Letter to the Editors

How Indicative of the Long-term Data Are Annual and Monthly Mean Atmospheric Radon Daughter Concentrations Obtained from Measurements Made over a Few Years?†

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Received February 15, 1999

Key Words : radon daughter, 20-year measurement, indication, central limit theorem

1. Introduction

A large number of papers have been published on the seasonal variations or annual mean levels of atmospheric radon and its daughters in many parts of the world. However, there have been very few reports describing how the measured values deviate from a "normal value". In meteorology, a normal value is defined as "the value averaged over a few decades", although the usual time interval may only be from 10 to 30 years[1]. In this paper, a normal value is defined as a 20-year mean.

I have measured the concentration of atmospheric radon daughters on a regular basis for the past 20 years. This paper shows how the central limit theorem can be applied to the analysis of the 20-year data to obtain information on the deviations of annual means from a normal value. This is useful as it allows us to evaluate the statistical accuracy of medium to long term measurements. Conversely, for those planning on starting new measurements, the information will allow them to estimate the number of years of observation needed to obtain truly representative data.

2. Observation

The atmospheric radon daughter concentration has been measured at our institute in Nagoya since 1979 using the filter method. Nagoya is located at the Pacific Ocean side of the island of Honshu, in the central part of the Japanese Islands.

The air sampling system consists of a blower drawing air at about 35 l/min through a 4-cm diameter millipore filter with a pore size of 1.2 μm. The sampling of air was done at a height of 3 m above the ground. The period of filtration was 15 min, at the end of which the α-activity on the filter was counted for 40 min using a ZnS(Ag) scintillation counter. This was done on every working day at 11 : 00 a.m., since the concentration at this time of the day has been shown to correlate well with the daily mean of the considerably large diurnal variation[2].

The instrument has been previously calibrated through a series of 480 simultaneous measure-

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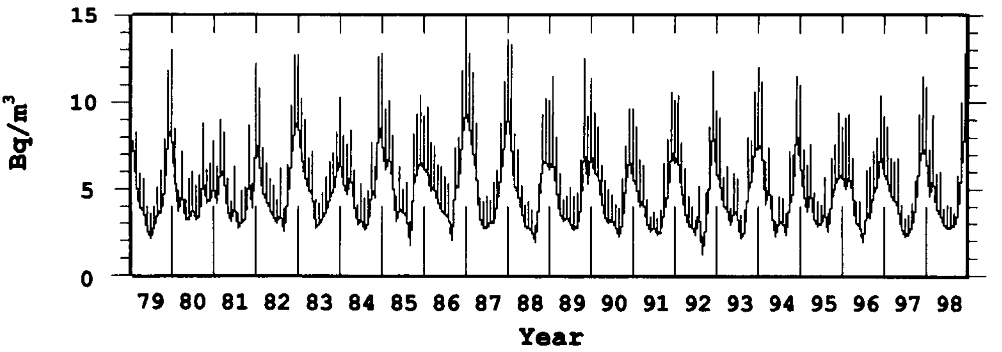

Fig. 1 The monthly mean concentrations of atmospheric radon daughters measured at Nagoya. The vertical bars indicate the respective standard deviations.

ments with a Nagoya University standard instrument[3].

A total of 4 401 measurements were taken between January 1979 and December 1998, inclusive. This averages to about 18 measurements per month. Figure 1 shows the distribution of the monthly means and the standard deviation for each month. The numerical values are given in Table 1, where μ is the normal monthly mean for a calendar month, σ the standard deviation of the monthly means, and m the annual mean.

3. Statistical Accuracy and Determination of the Period of Measuring Years

Usually, we want to be able to obtain the annual and monthly mean values quickly by taking measurements over as short a period as possible. However, if the period is too short the data may not be reliable. Therefore, how many years are needed to obtain a truly representative set of data? Let us consider this problem in the light of the central limit theorem in statistics.

Suppose a set X consists of N random samples taken from a population that has a mean μ and a standard deviation σ. If many sets are taken, the distribution of the set-mean $\langle X \rangle$ will approximate a normal distribution with a mean μ and a standard deviation $\sigma_{\langle X \rangle}$.

$$\sigma_{\langle X \rangle} = \sigma / N^{1/2}$$

We can calculate the coefficient of variation $\sigma_{\langle X \rangle}/\mu$ and use it as an indicator of the statistical accuracy of the observed data. This can be done by substituting the number of observation years into N in the above formula, and use the μ values given in Table 1.

Conversely, if the coefficient of variation is specified, then we can use the following formula to determine the required observation period N.

$$N = (\sigma/\mu)^2 / (\sigma_{\langle X \rangle}/\mu)^2$$

Tables 2 and 3 give examples of the coefficient of variation in the annual and monthly means calculated with the above formulas, using the values of σ and μ given in Table 1. The examples show that in order to calculate the required observation period, we must first set a criterion for the value of the coefficient of variation.

