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RADIATION LEVELS IN BACKFILLED AREAS AT DENISON MINES LTD.

J. BIGU, M. GRENIER, AND A. FRATTINI

ELLIOT LAKE LABORATORY

OCTOBER 1985

MINING RESEARCH LABORATORIES
DIVISION REPORT MRL 87-180(TR)

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by

J. Bigu*, M. Grenier** and A. Frattini+

ABSTRACT

Radiation field data are presented from an underground uranium mine (Denison Mines Ltd., Elliot Lake, Ontario) during and after the course of backfill operations in mined-out stopes using uranium tailings. Monitoring stations were set up at different locations during the experimental tests. Broadly speaking, an increase in the radiation level was observed from backfill material poured in some experimental stopes. The absolute contribution to the total radiation level from backfilled stopes is, however, somewhat uncertain. It should be noted that because of practical difficulties encountered during the underground tests, the data in this report should be considered of a preliminary nature, and caution should be exercised not to draw firm conclusions from the results presented.

Key words: Tailings; Backfill; Radon daughters; Uranium mines.

*Research Scientist and Radiation/Respirable Dust/Ventilation Project Leader. **Research Scientist, +Technologist, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario.

NIVEAUX DE RAYONNEMENT DANS LES SECTEURS REMBLAYÉS DES MINES DENISON LTD.

par

J. Bigu*, M. Grenier** et A. Frattini+

RÉSUMÉ

On présente des données sur le rayonnement obtenues dans une mine d'uranium souterraine (Denison Mines Ltd., Elliot Lake, Ontario), pendant et après le remblayage de chantiers d'abattage déjà exploités, avec des résidus de minerai d'uranium. Des stations de contrôle ont été mises sur pied à différents endroits, au cours des essais expérimentaux. En général, on a observé une augmentation du niveau de rayonnement due au matériau de remblayage déversé dans certains chantiers expérimentaux. Cependant, la contribution absolue des chantiers remblayés au niveau total de rayonnement est quelque peu incertaine. Il faut noter que les données fournies dans le présent rapport doivent être considérées comme étant de nature préliminaire à cause des difficultés rencontrées lors des essais souterrains; il faut donc s'assurer de ne pas tirer de conclusions définitives à partir des résultats présentés.

Mots clés : Résidus; remblayage; descendants radioactifs du radon; mines d'uranium.

*Chercheur et chef du projet Rayonnement/Poussières respirables/Ventilation.
**Chercheur, +technologiste, CANMET, Énergie, Mines et Ressources Canada, Elliot Lake (Ontario).

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INTRODUCTION

A backfill program was initiated at Denison Mines Ltd. a few years ago, initially to assist in pillar recovery operations in areas of the mine where there was low extraction during primary stopings. Lately, however, cemented backfill has been used to provide regional stability in areas near the Quirke/ Denison boundary pillar.

The backfill materials used in the stope filling program are residues derived from uranium extraction operations by hydrometallurgical processes. Because these residues are radioactive, i.e., they contain Ra-226, among other radioisotopes, it is important to determine the contribution from backfill operations to underground (U/G) radiation levels.

In early 1983, Denison Mines technical staff approached the Elliot Lake Laboratory (CANMET) for technical assistance regarding monitoring of mine areas intended for backfill operations. The monitoring program would consist of the determination of radiation levels, and other relevant variables at certain locations, before, during and after the designated mine areas were backfilled, and during mining, i.e., recovery, of the remaining pillars. Shortly afterwards, the Atomic Energy Control Board (AECB) expressed interest in this project and offered financial assistance to carry out the work.

The radiation monitoring program for U/G backfill operations has undergone a number of important changes, modifications and delays ever since its inception in 1983. The changes and modifications conform to personnel safety reasons and to practical considerations, e.g., rock fall, and the unanticipated initiation of certain mining activities in the same areas, or nearby, which were originally designated for the 'pilot' backfill program. The above changes made necessary the relocation of the sampling (monitoring) stations to locations less ideal for air sampling and monitoring than the ones originally chosen.

Considerable delay in the backfill monitoring program has occurred because of regional stability problems at the Quirke/Denison boundary pillar. This problem has made it necessary for Denison crews, and other staff, to place top priority and major efforts in the affected area of instability, with the natural detriment, and consequent delay, to the experimental mining and backfill monitoring program.

Because of the above reasons, the data presented here are only of a preliminary nature and caution should be exercised in the interpretation of the results.

The work described in this report has been conducted by the Elliot Lake Laboratory (ELL) at Denison Mines Ltd. (Elliot Lake) with partial funding by AECB.

EXPERIMENTAL PROCEDURE AND APPARATUS

An area underground was chosen. In this general area, there were several mined-out stopes suitable for backfilling and monitoring purposes. Two complete sampling stations were planned to be installed for monitoring purposes, one upstream and one downstream of the access drift in order to carefully monitor radiation levels, and other variables, at the intake and exhaust sites of the stope(s), respectively.

The sampling stations were equipped with instrumentation to monitor, on a continuous, unattended, basis, the radon daughter Working Level, WL(Rn), thoron daughter Working Level, WL(Tn), radon gas concentration, [Rn-222], and thoron gas concentration, [Rn-220]. Furthermore, a meteorological package/ data-logger, and associated sensors, gave information regarding temperature and barometeric pressure. All instruments were programmed to provide readings every hour, 24 h/day.

In addition to the above continuous measurements, grab-sampling measurements were also conducted on a quasi-periodic basis at several relevant locations of mine air flow, relative humidity, and radon gas (Rn-222) concentration dissolved in water draining from drainpipes through bulkheaded backfilled stopes.

Commercial instrumentation was mainly used in the backfill program. Some of the instrumentation used included continuous radon (thoron) progeny monitoring system models WLM-300 and RGA-400 from EDA Instruments (Toronto), grab-sampling Working Level monitor WL-1000C from Pylon Electronics Development (Ottawa), data-logger model 650, α-meters model 601, and other probes, from Alpha-NUCLEAR (Toronto), and radon gas analyzer model RGM-2 from Eberline (U.S.A.). Some comments on the performance of the instrumentation are given in Appendix A.

Instrumentation was placed in large (~3.5 m x 2 m x 2.5 m) thick gauge wire mesh, wooden frame, cages built for the backfill program. The purpose of these cages was two-fold: a) to allow representative mine air samples to be taken in their natural environment as air could pass through the cages with minimum disturbance, and b) to protect the instruments from accidental damage by passing vehicles and personnel.

The intended operational procedure was to start the monitoring of areas of interest at least two weeks prior to any backfill operation, in order to obtain a reference background, or 'base line'. Furthermore, two fully equipped sampling stations, one at the intake and one at the exhaust, were intended for monitoring purposes. Unfortunately, backfill operations in the first designated area began prematurely and when the sampling stations were not yet fully equipped. As a consequence a great deal of relevant data could not be obtained.

After the first originally chosen area was completely backfilled, another area was chosen to continue experimentation. This area was later discovered, however, to be unsuitable because of safety reasons. A third backfill area was finally selected for which a great deal of background information was collected, but which was never backfilled. This new location, however, presented a number of practical problems and was less than ideal for the pilot experiments. For simplicity, the first and third experimental areas will be referred to in the future as the old location and the new location, respectively.

Because of the practical difficulties indicated above, it was decided to discontinue the backfill monitoring program in the present area and to reactivate it sometime in the future in an alternative location. Monitoring equipment was withdrawn from the mine site early 1985. However, in order to help in the interpretation of the data collected in the old and new locations, a radiation survey between the old and new locations, and a ventilation survey in a larger, general, area including the backfill area, was undertaken during April 1985.

The idea behind this grab-sampling program was simply to measure the Working Levels, and other relevant variables, as a function of distance from a reference new intake location in order to establish the net contribution from backfilled stopes to the total radiation level.

EXPERIMENTAL RESULTS AND DISCUSSION

A layout of the general area of the mine where backfill operations were carried out is shown in Figure 1. This illustration shows the stope number, access drift number, location of the cages where the instrumentation was placed in the old and new locations, and the direction of air flow (arrows).

Figure 2 shows, in schematic form, the direction of air flow (arrows) and air flow (numbers in brackets) obtained from the ventilation survey conducted in April 1985. Also shown in the graph are the locations of the cages where data were collected, and the locations where grab-sampling measurements (encircled numbers) were taken.

Figures 3 and 4 show the amount of backfill material poured into the experimental stopes 37028, 37030, 37032 and 37034 (Figure 3), and stopes 37036 and 37038 (Figure 4). The first four stopes were filled during the period November 1983 to February 1984 when monitoring instrumentation was located at the old location. However, the other two stopes (37036 and 37038) were filled during the period September 1984 to December 1984 when most monitoring instrumentation had already been moved to the two cages in the new location (see for instance, Figure 1). The stopes where backfilling operations took place during the period 1983 to 1985 are shown by dotted shading in Figure 5.

A. RADON PROGENY MEASUREMENTS

Figure 5 shows the average WL(Rn), i.e., $\overline{WL(Rn)}$, from grab-sampling measurements taken for all the stopes in the general underground area of interest.

Figures 6 to 9 show grab-sampling measurements versus time for stopes and travelways in the general area where monitoring was conducted. Measurements were taken, whenever practically possible, at the working face of the stope. The monthly values given in the above Figures represent an average from all measurements taken during the corresponding month. It should be noted that the number of monthly measurements taken in the stopes varied from month to month and from stope to stope. Also shown in the graphs are the overall average values for WL(Rn) calculated over the time during which grab-sampling measurements were taken.

Figures 10 to 16 show WL(Rn) measurements conducted with continuous monitoring systems, grab-sampling (G.S) by the Thomas-Tsivoglou method (2), and using an automated grab-sampler Working Level Monitor by Pylon, Model WL-1000C. Tables 1 to 3 show radon daughter and thoron daughter data obtained by several methods (2-6).

Figures 10 to 12 show WL(Rn) as determined by the WLM-300. Data have been plotted as daily average, i.e., average of 24 readings/day at a rate of 1 reading/h, 60-min count/reading. Examination of Figures 10 to 12 shows that WL(Rn) is significantly higher (>20%) for the old location, where upstream backfill operations were carried out, than for the new location.

Figure 13 shows WL(Tn) data by grab-sampling and by the WL-1000C. Data by grab-sampling were significantly higher than that obtained by the WL-1000C. Thoron daughter data are also shown in Tables 1 to 3.

Figure 14 shows WL(Rn) data obtained with the WLM-300 (upper graph), and with the WL-1000C and by grab-sampling (lower graphs). There is quite a good correlation between the three graphs. However, data by the WLM-300 were higher than for grab-sampling, which in turn were higher than for the WL-1000C. Again this graph shows quite substantial differences between the old location and the new location.

Because of some difficulties in ascertaining the true [Rn-222], WL(Rn) and WL(Tn) contribution to the total, arising from backfill operations, radiation measurements were made upstream and downstream of the stopes where these operations took place. The measurements were conducted in conjunction with a ventilation survey in the area (see Figure 2).

Radiation measurements by grab-sampling using the Thomas-Tsivoglou method were done as follows. Twelve equidistant locations between the old and new sampling stations, including both stations, were chosen. The grab-sampling locations are denoted 1 to 12 (see Figures 2, 15 and 16) where positions 1 and 12 represent, respectively, the new and old monitoring stations. The duration of each complete survey (i.e., sampling) was 90 min, sampling three stations simultaneously. Three complete radiation surveys were conducted under constant airflow conditions. The results of the measurements are shown in Figures 15 and 16. Average values for the measurements at each location are also shown (continuous solid line).

Figure 15 shows a clear increase in WL(Rn) and WL(Tn) from the new location (upstream, location 1) to the old location (downstream, location 12). More data pertaining to these measurements are given in Table 2. The data in Figures 15 and 16 show that there is an increase of above 100% for WL(Rn) between positions 1 and 12. A somewhat lower increase for WL(Tn) was observed. Theoretical calculations for this area will be discussed in the Appendix.

B. RADON GAS MEASUREMENTS

Figures 17 to 20, and Tables 4 and 5. represent radon gas data collected in the old and new locations during the period 1983 to 1985. Figures 17 to 20 show the daily average and monthly average (continuous horizontal line) for the Rn-222 concentration, i.e., [Rn-222], as measured using the Eberline RGM-2 continuous monitor.

Figure 21 shows the monthly [Rn-222]. The broken lines represent the averages for the total period during which measurements were carried out in the old and new locations. Shaded areas represent the standard deviation from the mean value.

Figure 22 shows the monthly [Rn-222] averages as determined by four different methods, namely: Eberline RGM-2, Alpha-NUCLEAR 601, grab-sampling using 150 cm^3 scintillation cells, and Terradex passive radon gas samplers using SM type track-etch detectors. A summary of these data is given in Table 4.

Table 5 summarizes measurements of radon gas dissolved in water draining from drainpipes through bulkheaded backfilled stopes.

Table 6 shows [Rn-222] data obtained with Terradex track-etch passive monitors exposed for a week at a time, as in previous measurements, in some 'empty' stopes and in stopes during the course of backfill operations. Some of the monitors were of the same type as those used in the old monitoring station (see Table 4 and Figure 22). Exposures other than those indicated in Table 6 were also conducted at later dates during the backfill cycle. Unfortunately, the monitors were either lost underground, and could not be found, or were flooded with contamination during the backfill pouring operations and could, therefore, not be read reliably. However, from the sparse data available in Table 6, a noticeable increase in [Rn-222] was observed as a result of backfill pouring operations in stopes 37032 and 37034 (see Figure 3 and Table 6, December 9-15, and December 15-21, 1983 exposures).

Figure 23 shows monthly average values for [Rn-222] and WL(Rn) obtained, respectively, with the RGM-2 and WLM-300 in the old and new locations during the period November 1983 to February 1985. Also shown in the graph is the amount of fill during the backfill operations. It should be noted that backfilling of stopes 37036 and 37038 was conducted between September 1984 and December 1984, a period during which no data are available for the old location, situated downstream. As the above stopes are situated downstream from the new location, the amount of fill data on the top graph cannot be used directly in conjunction with the other data in Figure 23, but rather with data given in Figures 15 and 16.

From the above data the following observations are worth noticing:

1. Variation of [Rn-222] with time indicates the presence of mining activity and changes in the ventilation characteristics.
2. However, in spite of the different average values for [Rn-222] obtained by several methods, these differences are not statistically significant (see

Figure 22).

