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INDOOR RADON CONCENTRATION VARIABILITY AND RADON MEASUREMENT VARIATIONS

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ABSTRACT

The radon concentration in a house varies continually, which limits the precision of a seasonal average radon concentration estimate derived from a single measurement. Indoor radon concentrations were measured hourly with a continuous radon monitor for 1666 hours in a house averaging about 190 $Bq.m^3$ (4.9 $pCi.L^{-1}$). This data set is analyzed to show the effect of measurement periods from one hour to ten days on the variability of the measured radon concentration. The major influence on radon concentration variability is a four to six day cyclic variation. A stable estimate of the average radon concentration requires measurement periods of more than ten days to average over two or more concentration cycles. The effective measurement period of typical diffusion barrier charcoal radon collectors is not long enough to fully overcome the effect of the cyclic fluctuations.

INTRODUCTION

The variation of radon concentration with time in a house limits the precision with which the seasonal average radon concentration can be estimated from a single measurement. This is illustrated by analysis of a set of 1666 consecutive hourly continuous radon monitor measurements made in a house basement during the heating season in New York State. The average radon concentration over this period was 4.9 $pCi.L^{-1}$ (180 $Bq.m^{-3}$). Each point in Figure 1 is a measurement of the radon concentration averaged over one hour, and is corrected for the activity deposited in the scintillation cell by the preceding measurements. The standard deviation of successive individual measurements at 150 $Bq.m^{-3}$ with this equipment and procedure is about 25 $Bq.m^{-3}$ (16%).

CONCENTRATION VARIATION WITH TIME

Figure 1 shows three types of variability.

1 Short-term concentration fluctuations with periods from 2 to 24 hours produced by random fluctuations in count-rate; changes in radon supply and ventilation rate caused by occupant activities; plus day/night temperature effects.

2 Cyclic changes in concentration with periods of 4 to 6 days caused by large changes in radon supply. The underlying cause is the passage of weather systems, which occurs every 4 to 6 days.

3 Long term variation in concentration caused by seasonal changes in average ventilation rate and radon supply — as shown by the trend line.

Figure 1 shows that the conditions that cause high or low radon concentrations persist for some time, so successive measurements are correlated. Figure 2 shows the average correlation between successive hourly measurements separated by intervals of up to 48 hours. The high correlation (r^2>0.65) between measurements up to 3 hours apart shows that one concentration measurement is a good predictor of the concentration over the next two to three hours. Successive measurements of two or three hours duration will therefore track radon concentration changes almost as effectively as successive one-hour measurements. Figure 3 shows the reduction in "noise" produced by using three-hour average measurements. The underlying pattern of the major concentration variations is unchanged.

EFFECT OF MEASUREMENT DURATION

As the radon concentration varies from hour to hour, day to day, and month to month, the average radon concentration depends on the measurement duration (averaging period). Figure 4 shows the percentage standard deviation (COV) of average concentration estimates as a function of averaging period. The COV of a "n"-hour average is estimated from all possible sets of "n" consecutive hourly measurements from the set of 1666 consecutive hourly measurements illustrated in Figure 1.

The gradual reduction in COV with increasing averaging period is caused by the periodicity of the data set. The COV for the one-hour averages is 38%. A one-day average is much longer than the measurement noise and diurnal variations, and averages out those sources of variability, reducing the COV to 32%. A five-day average covers a major concentration cycle, reducing the COV to 18%. A fourteen-day average covers several major cycles, reducing the COV to 10%.

The decrease in COV with averaging period is much smaller than the change expected if the measurements were un-correlated (a random distribution). For example, the COV of one-hour averages is 38%, and the COV for twelve-hour averages is 34%. If the distribution of one-hour measurements was random with COV 38%, the COV of twelve-hour measurements would be 10%. Even though successive measurements are correlated, the distribution of individual one-hour duration concentration measurements is approximately log-normal, as shown in Figure 5. Even the distribution of four-day (96-hour) duration measurements is also approximately log-normal.

CONCLUSION

The COV of average indoor radon concentration is mainly determined by the cyclic variations in radon concentration during the averaging period. The COV for 2-day periods is 30%, over seven-day periods is 16%, and for fourteen-day periods is 10%. The measurement COV of short-term integration devices such as continuous radon monitors, electret discharge chambers, or high sensitivity alpha-damage detectors is <10%. The total measurement COV is therefore ~18% for seven-day measurements, and ~13% for fourteen-day measurements.

This suggests that when a single short-term measurement is used to estimate a seasonal (90-120 days) mean radon concentration, the measurement duration should be at least 7 days, and preferably 14 days.