The above calculations are valid for random sampling. However, if no long-term trend is observed in the data, then we can also apply the analysis to continuous sampling, which usually is more timesaving compared to random sampling. For example, Fig. 2 shows the auto-correlation coefficients for the column of January in Table 1. The figure reveals that the January mean value in a certain year has almost no correlation with the

Table 1 The observed values of monthly and annual mean concentrations

(Bq/m³)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	m
1979	7.68	5.29	3.88	3.69	2.54	2.14	2.77	3.48	3.58	5.03	8.05	8.34	4.70
1980	5.82	3.67	4.67	3.24	3.22	3.83	3.15	3.41	5.54	4.20	4.29	5.10	4.18
1981	4.21	6.08	5.56	3.73	3.07	3.98	2.72	3.02	3.21	5.53	3.88	7.70	4.39
1982	6.62	4.66	4.29	3.81	3.33	2.99	3.48	2.49	4.44	6.69	8.51	8.77	5.01
1983	6.78	5.67	4.87	4.78	2.75	2.92	3.28	3.57	4.47	4.82	5.93	6.61	4.70
1984	5.35	4.70	5.84	4.13	2.92	3.20	2.63	2.92	4.91	4.49	8.69	7.74	4.79
1985	6.10	6.90	5.48	3.14	3.79	3.64	3.39	1.71	5.09	6.04	6.53	6.11	4.83
1986	6.00	4.88	5.03	4.34	3.71	3.47	3.41	1.98	5.07	5.08	8.02	9.41	5.03
1987	8.67	7.24	6.10	3.26	2.75	2.74	3.01	3.02	4.06	5.81	7.83	9.21	5.31
1988	7.77	5.10	4.67	3.65	2.78	2.68	2.47	1.91	4.16	6.40	6.64	6.14	4.53
1989	6.64	4.95	3.54	3.08	3.31	2.86	2.59	2.68	4.03	7.40	5.32	6.97	4.45
1990	5.90	5.85	4.30	3.25	2.99	3.15	2.78	2.21	3.04	5.31	6.74	5.58	4.26
1991	5.09	4.00	4.27	3.03	2.48	2.70	2.28	2.38	3.68	4.69	7.19	6.52	4.03
1992	6.77	4.89	3.71	2.80	2.77	2.33	3.74	1.22	2.87	5.69	8.52	5.85	4.26
1993	5.39	3.99	3.94	2.92	3.75	3.51	2.14	2.51	4.95	5.46	7.31	7.33	4.43
1994	7.49	4.09	5.12	3.40	2.18	3.08	2.96	2.32	4.06	4.86	8.44	6.50	4.54
1995	4.66	3.74	4.78	3.25	2.75	2.94	3.56	2.53	4.29	5.21	5.70	5.73	4.09
1996	5.01	5.67	4.75	3.03	2.85	1.90	3.63	3.30	4.72	5.22	7.01	5.93	4.42
1997	5.35	4.60	4.30	3.92	2.58	2.25	2.33	2.83	3.87	6.35	7.33	6.89	4.38
1998	4.59	5.56	3.80	3.51	2.94	2.65	2.72	2.79	3.57	6.05	8.29	7.84	4.53
μ	6.09	5.08	4.64	3.50	2.97	2.95	2.95	2.61	4.18	5.52	7.01	7.01	4.54
σ	1.17	0.96	0.70	0.50	0.42	0.54	0.47	0.60	0.71	0.78	1.37	1.21	0.32
σ/μ	0.19	0.19	0.15	0.14	0.14	0.18	0.16	0.23	0.17	0.14	0.20	0.17	0.07

Table 2 Examples of the number of measuring years needed to produce a given coefficient of variation in the annual mean

Annual mean

$\sigma_{\langle x \rangle}/\mu$ (%)	No. of years
3	5.5
4	3.1
5	1.9

value in the following year. Further autocorrelation calculations confirmed that this is true also for the other calendar months. Therefore, this shows that it may be all right to apply the above formulas to data obtained from continuous sampling.

4. Concluding Remarks

The pattern and level of the seasonal variation is expected to vary greatly from place to place.

Table 3 Examples of the number of measuring years needed to produce a 10% coefficient of variation in the monthly mean for all the calendar months

Monthly mean $\sigma_{\langle x \rangle}/\mu=10\%$

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
No. of years	3.6	3.6	2.3	2.0	2.0	3.4	2.5	5.3	2.9	2.0	4.0	2.9

Fig. 2 The auto-correlation coefficients for the January mean concentrations.

Table 1 may therefore not be applicable to other places in the world. However, since at present, such long-term data as that presented in this paper are rare, we can at least use the data to make rough estimates for other places.

Recently, the passive-sampling method is getting more and more popular in the monitoring of environmental radon concentrations. The passive monitors are usually exposed for 2, 3 or 6 months. The method of analysis described in this paper is applicable also to this type of data. The means for the relevant exposure periods can be reproduced from Table 1.

Acknowledgment

The author wishes to thank Dr. K. K. Lai of the University of Brunei Darussalam for reading the manuscript critically and improving on the English.

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