3. [Rn-222] in the old location, where backfill operations were conducted, was significantly higher than in the new location where no backfill operations were conducted (see Figures 21 and 22). The same observation applies to WL(Rn) and WL(Tn), as shown below.

4. The data in Figure 23 for the old location show a significant increase in [Rn-222] and WL(Rn) during the backfill operation (see also Figure 3), up to February 1984. Between February 1984 and September 1984 many underground changes occurred, including relocation of some instrumentation and hence no firm conclusions can be drawn from the data during this interim period. However, as previously indicated, there is a substantial difference between the radiation levels measured at the old and new locations. The contribution from mine surfaces as opposed to backfill is discussed in the Appendix.

5. Part of the observed increase in values for WL(Rn) and WL(Tn) (see Figures 15 and 16, and for [Rn-222], see Figures 21 and 22), is due to the contribution, to the total, of these variables from emanation of Rn-222 and Rn-220 from mine walls between positions 1 and 12.

C. CONTRIBUTION FROM MINE WALLS

Contribution from mine walls can be determined theoretically using suitable radiation mine models provided some physical variables, such as Rn-222 and Rn-220 mine wall emanation rates and air flow, and some geometrical considerations, e.g., length and cross-section of the mine area, are known. Alternatively, the same information can be obtained experimentally by direct field measurements, before and after backfill operations, provided no changes other than backfill itself have been introduced during this time, such as mine lay-out changes, redirection of air flow, and other changes.

The difficulty in separating the contribution to the total [Rn-222], WL(Rn) and WL(Tn) due to backfill material (stopes 38028, 37030, 37032, 37034, 37036 and 37038) from the contribution due to mine emanating surfaces such as walls, ceilings and floor, between locations 1 and 12 is rather obvious in such a complex mine layout and ventilation network as the one here. Some of the difficulties are the following:

1. Complex ventilation characteristics of the area (Figure 2).
2. Lack of accurate information regarding the Rn-222 and Rn-220 emanation characteristics of mine surfaces. Although measurements of Rn-222 emanation rates from mine walls were planned for the backfill program, some U/G experimental difficulties precluded successful completion of this part of the program.
3. Variability of the ventilation characteristics of the area, e.g., opening and closing of ventilation doors; building of bulkheads; initiation of mining operations, other than backfill; sporadic operation of auxiliary exhaust fans; and breakage of air passages in certain areas for specific reasons according to some mining operation needs.
4. Changes introduced in the backfill program according to practical needs and considerations.

In order to gain some information regarding the contribution to measurements in the old location from mine surfaces, a mine radiation model for Rn-222, Rn-220 and their decay products was developed and used (7) as described elsewhere. Emanation data from other areas of the mine, assumed to be approximately representative of our area of interest, were used. Theoretical data are given in the Appendix B.

SUMMARY AND CONCLUSIONS

A summary of some of the data obtained during and after the backfill program is given in Table 3. The table shows the range of values for a number of relevant variables. Of particular interest are the radon daughter disequilibrium ratio, RDDR = 1:0.6:0.4, the Working Level Ratio, WLR ~0.7, and the ratio WL(Tn)/WL(Rn) ~0.9. These three ratios give information on the 'age' of mine air (7-9).

Some discrepancies were noted between data obtained by several grab-sampling methods and continuous monitoring. No satisfactory explanation can be offered at present as the instrumentation used was checked and calibrated prior to field use.

The data in Tables 1 to 6 and Figures 10 to 16 and 21 to 23 show that there is a significant, although not excessive, difference (~30%) between [Rn-222], WL(Rn) and WL(Tn) for the old and new locations. However, this difference is due to Rn-222 emanation contributions from three independent locations:

1. Contribution from the main drift (35950) mine walls between the new and old locations. This contribution is treated as essentially constant throughout the period of experimentation.
2. Contribution from stopes between the new and old locations with air flow in the direction of the main drift. It should be noted that stopes 37028 to 37038 were bulkheaded at the junction with drift 37950 prior to backfilling operations. Hence, there was no air flow into 35950 and the only contribution from the stopes into the drift was from Rn-222, leaking out of the stopes because of diffusion and pressure differentials between the stopes and the main drift.
3. Contribution from exposed backfill surface in stopes 37028 to 37038.

With regard to item 3, the following should be noted:

a) Emanation of Rn-222 from exposed backfill surface increases as the curing of backfill material progresses. This is so because initially a large amount of Rn-222 is dissolved in water which either drains out of the stope or evaporates into the stope area. Radon gas concentration in water was 3×10^4 - 6.6×10^4 pCi/L H_2O;

b) The total Rn-222 emanating from a stope is a function of the total exposed backfill surface area and thickness of the material. Hence, as the stope is being filled the exposed surface area varies, increasing in the beginning followed by a decrease towards the end of pouring, until it reduces, eventually, to the size of the stope opening. Furthermore, emanation from backfill is limited to a thickness of about the 'diffusion length' of Rn-222 in the material (~1 m). Hence, the total contribution from completely filled stopes may not be excessive;

c) If ventilation in the stope is increased during the backfill operation to protect personnel in the area, the radiation level will be reduced even if the emanation from backfill material is significantly elevated.

Notwithstanding the above observations, a close examination of the data from Figure 23 shows a noticeable increase in Rn-222 and WL(Rn) in the old location as a function of the total amount of backfill poured into stopes 37028 to 37038. (It should be noted that when backfill was poured into stopes 37036 and 37038 no monitoring in the old location was carried out. Hence, the results of Figure 23 pertaining to the new location, upstream of these stopes, are not relevant in the context of this discussion.)

In summary, an increase in the radiation level has been brought about by backfill operations with uranium tailings. However, this increase does not seem unduly large, or very significant for the backfill material used and the particular experimental conditions of the backfill operations. It should be noted, however, that the increase in backfill operation practices using uranium tailings should be closely monitored to avoid potentially undesirable radiation levels in underground working areas. More experimentation, under better controlled conditions, will be necessary to properly assess the radiological impact of backfill operations using uranium tailings in underground uranium mines.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution of S. Hardcastle in conducting a ventilation survey in the area of interest. Thanks are extended to Denison Mines Ltd. (A. Sheik) for providing the facilities to conduct this work and to AECB for financial assistance.

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Table 1 - Data obtained with the WL-1000C and several grab-sampling methods.

Date	Time	[RaA] pCi/L	[RaB] pCi/L	[RaC] pCi/L	WL(Rn)	RDDR+	[ThB] pCi/L	[ThC] pCi/L	WL(Tn)	[ThC]/[ThB]	WL(Tn)/WL(Rn)	Location
Nov. 17/83	8:52	49.62	25.81	19.90	.26	1:0.52:0.40	2.16	.96	.26	.44	1.00	Old location
" 17/83	10:26	61.06	33.63	24.26	.32	1:0.55:0.40	3.17	1.02	.40	.32	1.23	" "
" 22/83	8.52	63.75	36.12	29.88	.36	1:0.57:0.47	2.69	1.04	.34	.39	.94	" "
" 22/83	10:06	71.90	40.62	30.98	.40	1:0.56:0.43	3.04	1.40	.39	.46	.98	" "
" 24/83	8:46	73.28	41.44	33.25	.41	1:0.57:0.45	2.62	1.17	.34	.45	.82	" "
" 24/83	10:01	81.29	46.83	35.78	.46	1:0.58:0.44	3.59	1.27	.45	.35	.99	" "
Dec. 1/83	10:07	75.40	36.32	26.62	.36	1:0.48:0.35	2.93	1.28	.37	.44	1.03	" "
" 9/83	8:59	73.16	34.34	27.74	.35	1:0.47:0.38	2.78	1.16	.35	.42	1.00	" "
" 13/83	8:57	61.77	32.74	24.73	.32	1:0.53:0.40	2.46	.80	.31	.32	.96	" "
" 15/83	8:59	86.04	59.00	45.20	.56	1:0.69:0.53	3.59	1.78	.46	.50	.82	" "
" 15/83	10:17	96.94	58.20	47.50	.57	1:0.60:0.49	3.34	1.63	.43	.49	.75	" "
" 19/83	9:01	132.74	83.10	63.48	.80	1:0.63:0.48	4.63	2.67	.60	.58	.75	" "
" 19/83	10:14	114.46	78.46	60.28	.74	1:0.69:0.53	4.24	1.93	.54	.45	.73	" "
" 21/83	9:01	63.94	34.83	28.08	.35	1:0.54:0.44	2.09	1.32	.27	.63	.78	" "
Nov. 2/84	9:25	19.72	11.42	7.16	.10	1:0.58:0.36	6.39*	1.33	.80	.21	7.58	New location
" 2/84	10:40	24.77	11.38	8.87	.12	1:0.46:0.36	1.91	1.24	.25	.65	2.13	" "
" 6/84	8:49	20.38	10.92	7.92	.10	1:0.54:0.39	3.11	1.35	.40	.43	3.73	" "
" 6/84	10:01	23.50	12.86	8.86	.12	1:0.55:0.38	1.66	.93	.21	.56	1.74	" "
" 7/84	8:50	23.41	10.20	7.05	.10	1:0.44:0.30	.90	1.07	.12	1.19	1.19	" "
" 7/84	10:02	23.16	11.97	8.78	.12	1:0.52:0.38	1.65	1.29	.22	.78	1.84	" "
" 8/84	8:47	15.02	9.17	7.01	.09	1:0.61:0.47	.66	1.16	.09	1.77	1.06	" "
" 8/84	10:01	21.84	12.82	9.64	.12	1:0.59:0.44	.90	1.97	.13	2.20	1.07	" "
" 9/84	8:48	19.46	13.90	9.57	.13	1:0.71:0.49	1.78	1.85	.24	1.03	1.89	" "
" 9/84	9:59	24.78	14.85	10.04	.14	1:0.60:0.41	1.29	2.03	.18	1.57	1.31	" "
" 15/84	8:51	29.72	19.14	11.74	.17	1:0.64:0.40	.83	2.69	.13	3.24	.77	" "
" 15/84	10:03	32.73	20.63	14.58	.19	1:0.63:0.45	1.67	2.82	.22	1.69	1.15	" "
" 22/84	8:47	26.6	16.3	10.57	.15	1:0.61:0.40	.57	2.09	.09	3.67	.63	" "
" 30/84	8:50	21.97	14.63	8.29	.13	1:0.67:0.38	.74*	1.88	.11	2.53	.88	" "
Jan. 3/85	8:49	28.14	17.84	10.11	.16	1:0.63:0.36			LOW			" "
" 3/85	10:07	33.62	18.53	11.53	.17	1:0.55:0.34	1.76	2.97	.25	1.69	1.45	" "
" 10/85	8:54	17.92	12.15	8.82	.12	1:0.68:0.49	.67	2.11	.11	3.15	.94	" "
" 10/85	10:06	16.94	9.85	6.77	.10	1:0.58:0.40	.84	1.91	.13	2.27	1.34	" "
Nov. 17/83[1]	8:58	50.37	31.02	22.88	.31	1:0.62:0.45	3.02	-	.37	-	1.22	Old location
" 17/83[1]	10:09	60.19	36.52	28.23	.36	1:0.61:0.47	3.27	-	.45	-	1.24	" "
" 22/83[1]	8:54	79.73	54.90	39.24	.51	1:0.69:0.49	4.08	-	.56	-	1.10	" "
" 22/83[1]	10:06	82.49	57.49	40.42	.53	1:0.70:0.49	3.85	-	.47	-	.90	" "
" 24/83[2]	8:56	78.50	47.90	37.83	.48	1:0.61:0.48	3.59	-	.44	-	.91	" "
" 24/83[2]	9:42	94.59	54.99	35.25	.51	1:0.58:0.37	3.95	-	.49	-	.95	" "
Dec. 1/83[3]	9:23	44.68	30.47	25.76	.30	1:0.68:0.58	2.54	3.04	.35	1.20	1.18	" "
" 9/83[3]	9:25	77.08	41.20	29.44	.40	1:0.53:0.38	2.93	2.45	.39	.83	.98	" "
" 13/83[3]	9:21	85.82	48.58	34.78	.46	1:0.57:0.41	3.39	3.16	.46	.93	.99	" "
" 15/83[3]	9:25	111.96	76.02	56.58	.71	1:0.68:0.51	4.59	1.36	.58	.30	.82	" "
" 19/83[3]	9:25	169.54	117.48	85.94	1.09	1:0.69:0.51	6.20	5.69	.84	.92	.77	" "

[1] WL(Rn) obtained as an average of Thomas-Tsivoglou (T-T), Markov and Kusnetz methods. WL(Tn) and [ThB] obtained by the Rock method. [RaA], [RaB] and [RaC] obtained by the T-T method.
[2] WL(Rn) obtained as an average of Thomas Tsivoglou and Markov methods. The rest of the data obtained as indicated in (1).
[3] Data obtained by the Kahn et al. method.
* Probably in error.
+ Stands for radon daughter disequilibrium ratio.

Table 2 - Grab-sampling data taken at 12 different locations between the old and new locations.

Location	[RaA] pCi/L	[RaA] pCi/L	[RaB] pCi/L	[RaB] pCi/L	[RaC] pCi/L	[RaC] pCi/L	WL(Rn)	WL(Rn)	[ThB] pCi/L	[ThB] pCi/L	WL(Tn)	WL(Tn)	RDDR[1]	WL(Tn)/WL(Rn)
1	45.70	25.03	25.31	15.10	19.00	13.02	0.25	0.15	2.37	1.78	0.33	0.22		
2	41.37	46.36	24.90	23.06	19.29	16.04	0.24	0.22	2.52	2.54	0.35	0.31		
3	46.26	31.09	28.21	21.21	20.37	17.78	0.27	0.21	2.16	1.86	0.30	0.23		
4	46.28	50.66	28.41	26.27	26.09	16.59	0.29	0.25	2.73	2.41	0.38	0.30		
5	52.10	37.57	30.60	20.56	20.20	16.20	0.28	0,20	2.51	2.17	0.35	0.27		
6	73.70	52.19	36.00	26.48	20.00	15.33	0.33	0.24	3.06	2.54	0.42	0.31		
7	73.70	54.71	28.60	31.26	20.80	34.33	0.35	0.34	3.20	2.97	0.44	0.37		
8	70.40	65.60	38.50	37.60	23.80	21.35	0.36	0.34	2.74	3.44	0.38	0.42		
9	65.60	40.73	35.80	23.08	24.30	19.09	0.34	0.23	2.96	2.56	0.41	0.32		
10	76.90	43.85	43.20	33.50	28.90	27.55	0.41	0.32	3.54	2.91	0.49	0.36		
11	108.80	72.54	47.27	48.58	29.60	35.31	0.46	0.45	3.60	3.70	0.50	0.46		
12	76.40	91.73	49.30	54.26	48.90	35.87	0.51	0.50	3.76	4.23	0.52	0.52		
Average Value	57.89		32.38		23.74		0.31		2.84		0.37		1:0.56:0.41	1.18

[1] Stands for radon daughter disequilibrium ratio.