CARBON CANISTER MEASUREMENTS

Many radon measurements are made with carbon canisters that passively collect and store radon. These devices are not perfect integrators, for the radon decays during the collection period, and the collection rate depends on both the amount of radon and water collected by the carbon. The collected activity (typically ~4 000 Bq) is estimated by γ-counting over a few minutes, so measurement precision is low. The average radon concentration is then estimated as equal to the constant radon concentration that would give the same collected activity over the same collection period.

Scarpitta and Harley[1,2] show that at constant humidity the collection and loss of ^{222}Rn by charcoal canisters can be approximated by:

$$\frac{dQ}{dt} = kC - (1/\tau + \lambda)Q \qquad (1)$$

where:

Q = Quantity of radon collected by the carbon (Bq)
k = Sampling rate (m^3h^{-1})
C = Radon concentration in air (Bqm^{-3})
τ = Desorption time constant (h)
λ = Radon decay constant (h^{-1})

The amount of radon collected by a carbon canister during an exposure to constant radon concentration C_c and humidity for time t, Q_t is therefore:

$$\frac{Q_t}{C_c} = k(1 - e^{(1/\tau + \lambda)t}) \quad (2)$$

As Q_t approaches a constant value for exposure times >2τ, 2τ is a practical upper limit to the measurement duration. Table 1 shows estimates of τ and collection time for two common canister types.

Table 1

Canister type	Desoprtion time constant (τh)[1]	Upper limit to collection time (d)
Open face	30	2
Diffusion barrier	75	7

EFFECT OF CONCENTRATION VARIATIONS DURING EXPOSURE ON CARBON MEASUREMENTS

Figure 6 shows the simulated time course of radon collection in a diffusion barrier collector exposed to variable radon concentrations over 7 days. An increase in radon concentration near the end of the exposure period biases the concentration estimate high, and a decrease biases the estimate low. The increase in variability produced by this effect in carbon canister measurements was estimated using the data of Figure 1 with Equation 1 to simulate multiple two and four day measurements with open-face canisters; and sets of four, seven and ten day measurements with diffusion barrier collectors.

Figure 7 shows that the COV of simulated open-face carbon measurements is similar (28%) for both two-day and four-day measurements. The precision is not improved by extending the collection time past the nominal limit of two days. The COV for simulated diffusion barrier measurements is 17% for ten-day duration measurements, considerably larger than the 10% COV of ten-day average concentrations. A COV of 17% is similar to that of six-day average concentrations, suggesting an effective averaging time for this simulated diffusion barrier collector of ~6 days.

REFERENCES

1 Scarpitta S. C.; Harley N. H. An improved ^{222}Rn canister using a two-stage charcoal system. *Health Phys.* 60:177-188; 1991.

