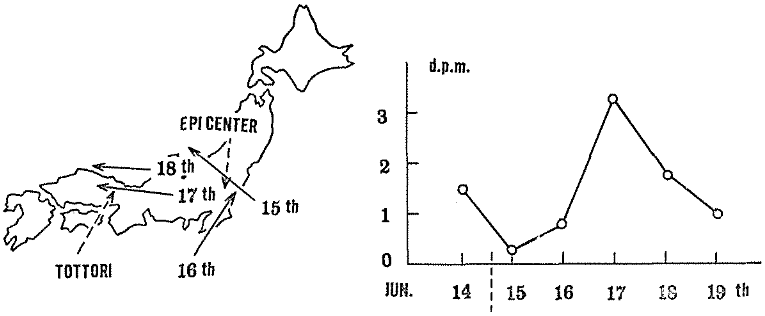

Fig. 11. Relation between the variation of atmospheric Radon-content at Tottori and the direction of wind in case of the distant earthquake in Ibaraki Prefecture.

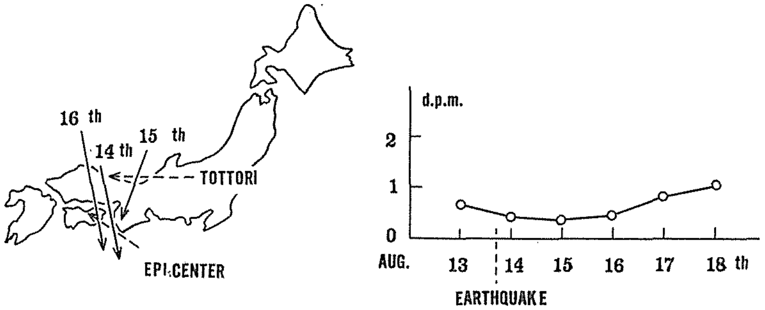

Fig. 12. Relation between the variation of atmospheric Radon-content at Tottori and the direction of wind in case of the distant earthquake in Tokushima Prefecture.

In concluding the present investigation, the fact that the Radon-content in the atmosphere near the ground surface is certainly increased by the occurrence of local shocks near the observation station was fairly ascertained from the standpoint of stochastics. In this case the effects caused by change of barometric pressure, atmospheric temperature, and precipitation, and especially the influence by wind intensity and direction should carefully be corrected. The effort will be exerted, in a near future, to detect directly the influence of earthquake occurrence upon the change of atmospheric Radon-content for each earthquake by suitable methods of automatic and continuous observation of atmospheric Radon and ground radiation in general.

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REFERENCES

1. J. Elster and H. Geitel, Phys. zs. **2** (1901), 590.
2. H. Israël, Compendium of Meteorology (American Meteorological Society Boston) 155 (1951).
3. R. P. Vancour, Thesis. Fordham University, New York (1950).
4. A. Sella, Atti. Acad. Lincei. **11** (1902), 57.
5. M. H. Wilkening, Rev. Sci. Instrum. **23** (1952), 13.
6. G. Eckmann, Jb. Radioakt. **9** (1912), 157.
7. H. Gerdien, Phys. zs. **6** (1905), 465.
8. L. A. Bauer, Carng. Instn. Wash. Publ. No. 175 (1916), 3.
9. C. C. Lauritsen and T. Lauritsen, Rev. Sci. Instrum. **8** (1937), 438.
10. A. S. Eve, Phil. Mag. [6] **10** (1905), 98.
11. F. Becker, Beitr. Geophys. **42** (1934), 365.
12. O. Maćek and W. Illing, Beitr. Geophys. **43** (1935), 388.
13. W. Messerschmidt, zs. f. Phys. **81** (1933), 84.
14. W. Kosmath, Beitr. Geophys. **43** (1935), 258.
15. J. Priebsch, Beitr. Geophys. **50** (1937), 55.
16. L. B. Smyth, Phil. Mag. **24** (1912), 632.