Remark: The two sets of data for each variable represent data taken on two different days.

Table 3 - Summary of data collected in the general backfill area.

[Rn-222] pCi/L	[RaA] pCi/L	[RaB] pCi/L	[RaC] pCi/L	RDDR	WL(Rn)	[ThB] pCi/L	[ThC] pCi/L	WL(Tn)	[ThC]/[ThB]	WL(Tn)/WL(Rn)	Remarks
	WL by WL-1000C										
-	55-124	29-81	22-62	1:0.57:0.44	0.29-0.8	2-4	0.8-2	0.3-0.57	0.32-0.6	0.73-1.0	Old location
-	17-31	11-20	8-13	1:0.59:0.40	0.11-0.18	0.6-2.4	1-2.8	0.09-0.52	0.4->3.0	0.6->2.0	New location
	WL Grab-Sampling by Several Methods (see Table 1)										
-	45-170	30-117	23-86	1:0.63:0.47	0.3-1.1	2.5-6.2	1.4-5.7	0.35-0.84	0.3-1.2	0.77-1.24	Old location
	WL Grab-Sampling in 12 locations (see Table 2)										
-	25-109	15-54	13-49	1:0.56:0.41	0.15-0.51	1.78-4.23	-	0.22-0.52	-	∼1.18	12 locations
	Rn-222 by Several Methods (see Table 4)										
69-106	-	-	-	-	-	-	-	-	-	-	Old location
43-70	-	-	-	-	-	-	-	-	-	-	New location

Table 4 - Radon gas concentration, [Rn-222], measured by several methods.
The values given represent monthly averages.

Date	Eberline RGM-2 pCi/L	α-NUCLEAR pCi/L	Grab-Sampling pCi/L	Terradex SM pCi/L	Remarks
Nov. 83	-	93.6 ± 20.4	98.8 ± 5.5[1]	105.96 ± 25.2[4]	Old location
Dec. 83	69.6 ± 8.7	90.0 ± 14.3	-	104.68 ± 27.8[5]	"
Jan. 84	68.5 ± 7.2	79.1 ± 25.8	97.9 ± 14.3[2]	-	"
Feb. 84	79.8 ± 4.5	86.9 ± 33.0	83.3 ± 1.1[3]	-	"
Aug. 84	76.8 ± 11.9	-	-	-	"
Sept. 84	69.8 ± 5.6	-	-	-	"
Oct. 84	55.0 ± 3.0	65.6 ± 13.8*	-	-	New location
Nov. 84	62.1 ± 6.8	70.4 ± 10.7*	-	-	"
Dec. 84	62.2 ± 5.2	-	-	-	"
Jan. 85	47.8 ± 9.1	-	-	-	"
Feb. 85	43.4 ± 2.5	-	-	-	"

* with foam

1 Average of 4 measurements on Nov. 22/83 and 4 measurements on Nov. 24/83.

2 Average of 2 measurements on Jan. 10/84, 2 measurements on Jan. 17/84 and 2 measurements on Jan. 25/84.

3 Average of 2 measurements on Feb. 2/84.

4 Average of 4 detectors exposed Nov. 10-17/83 and 4 detectors exposed Nov. 17-24/83.

5 Average of 3 detectors exposed for one week.

Table 5 - Radon gas concentration, [Rn-222], in water draining from bulkheaded stopes.

Date	Sample No.	Location	[Rn-222] pCi/L(H_2O)	[Rn-222] Average Value pCi/L(H_2O)	
Feb. 2/84	1	See below*	6.1×10^3	5.95×10^3	
" "	2	" "	5.8×10^3		
Feb. 8/84	3	37032 Drain	3.07×10^4	3.23×10^4	
" "	4	" "	3.40×10^4		
Feb. 9/84	5	37030 Drain	4.07×10^4	4.74×10^4	
" "	6	" "	5.41×10^4		4.81×10^4
Feb. 15/84	7	37030 Drain	6.29×10^4	6.29×10^4	
Feb. 16/84	8	" "	6.63×10^4	6.63×10^4	

Table 6 - Radon gas measurements using Terradex passive detectors.

Stope	Date (Exposure period)	[Rn-222], pCi/L	Detector Type
37023	Dec. 6-13/83	52.35	
37024		57.94	
37026		90.08	SM
37028		64.23	
37038		274.51	
37034	Dec. 9-15/83	227.35 ; 133.62	ME18 ; FI18
37032		254.58 ; 188.37	ME18 ; FI18
37032	Dec. 15-21/83	361.91 ; 141.38	ME18 ; FI18
37034		348.49 ; 260.33	ME18 ; FI18

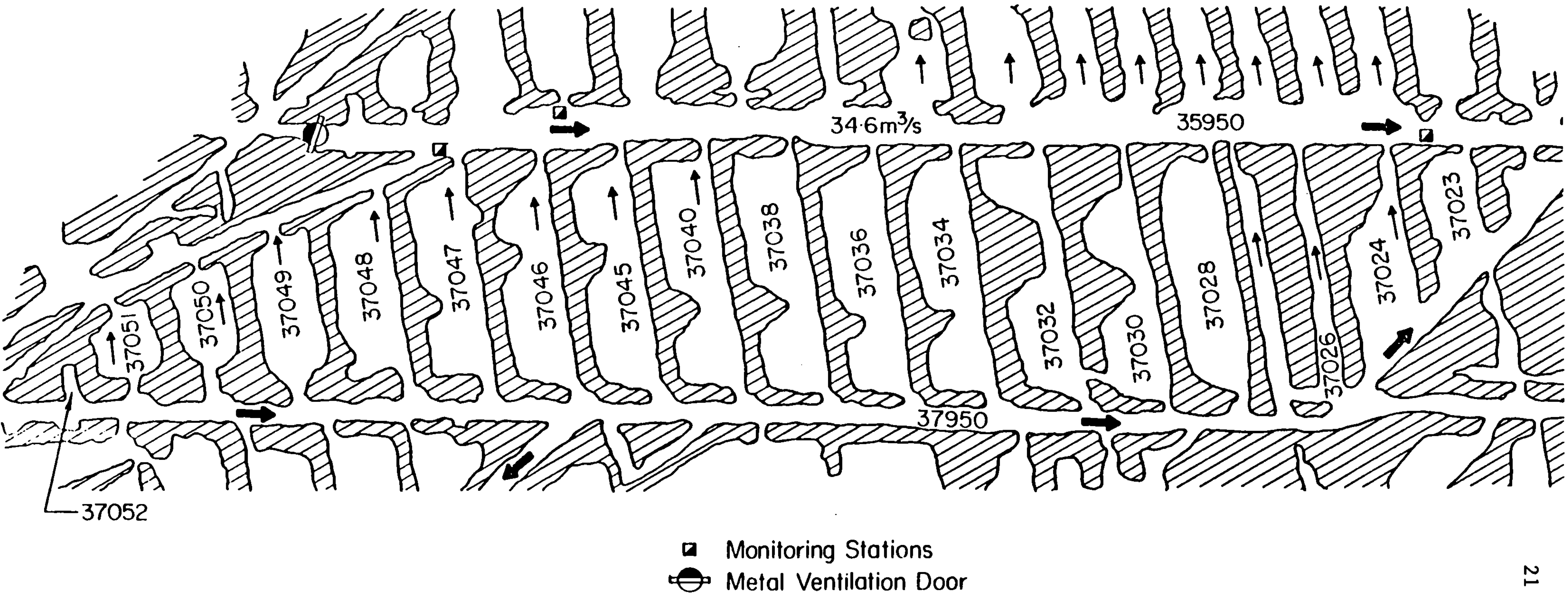


Fig. 1 - Lay-out of the general U/G area where backfill operations were carried out. Arrows indicate direction of air flow. Stopes and travelways are indicated by a five-digit number.

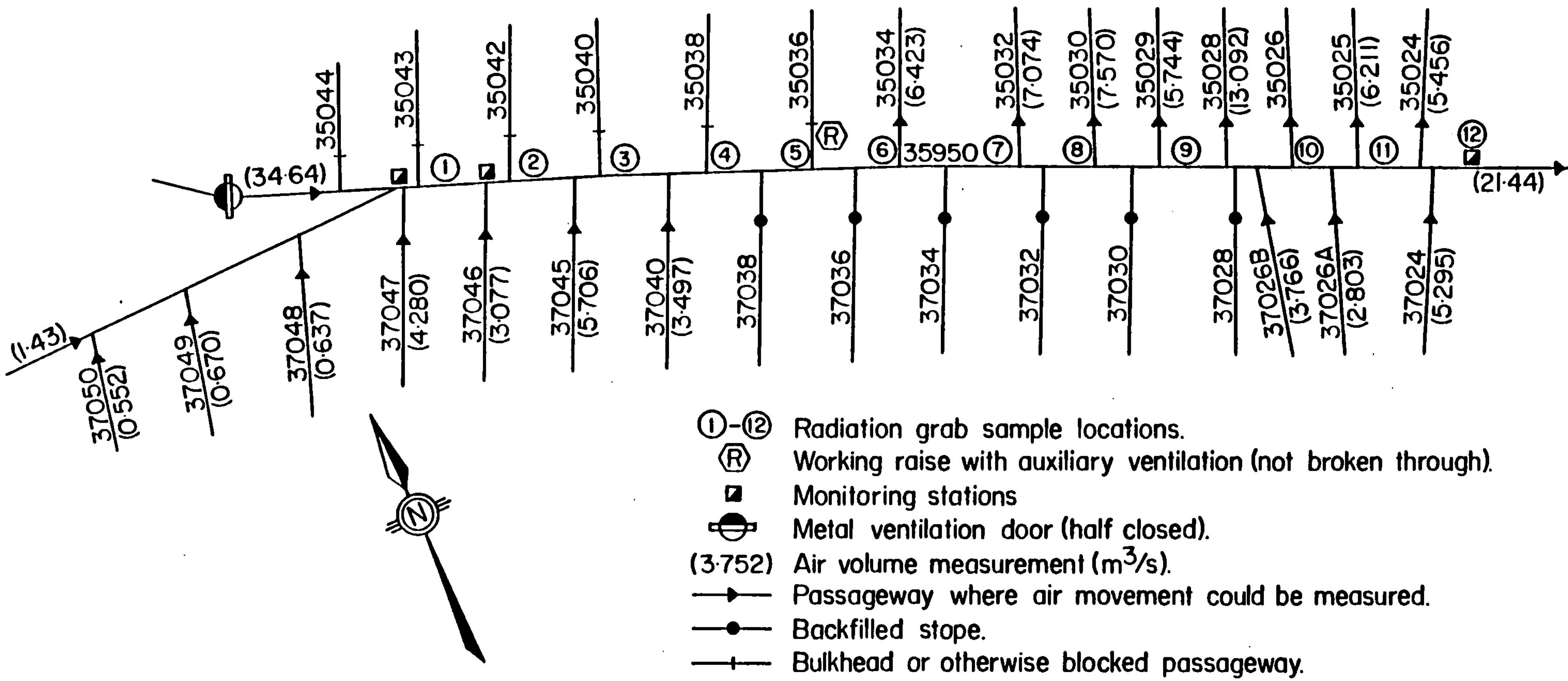


Fig. 2 - Ventilation survey data in the general U/G backfill area.

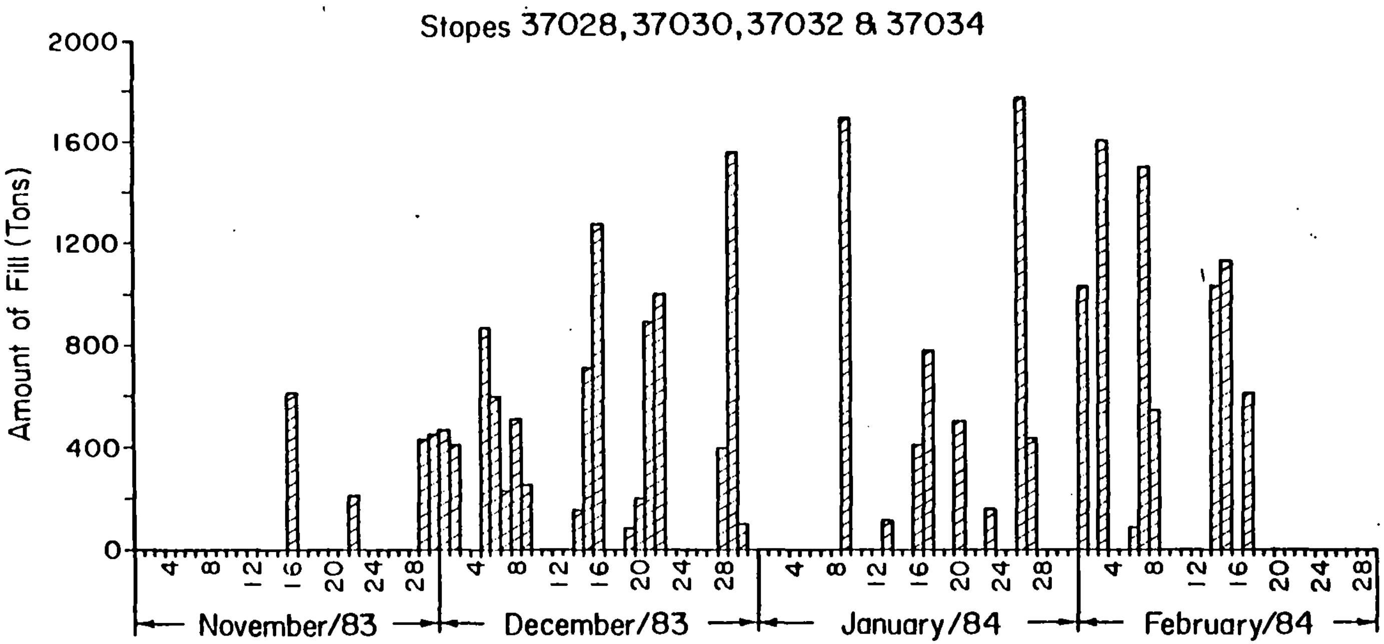


Fig. 3 - Amount of backfill poured in experimental stopes.