2 Scarpitta S. C.; Harley N. H. Radon calibration factor for charcoal canisters. *Health Phys.* 60:276-278; 1991.

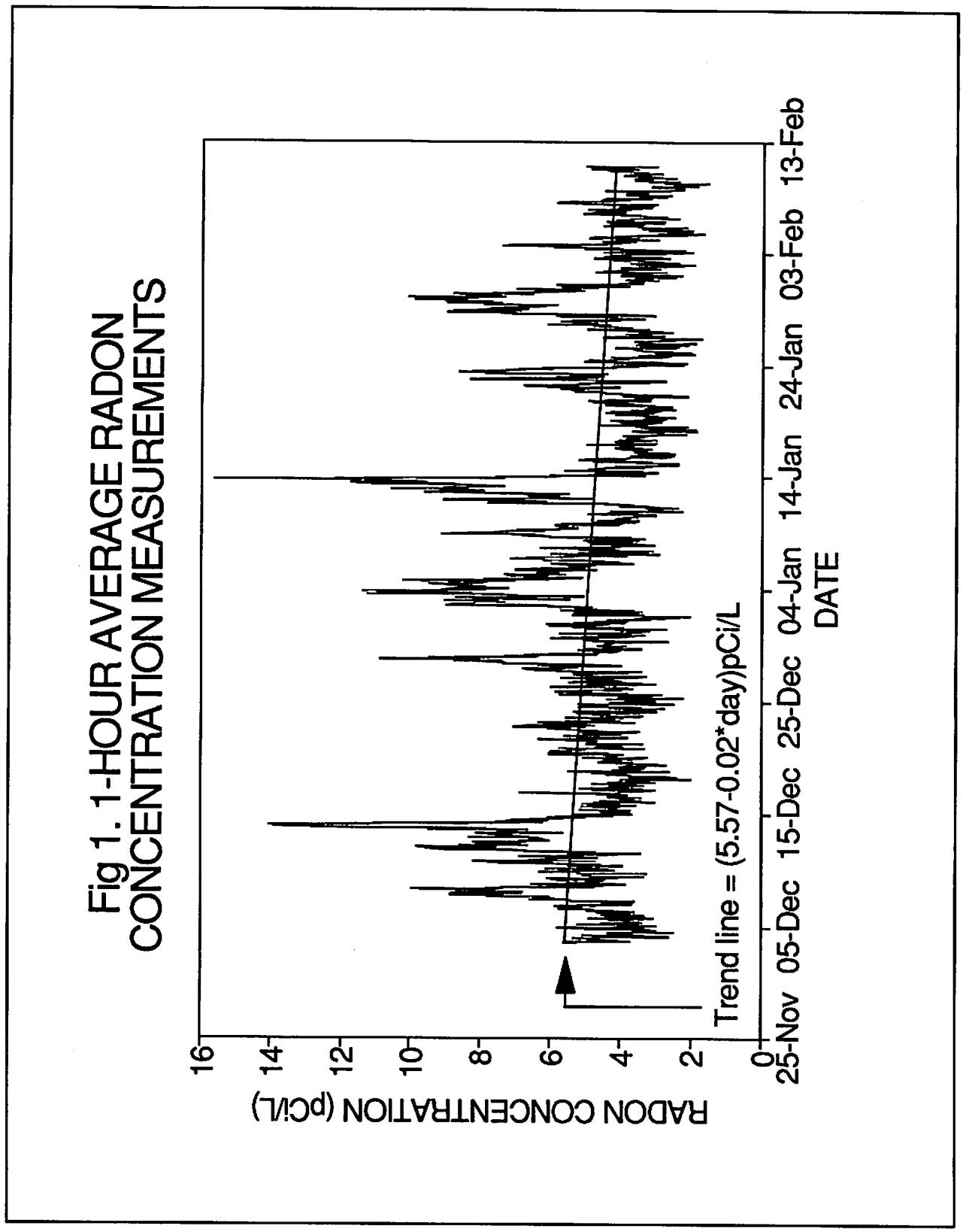


Fig 1. 1-HOUR AVERAGE RADON CONCENTRATION MEASUREMENTS
RADON CONCENTRATION (pCi/L)
16
14
12
10
8
6
4
2
0
Trend line = (5.57-0.02*day)pCi/L
25-Nov 05-Dec 15-Dec 25-Dec 04-Jan 14-Jan 24-Jan 03-Feb 13-Feb
DATE

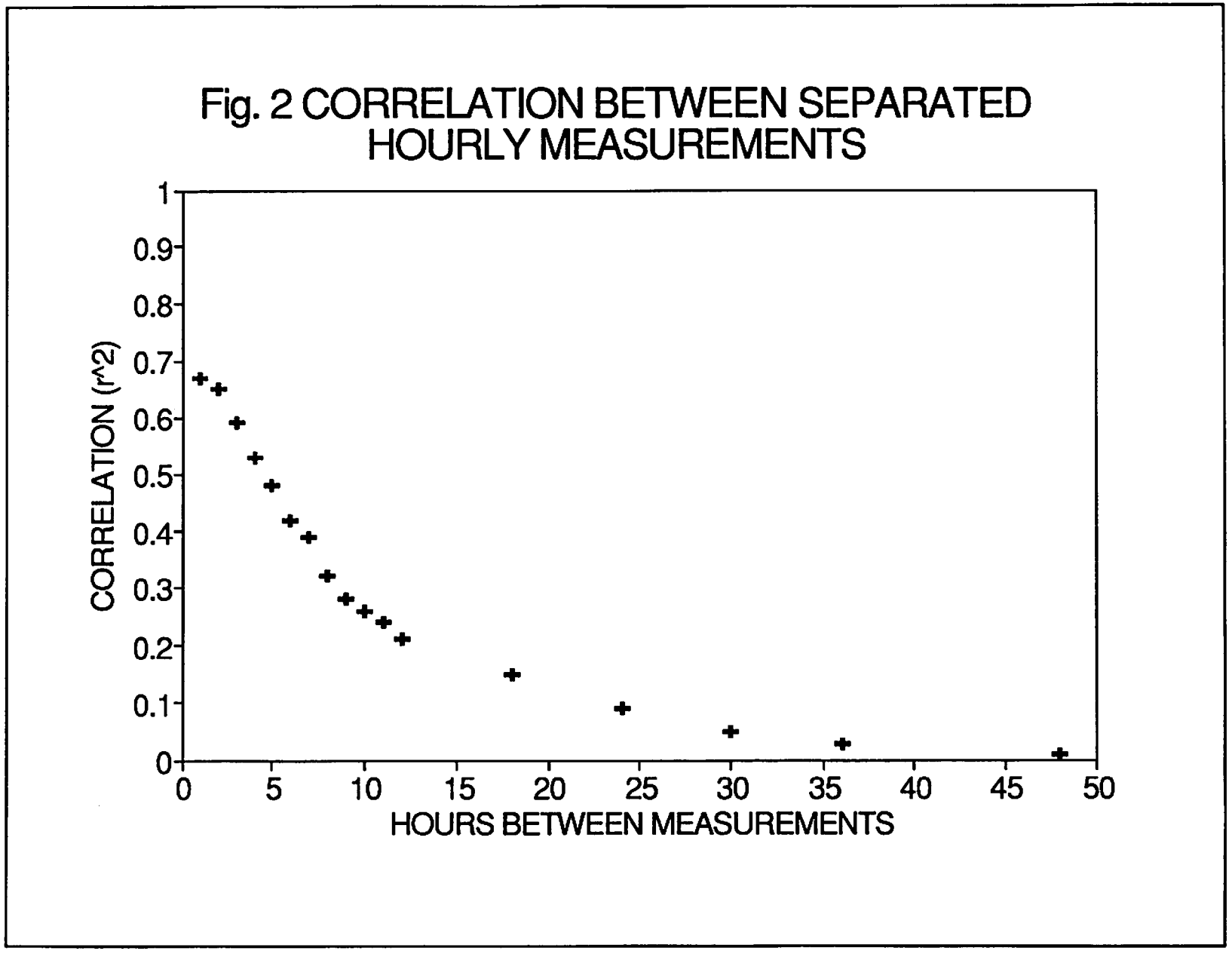


Fig. 2 CORRELATION BETWEEN SEPARATED HOURLY MEASUREMENTS
CORRELATION (r^2)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45
50
HOURS BETWEEN MEASUREMENTS