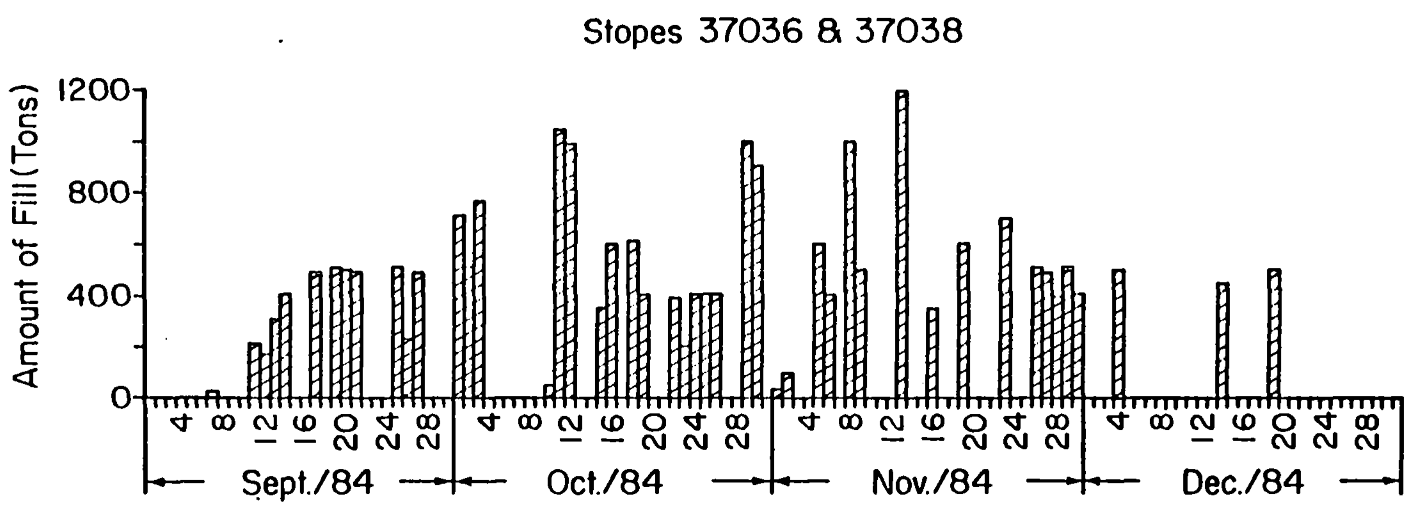


Fig. 4 - Amount of backfill poured in experimental stopes.

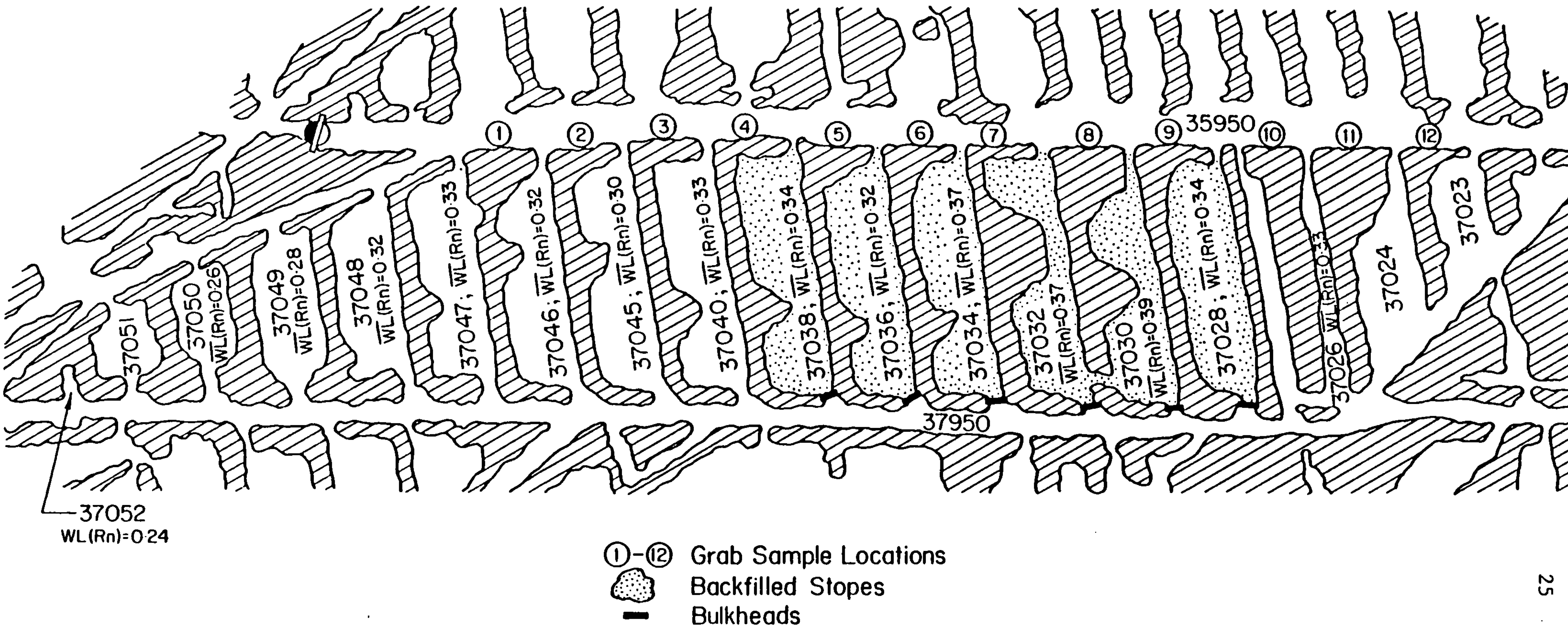


Fig. 5 - Average WL(Rn) from grab-sampling measurements in the general U/G backfill area.

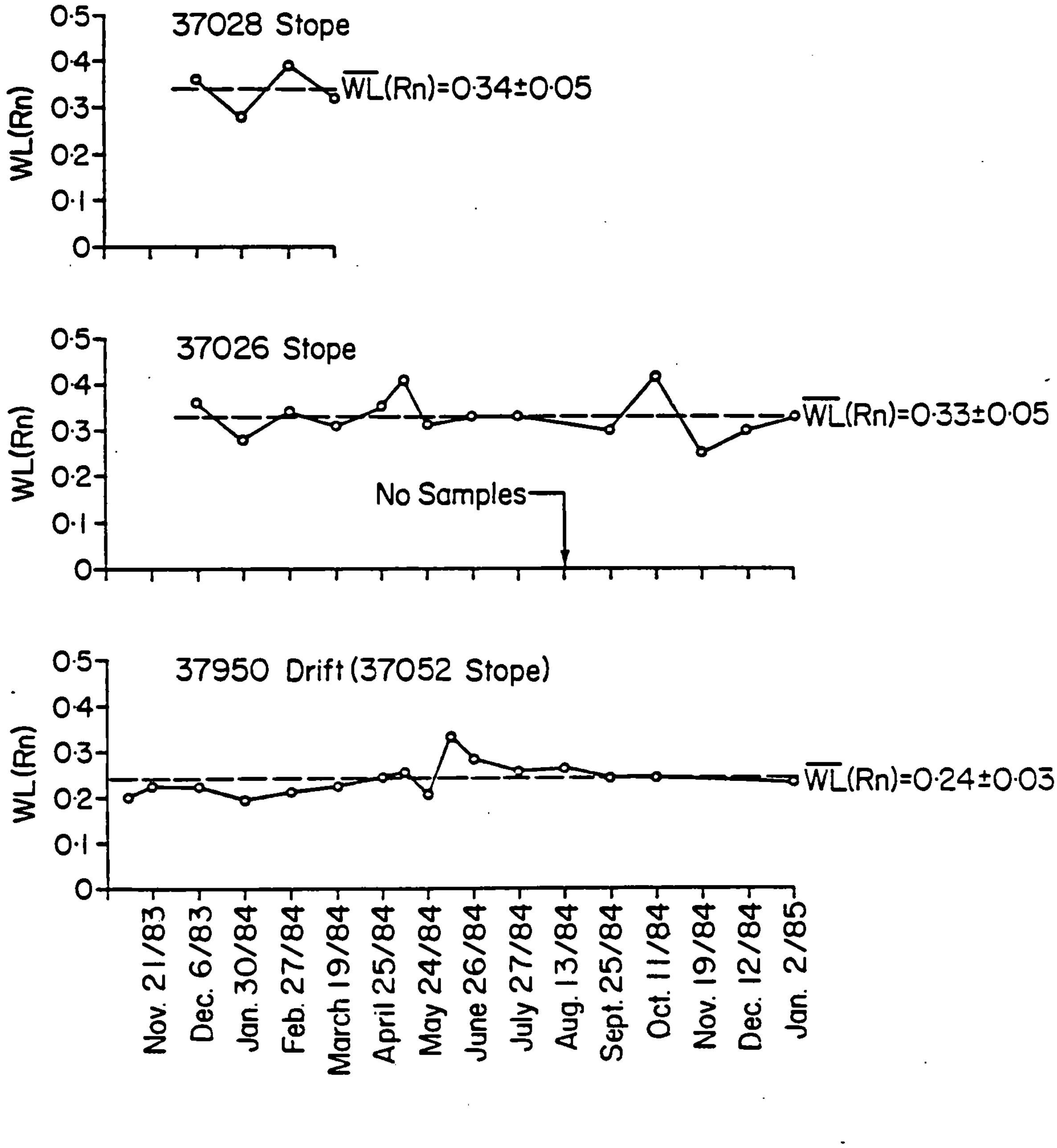


Fig. 6 - WL(Rn) grab-sampling measurements for several stopes and the average values over the entire period.

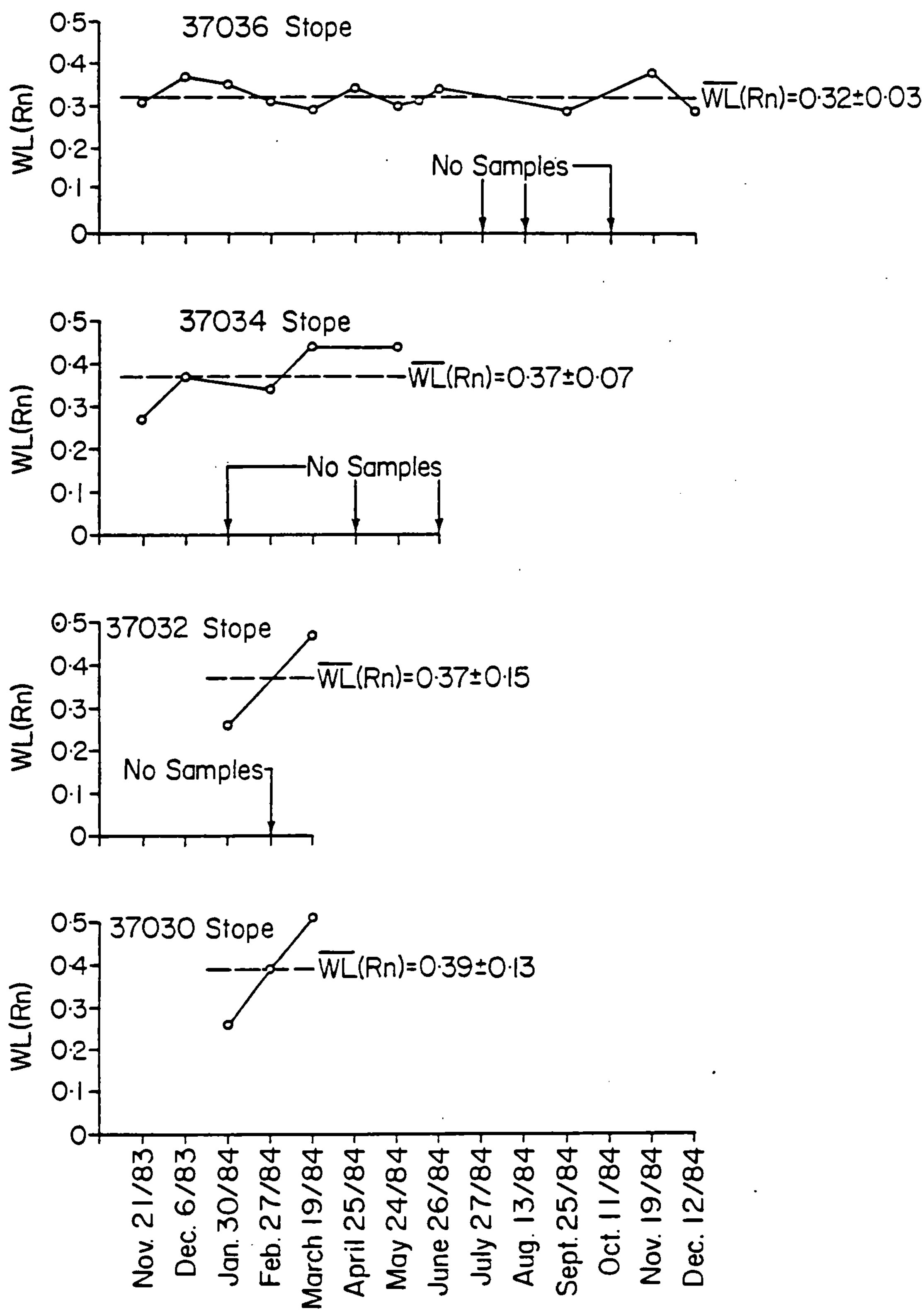


Fig. 7 - WL(Rn) grab-sampling measurements for several stopes and the average values over the entire period.