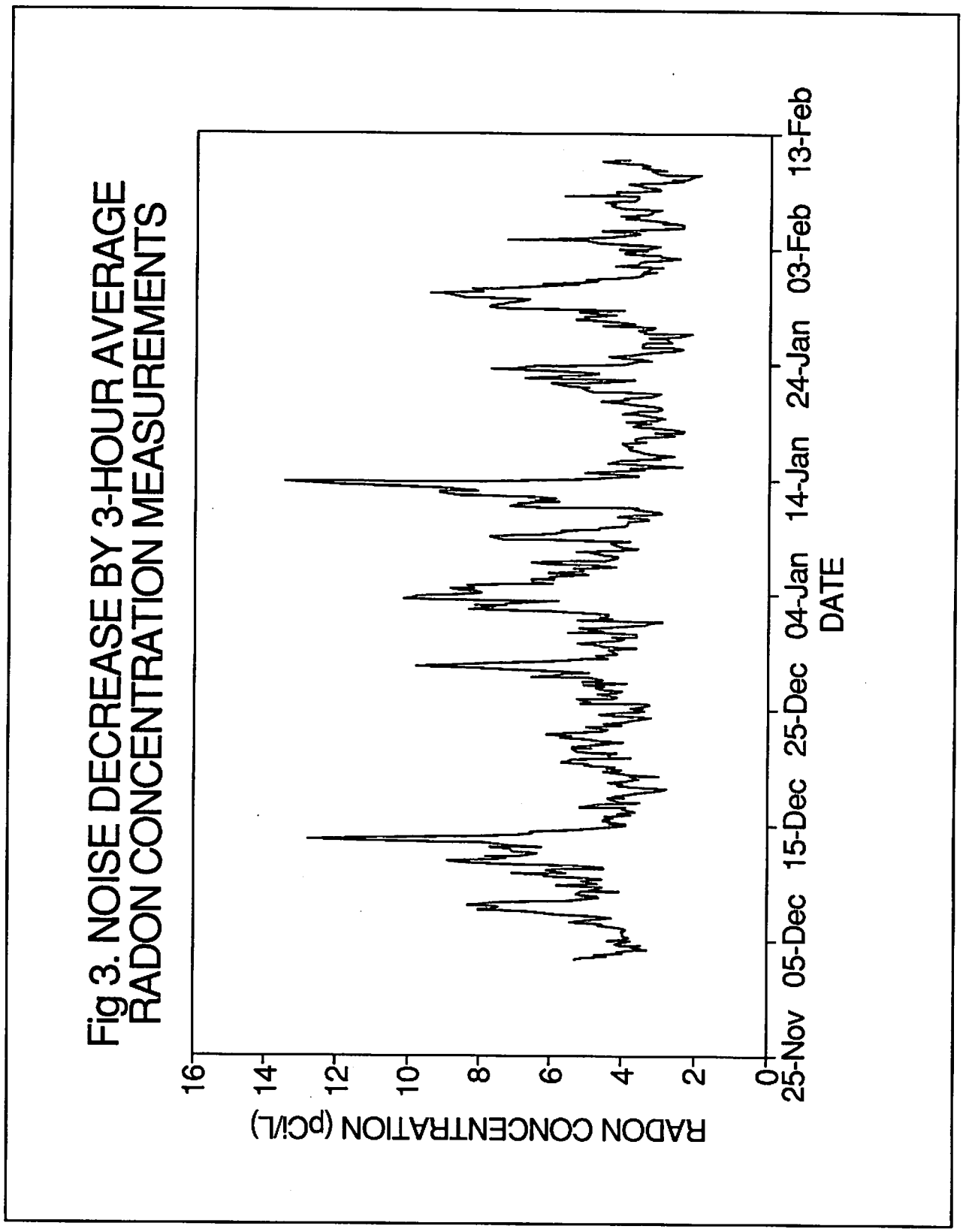


Fig 3. NOISE DECREASE BY 3-HOUR AVERAGE
RADON CONCENTRATION MEASUREMENTS
RADON CONCENTRATION (pCi/L)
0
2
4
6
8
10
12
14
16
25-Nov
05-Dec
15-Dec
25-Dec
04-Jan
14-Jan
24-Jan
03-Feb
13-Feb
DATE

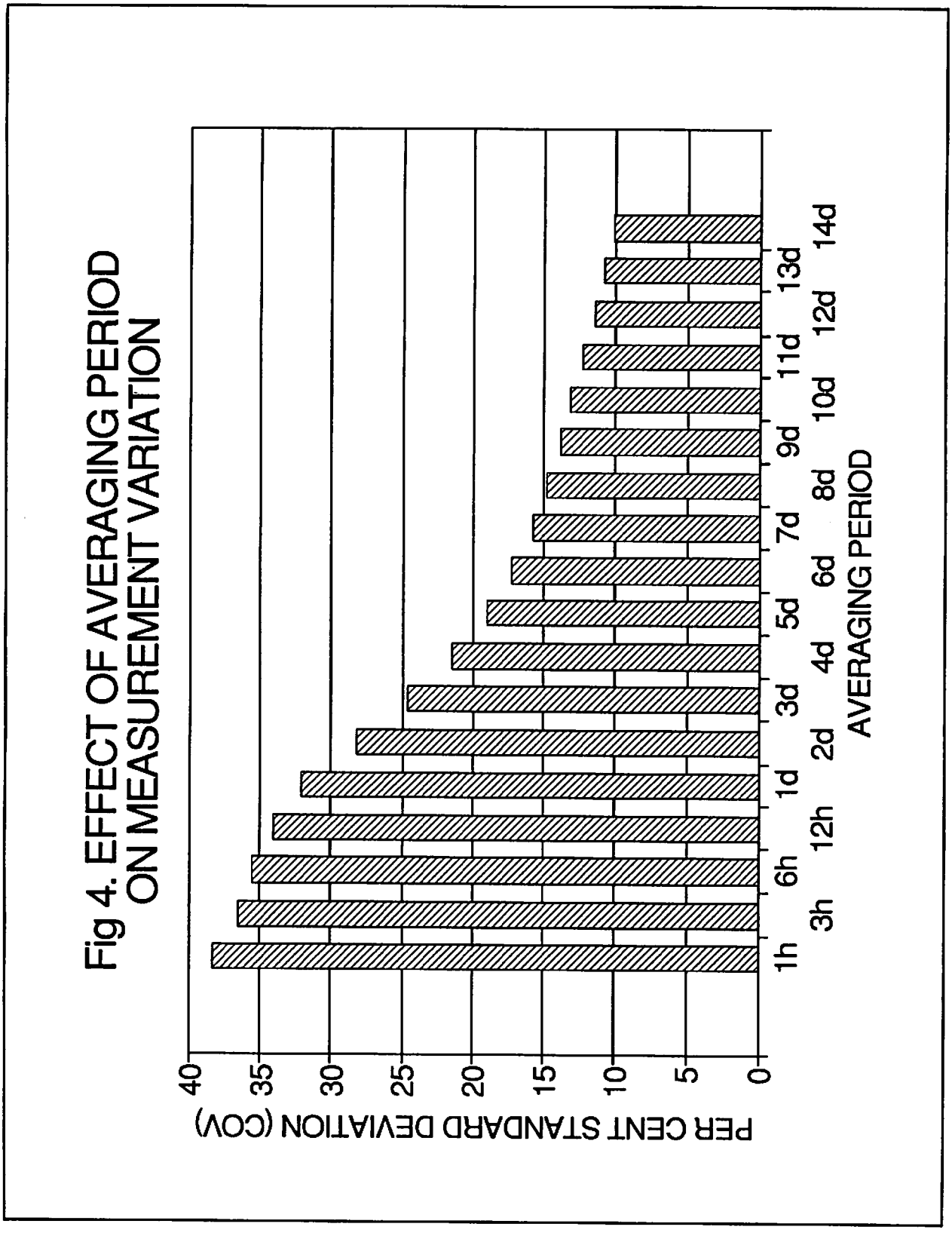


Fig 4. EFFECT OF AVERAGING PERIOD ON MEASUREMENT VARIATION
PER CENT STANDARD DEVIATION (COV)
0
5
10
15
20
25
30
35
40
AVERAGING PERIOD
1h
3h
6h
12h
1d
2d
3d
4d
5d
6d
7d
8d
9d
10d
11d
12d
13d
14d