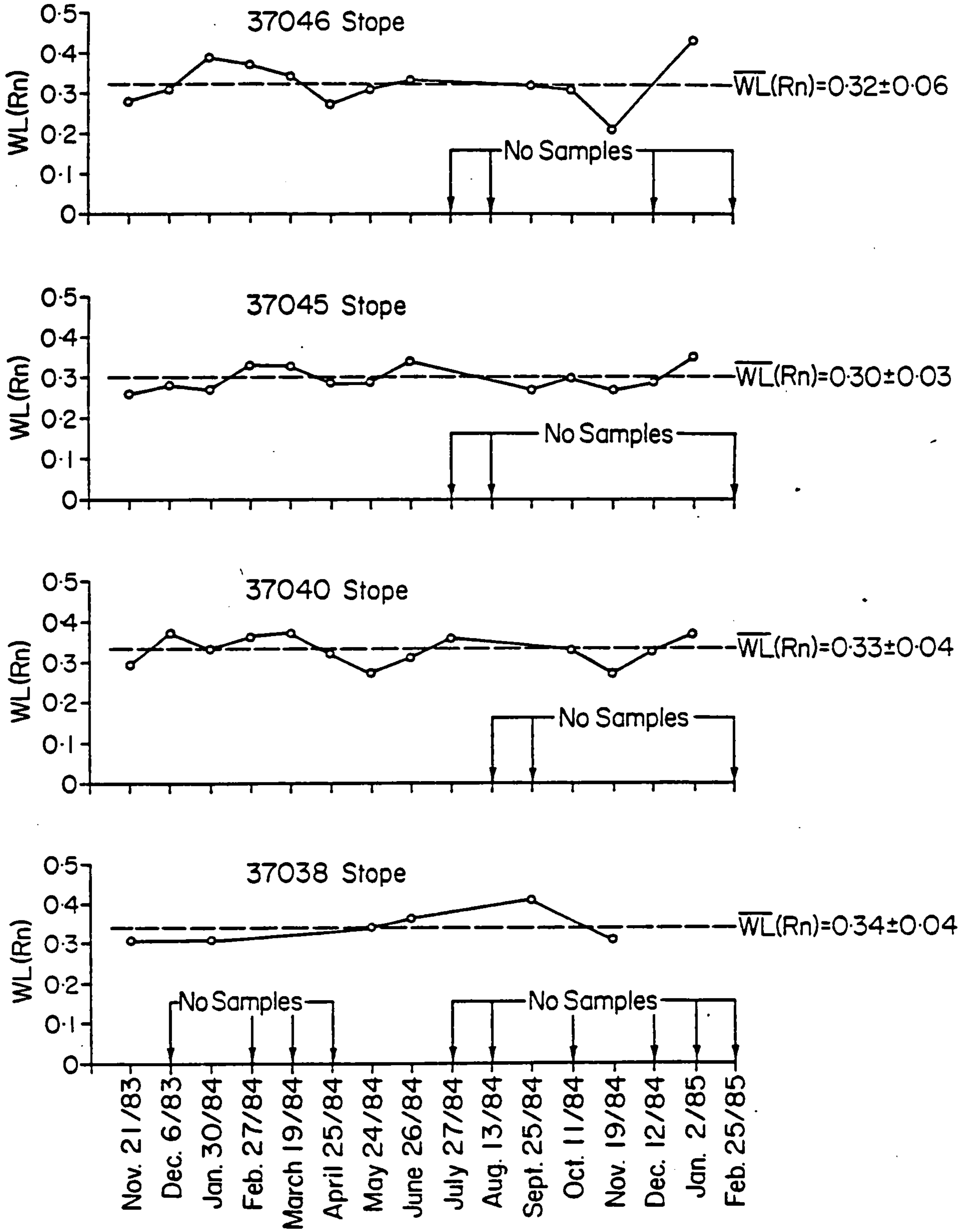


Fig. 8 - WL(Rn) grab-sampling measurements for several stopes and the average values over the entire period.

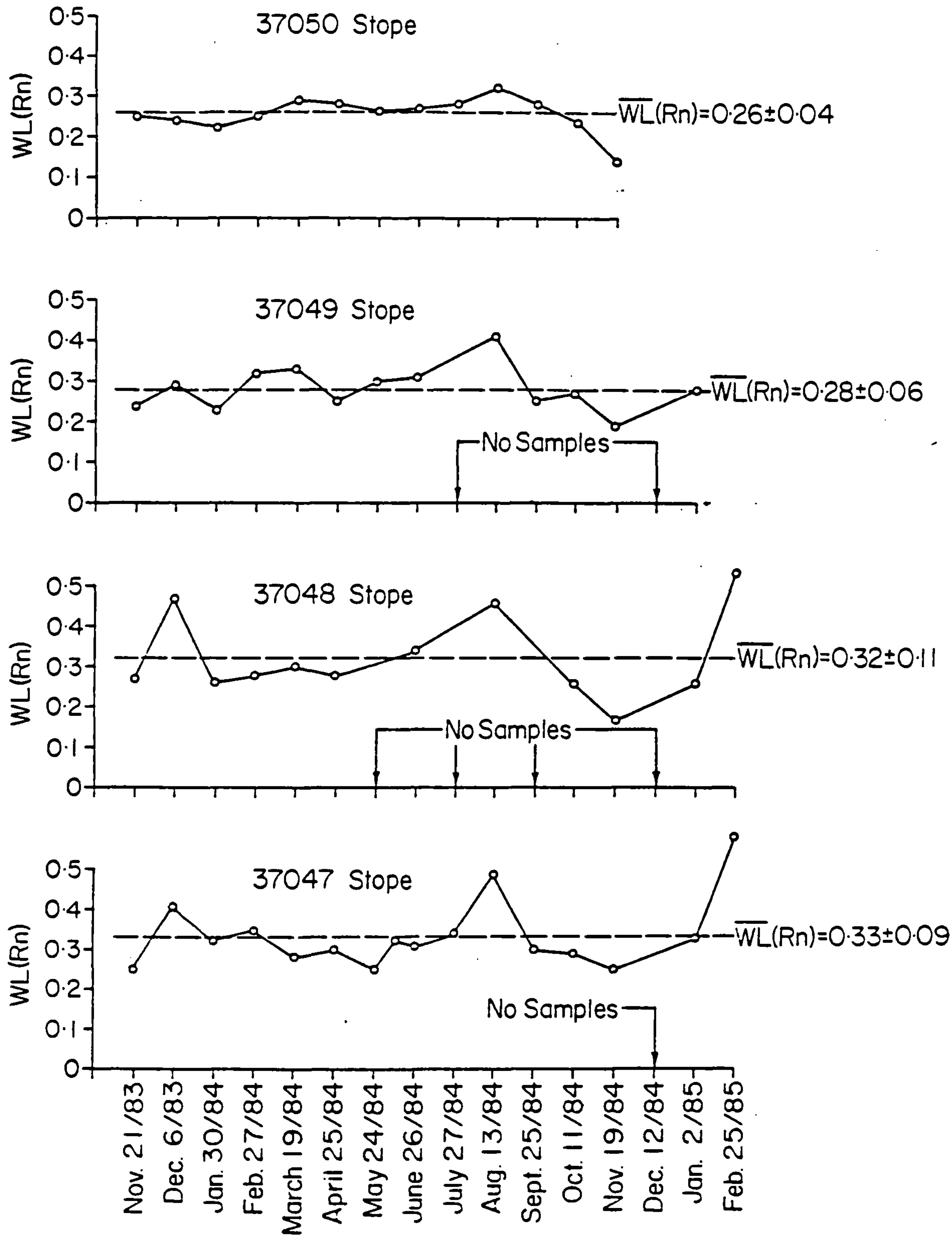


Fig. 9 - WL(Rn) grab-sampling measurements for several stopes and the average values over the entire period.

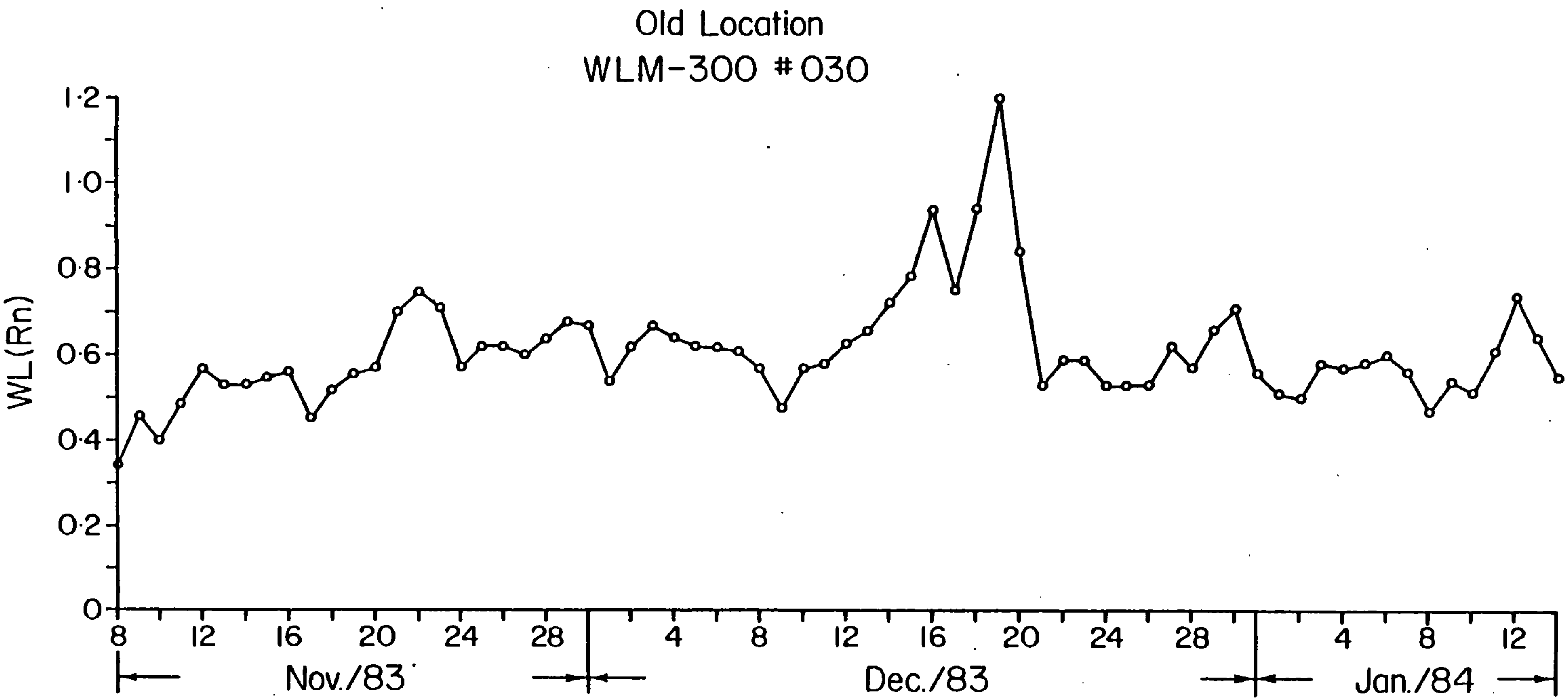


Fig. 10 - WL(Rn) as a function of time (old location).

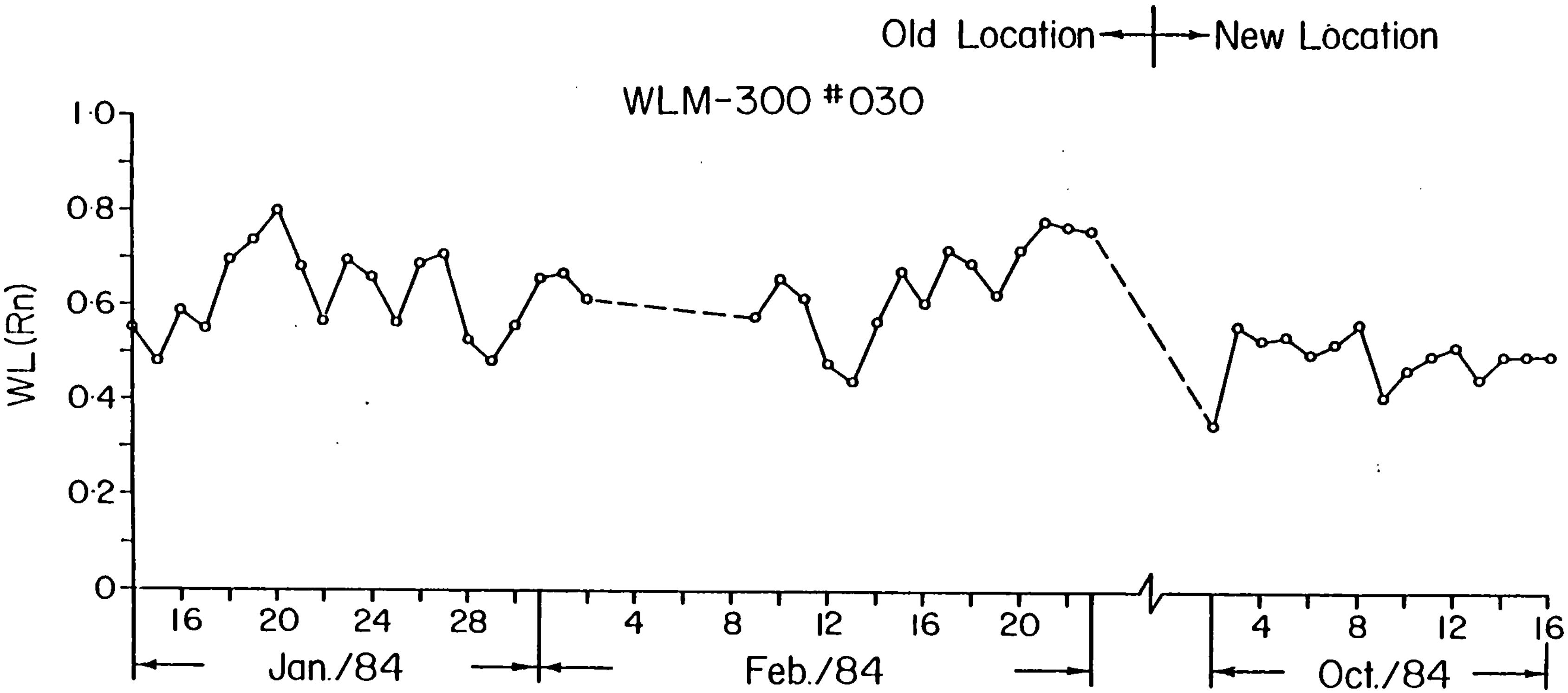


Fig. 11 - WL(Rn) as a function of time (old and new locations).