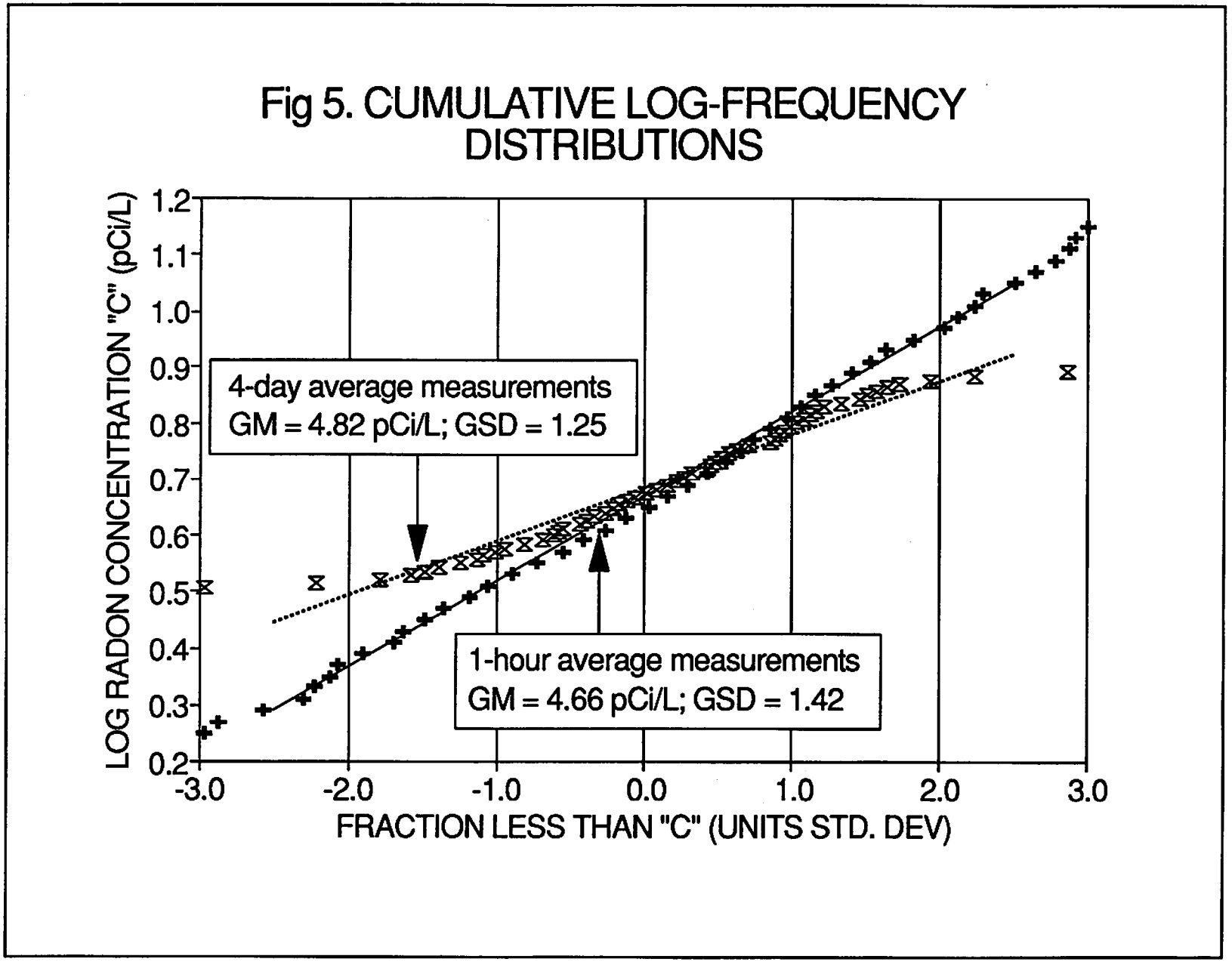
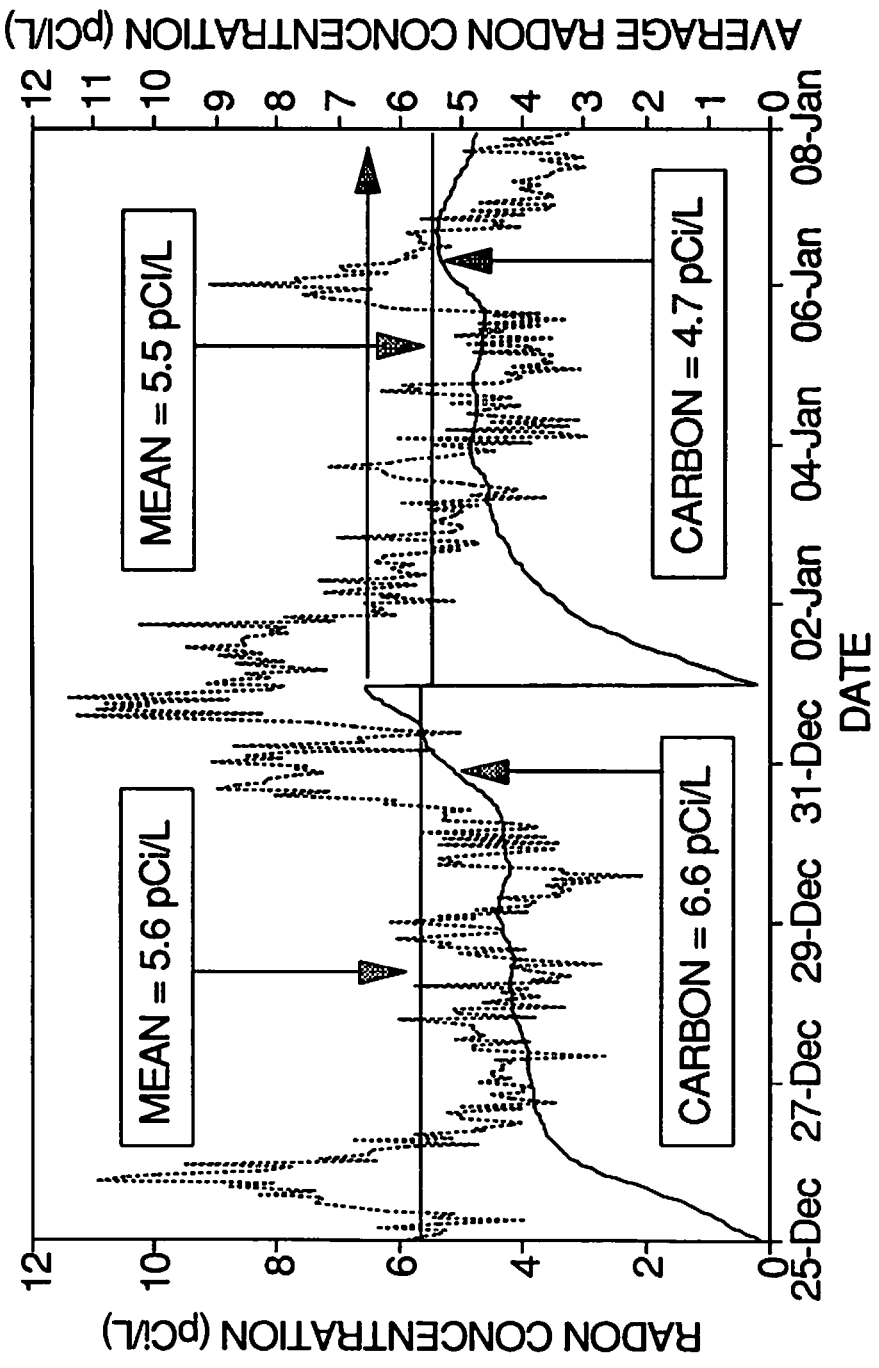


Fig 5. CUMULATIVE LOG-FREQUENCY DISTRIBUTIONS
LOG RADON CONCENTRATION "C" (pCi/L)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
4-day average measurements
GM = 4.82 pCi/L; GSD = 1.25
1-hour average measurements
GM = 4.66 pCi/L; GSD = 1.42
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
FRACTION LESS THAN "C" (UNITS STD. DEV)

Fig 6. RADON ACCUMULATION BY CARBON FROM VARIABLE CONCENTRATION



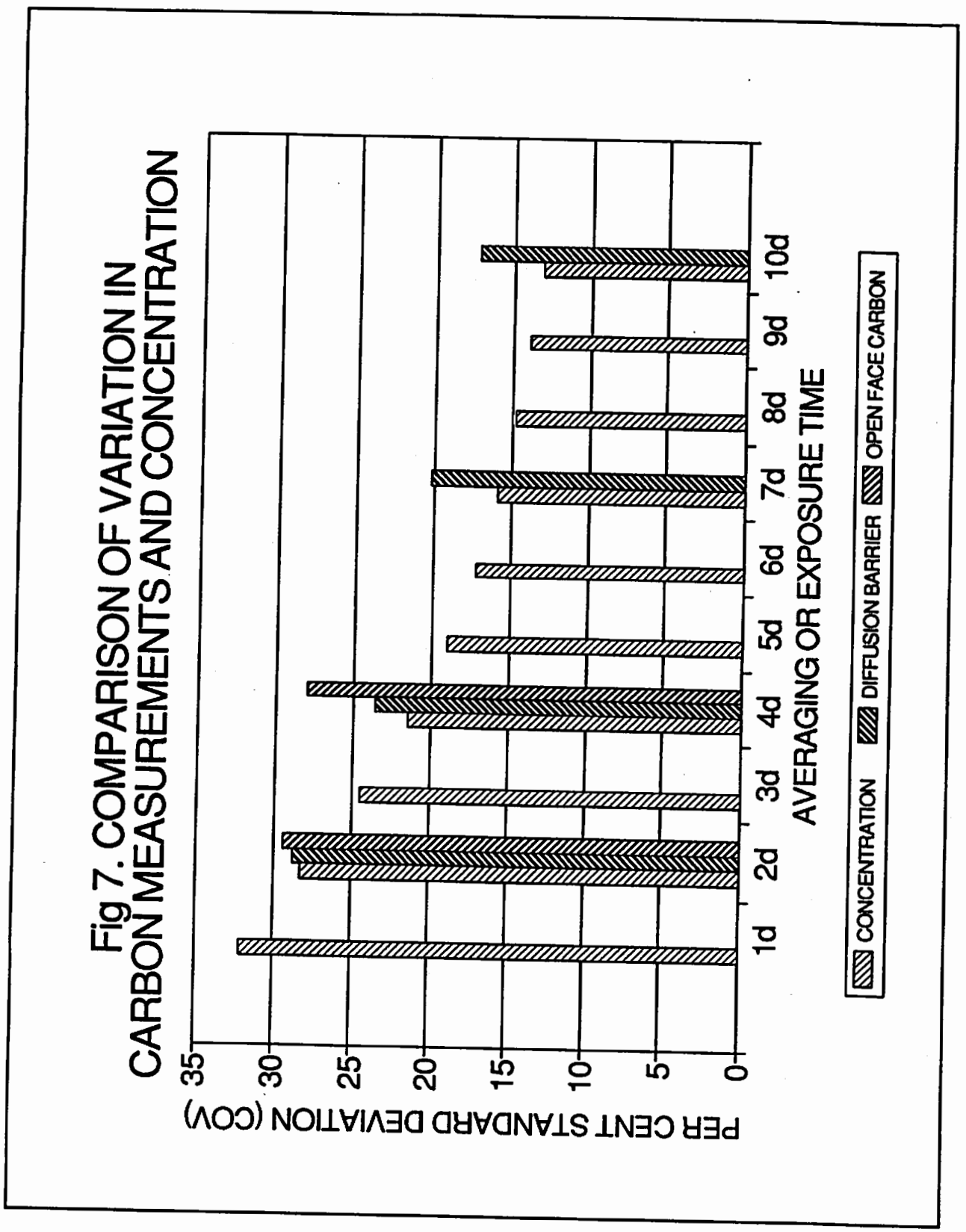


Fig 7. COMPARISON OF VARIATION IN CARBON MEASUREMENTS AND CONCENTRATION
PER CENT STANDARD DEVIATION (COV)
0
5
10
15
20
25
30
35
1d
2d
3d
4d
5d
6d
7d
8d
9d
10d
AVERAGING OR EXPOSURE TIME
CONCENTRATION
DIFFUSION BARRIER
OPEN FACE CARBON