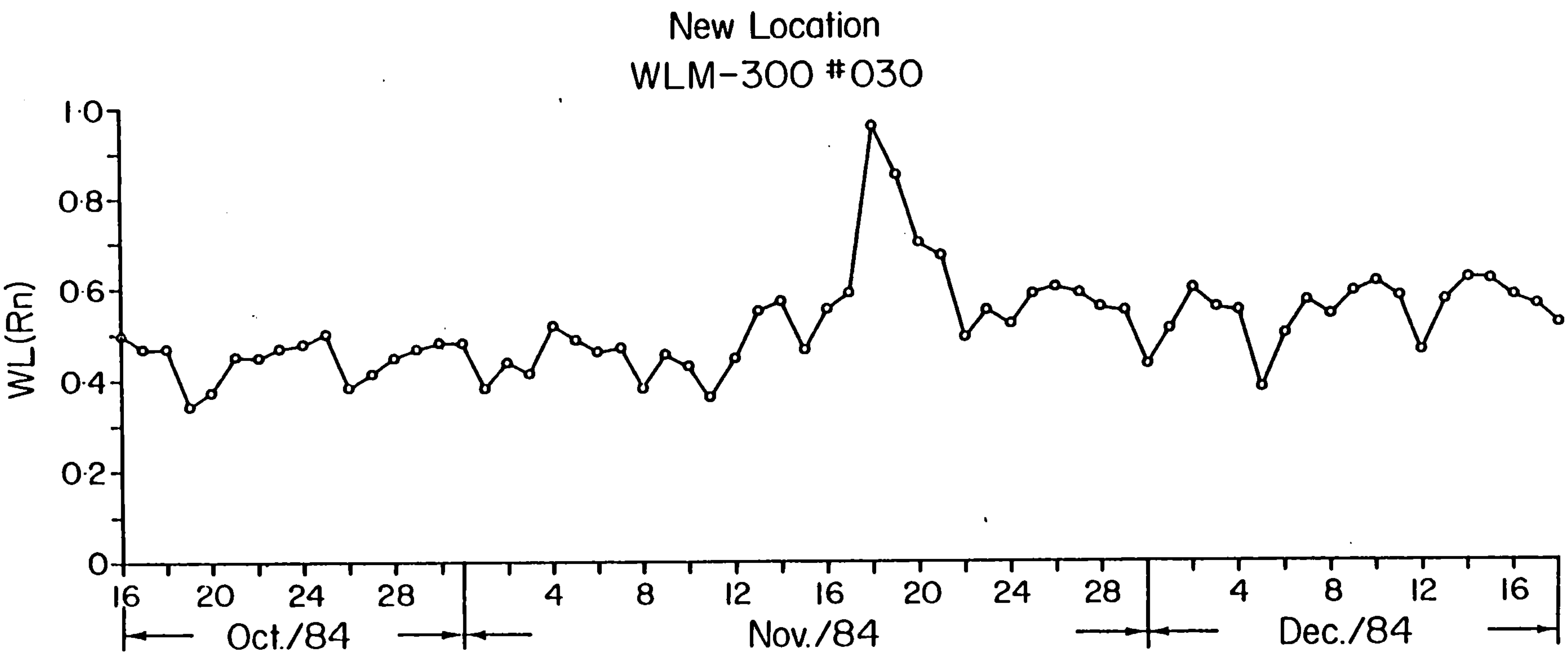


Fig. 12 - WL(Rn) as a function of time (new location).

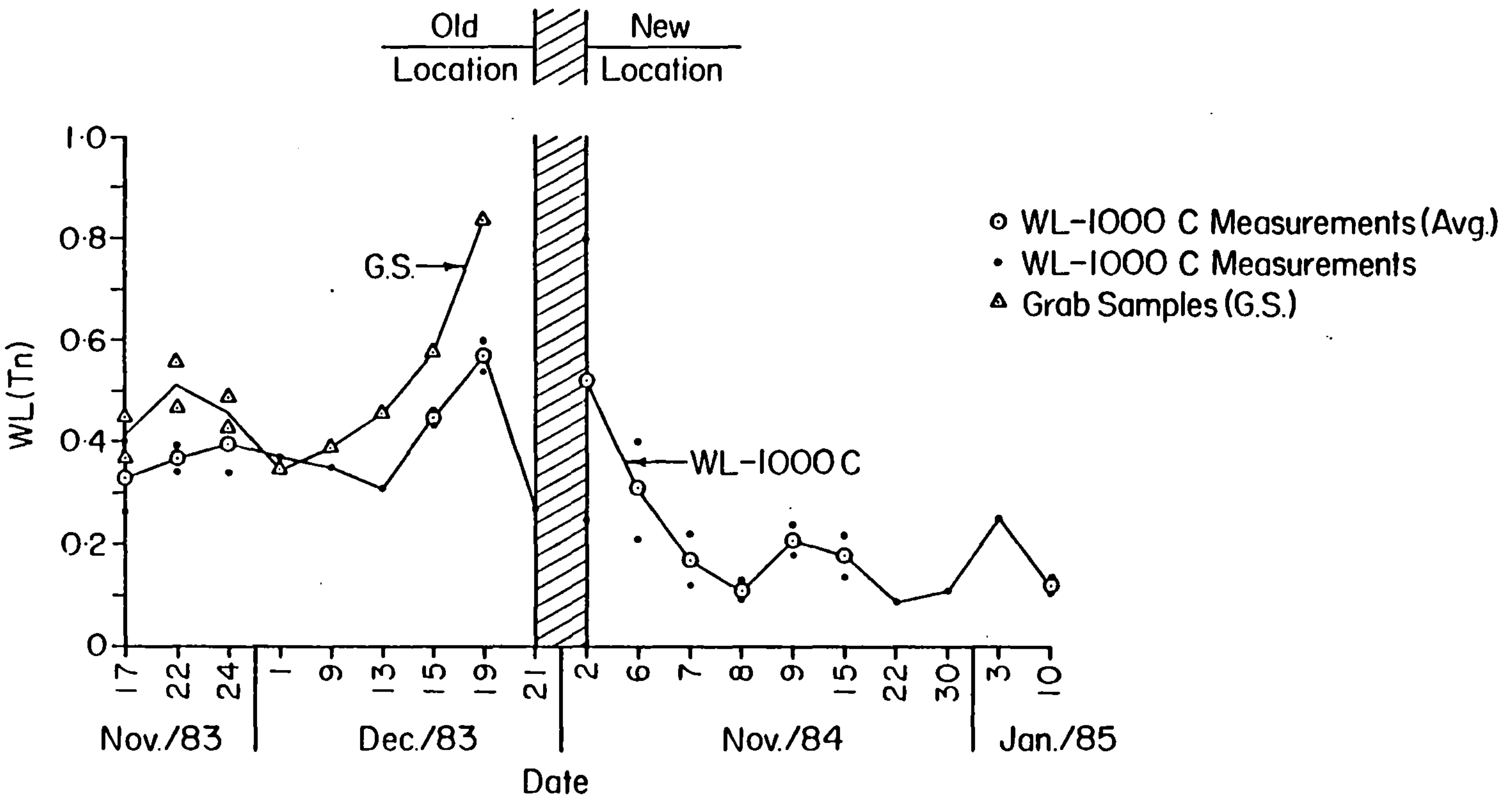


Fig. 13 - WL(Tn) as a function of time (new and old locations).

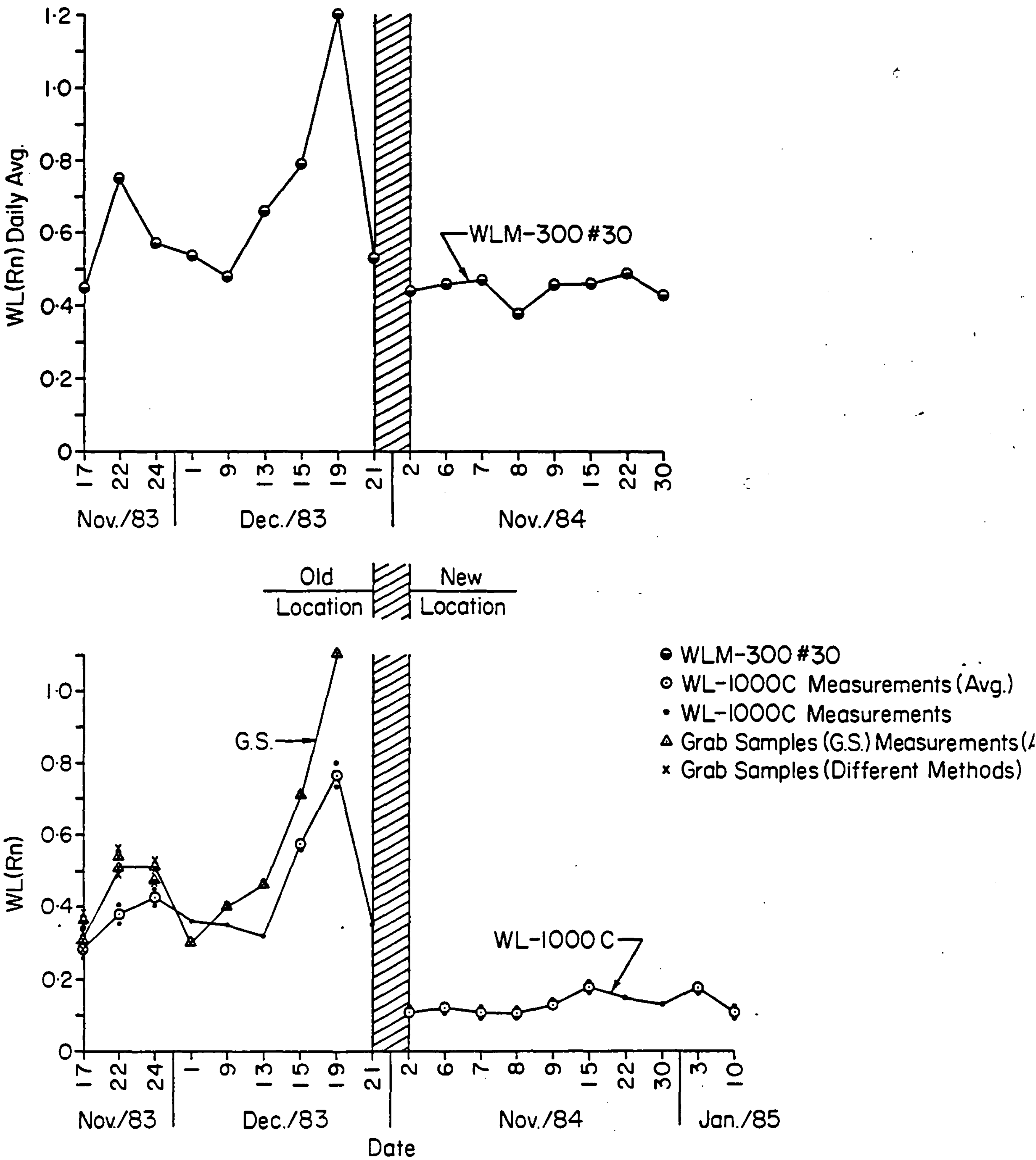


Fig. 14 - WL(Rn) as a function of time (old and new locations).

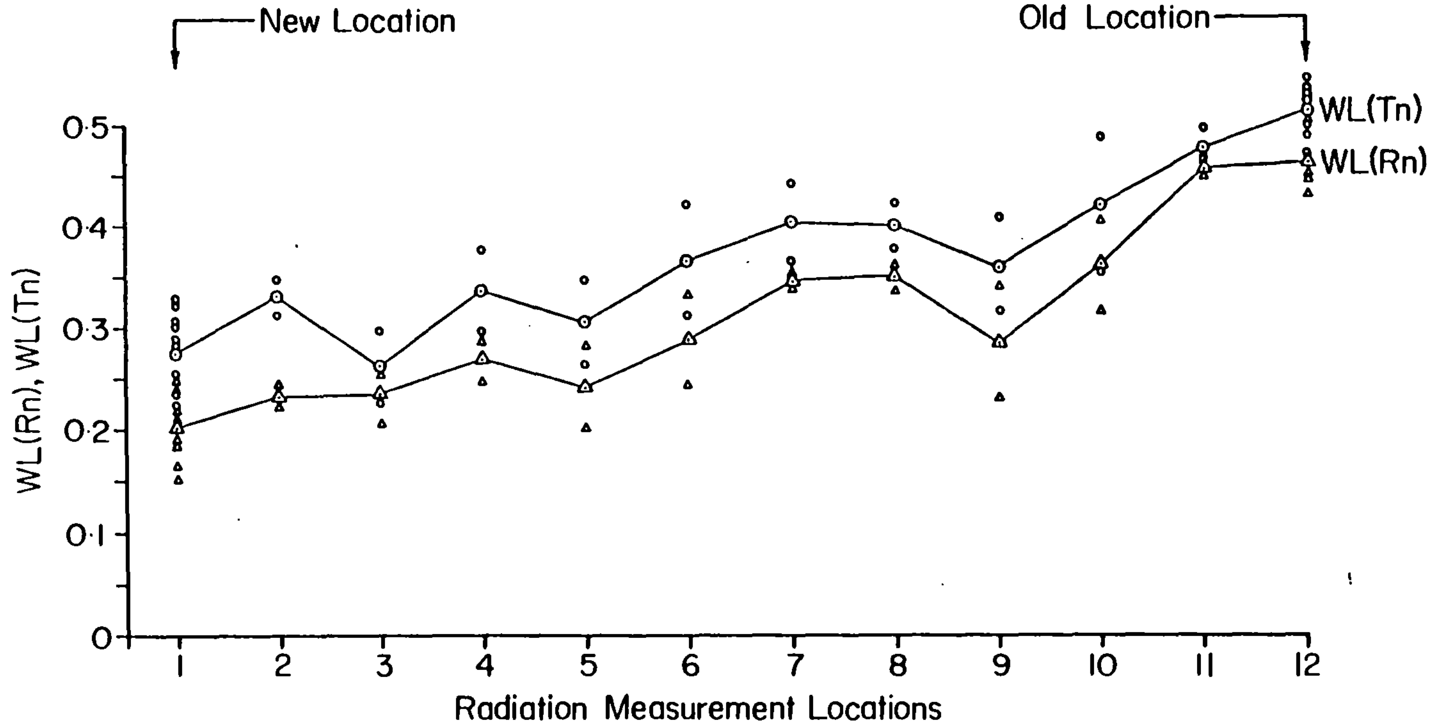


Fig. 15 - Grab-sampling measurements taken at 12 different locations along the 35950 travelway.

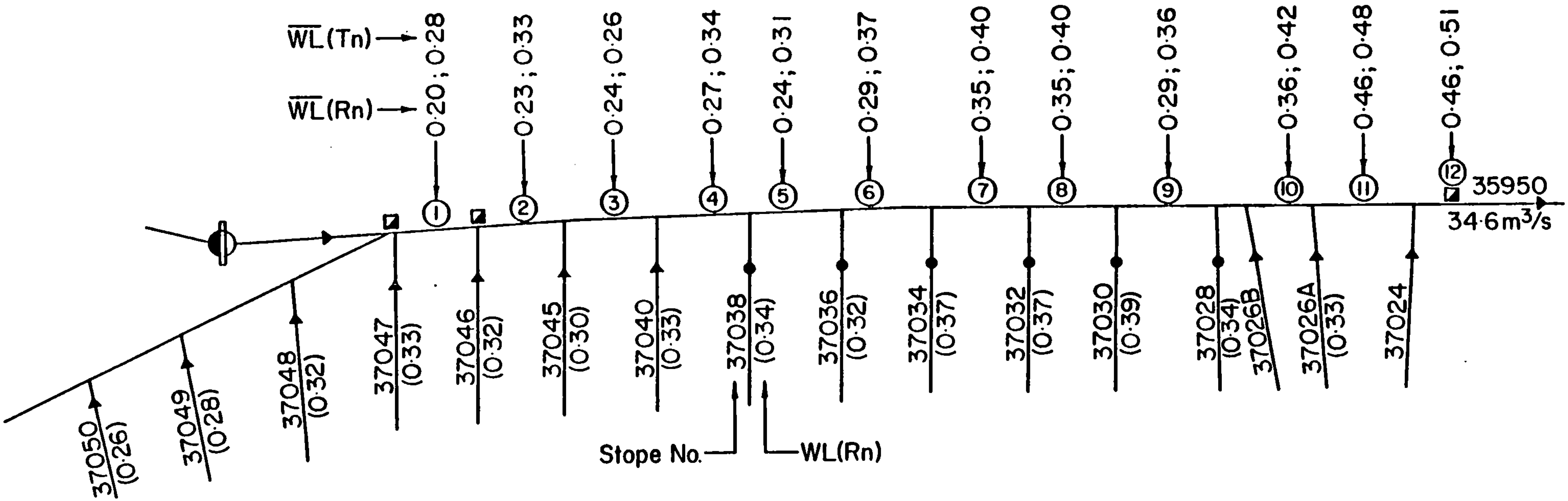


Fig. 16 - Grab-sampling measurements taken at 12 different locations along the 35950 travelway.

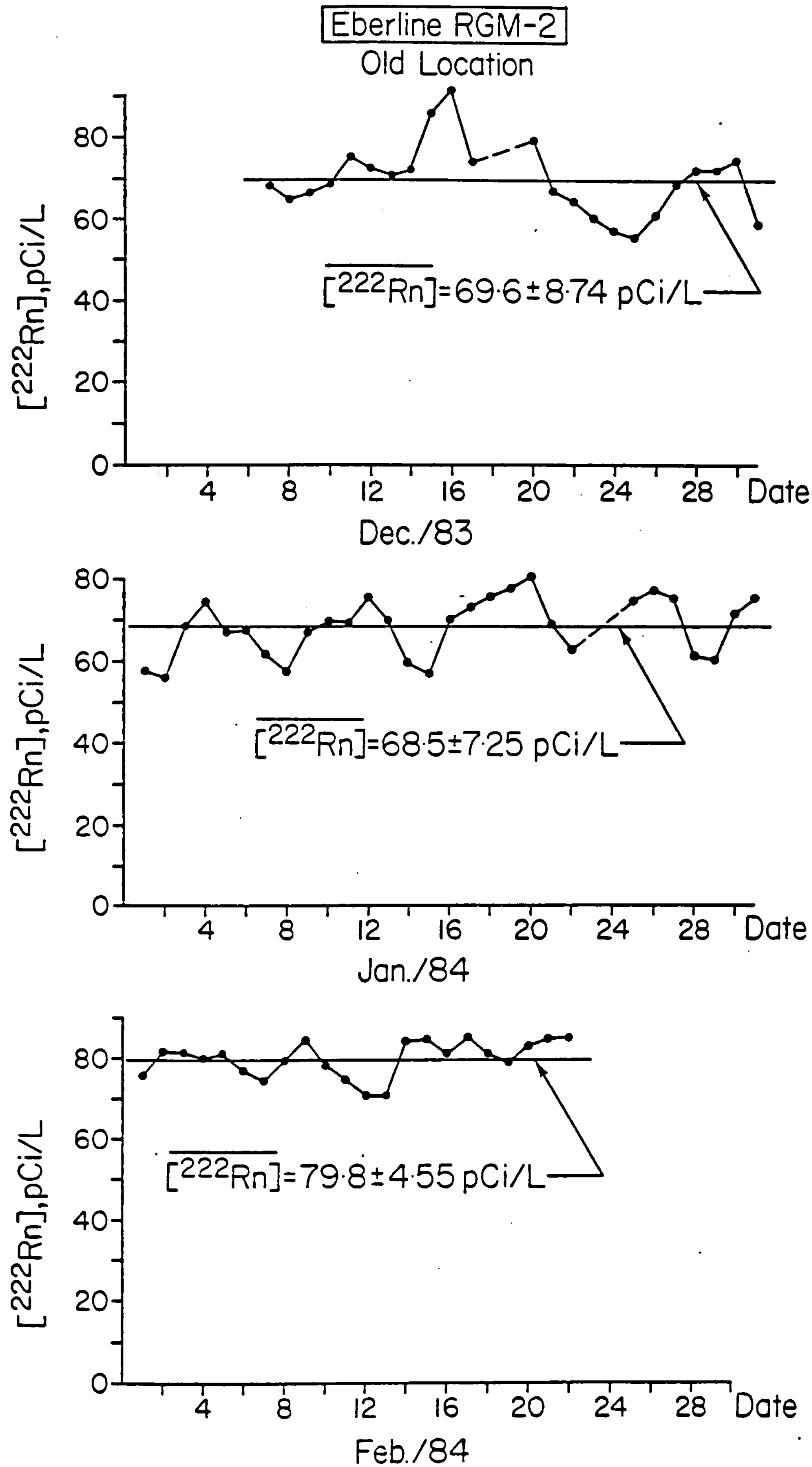


Fig. 17 - Radon gas concentration (old location) versus time and the monthly average values.

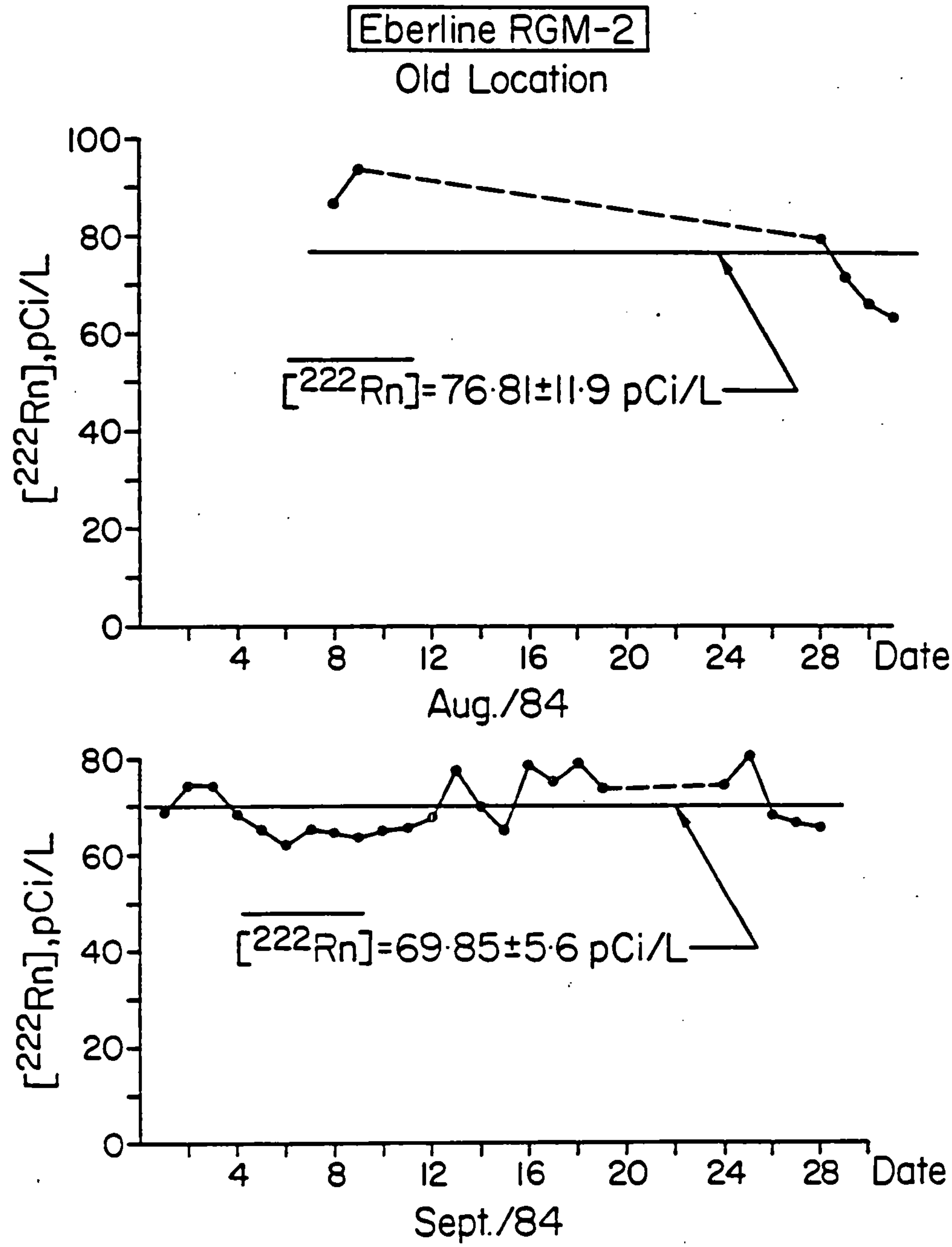


Fig. 18 - Radon gas concentration (old location) versus time and the monthly average values.

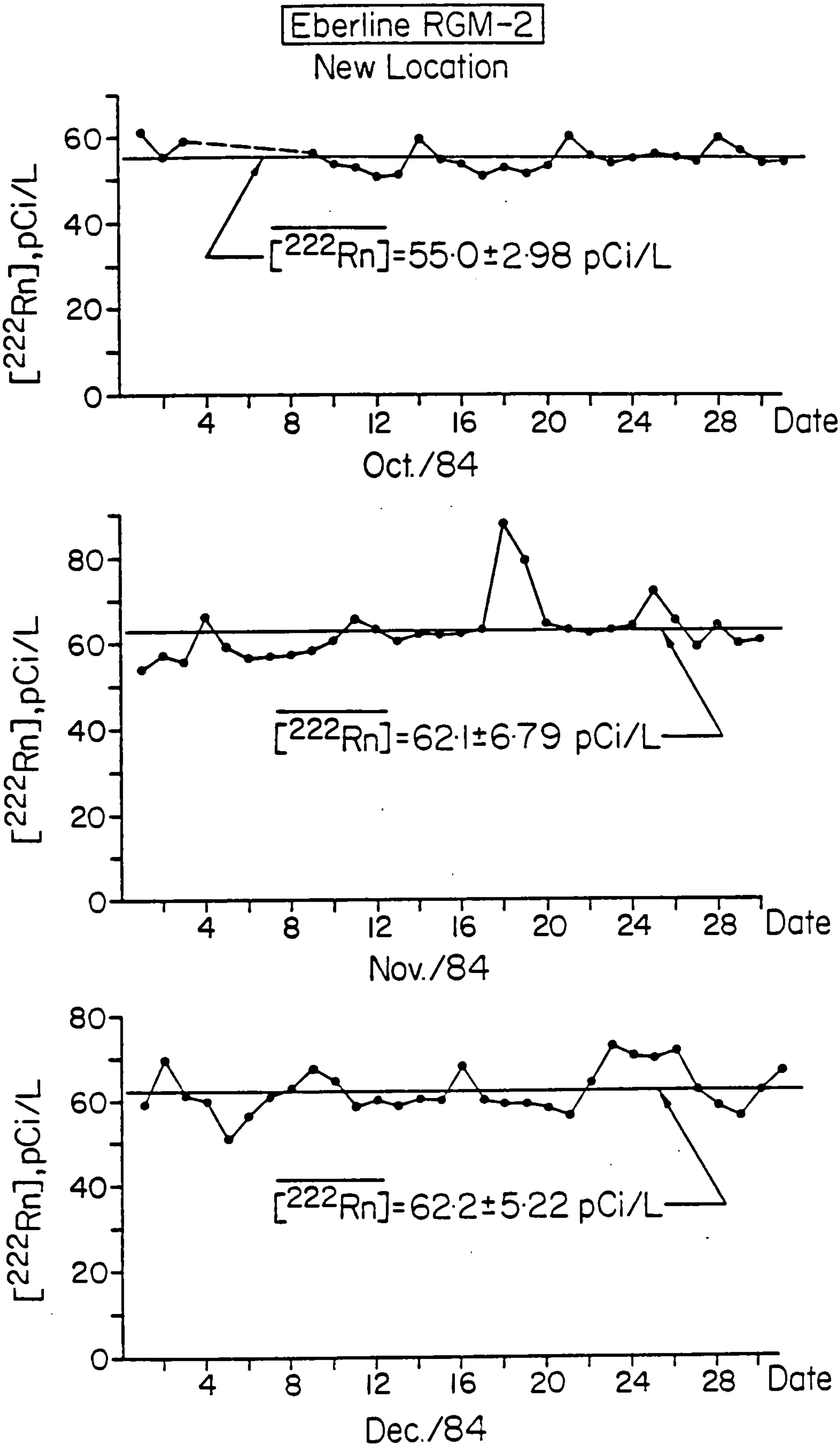


Fig. 19 - Radon gas concentration (new location) versus time and the monthly average values.

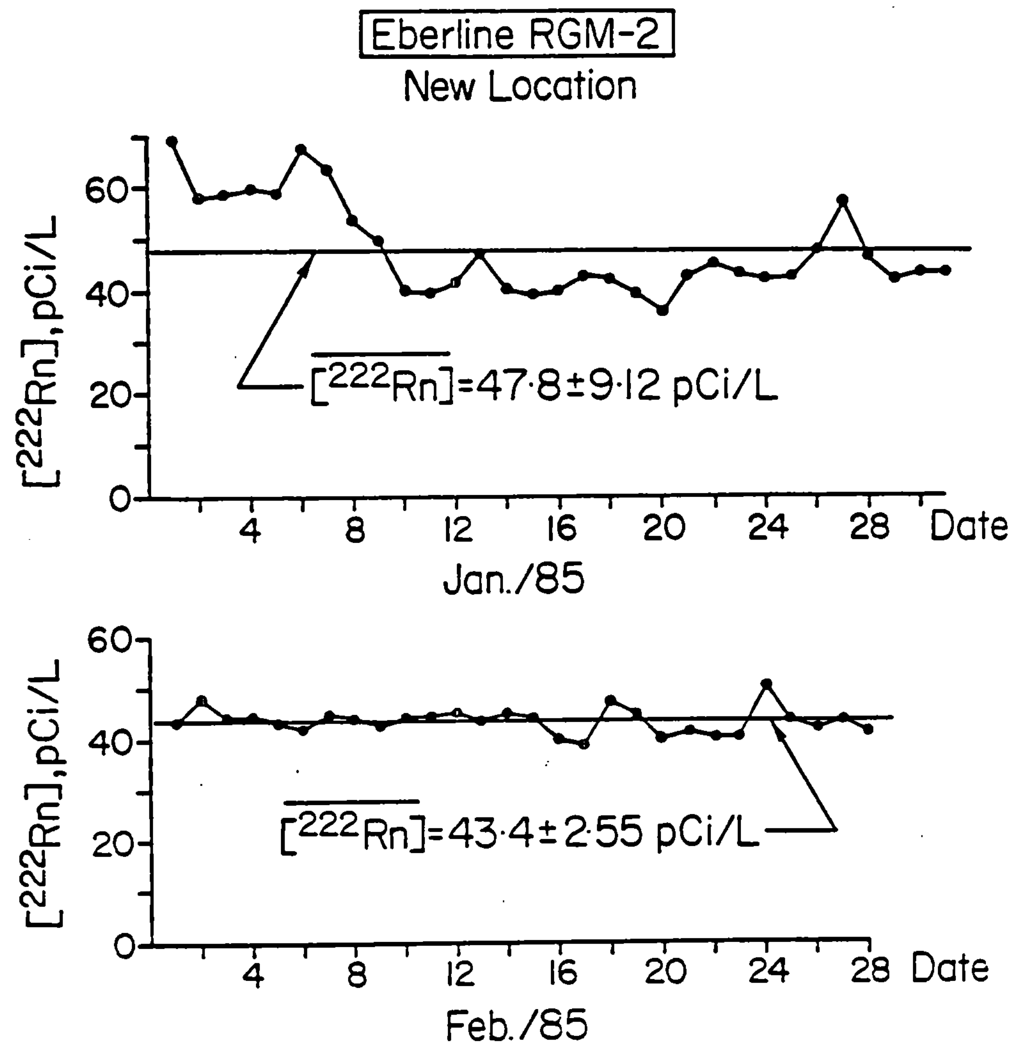


Fig. 20 - Radon gas concentration (new location) versus time and the monthly average values.

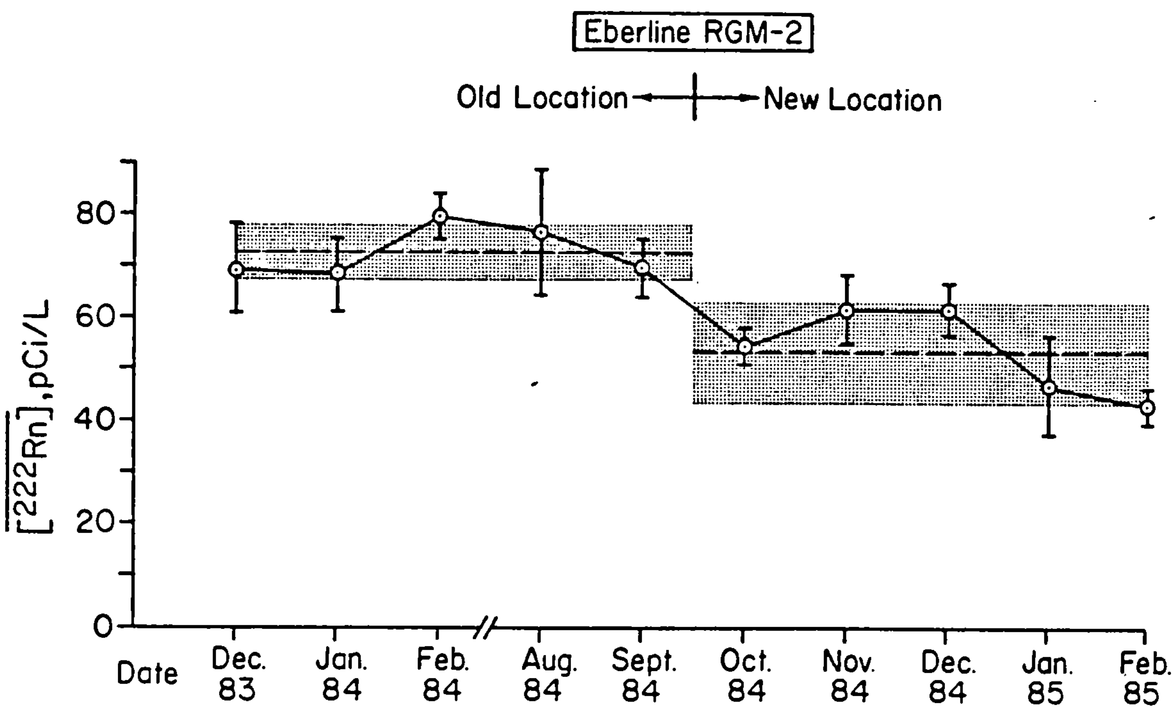


Fig. 21 - Radon gas concentration (monthly average) for the old and new locations.

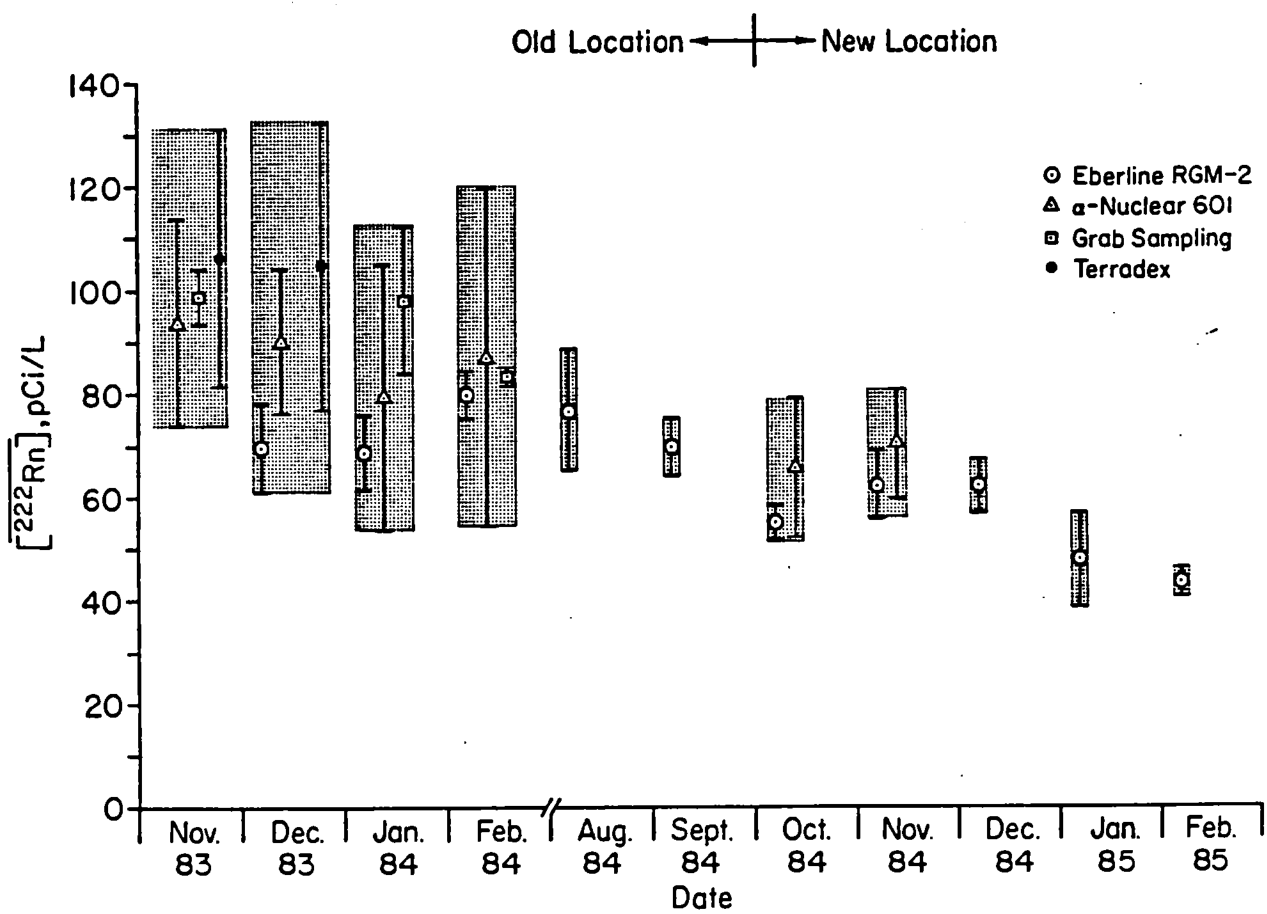


Fig. 22 - Radon gas concentration as determined by four different methods.

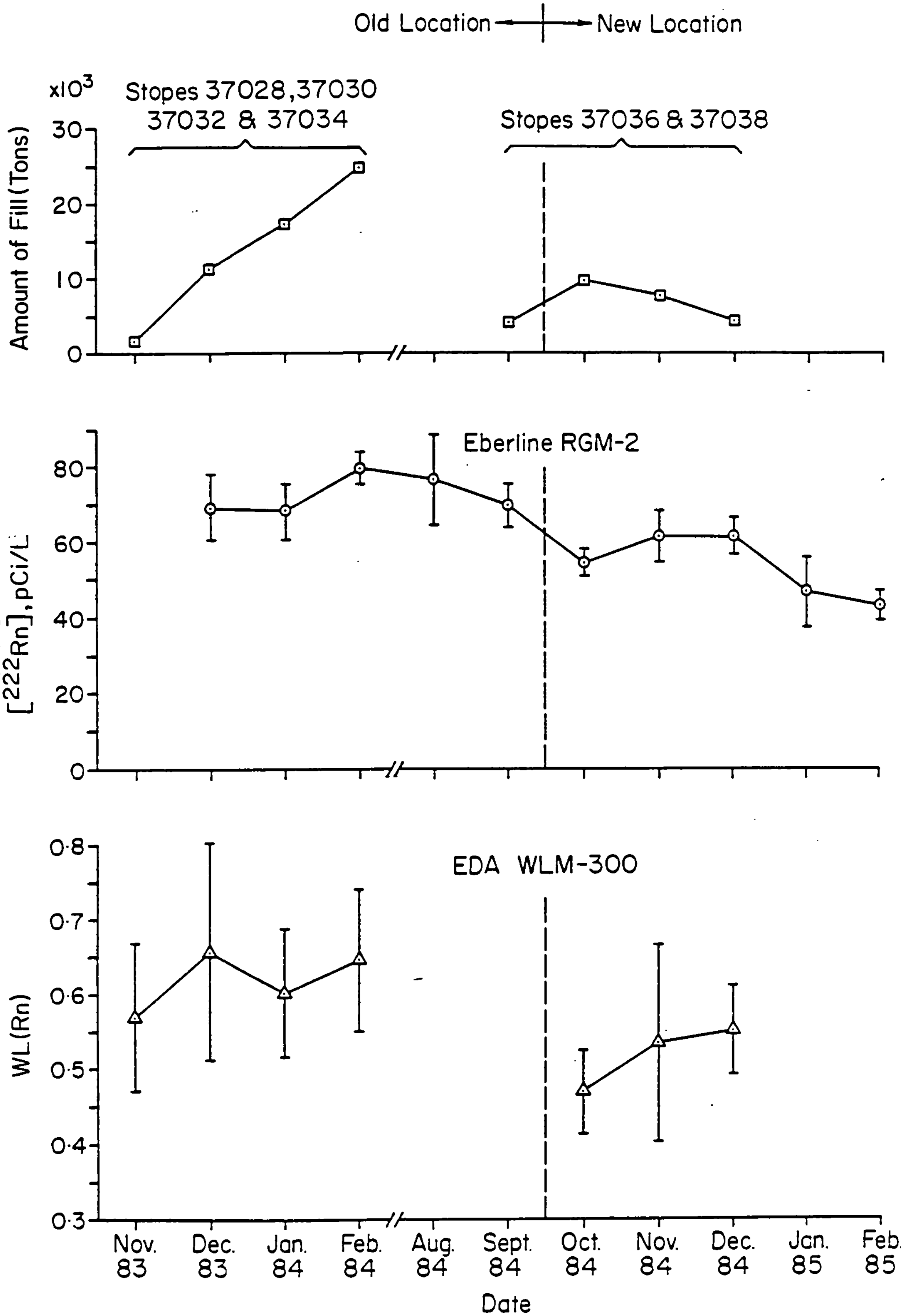


Fig. 23 - Radon gas concentrations, WL(Rn) and amount of fill poured in the experimental stopes as a function of time.

APPENDIX A - INSTRUMENT EVALUATION

As the conclusions that can be drawn for any test depend partly on the 'goodness' of the data obtained with some type of instrumentation, an evaluation of the performance of the instrumentation used is an important consideration. It is, therefore, quite appropriate to outline briefly some observations on the reliability of the instrumentation used during the backfill U/G tests. In this regard, some degradation in instrumentation performance was evident in a number of cases, as indicated below. It should be noted, however, that the instrumentation used in the backfill project was tested and calibrated under laboratory-controlled conditions before the U/G tests. Hence, the malfunctions and deviations from calibration values observed during the field work are mostly attributed to the long-term effect of harsh environmental and fast changing field conditions on instrumentation performance.

Most data were obtained by continuous monitoring. For this purpose four different radiation instrumentation systems were used, namely: WLM-300 and RGA-400 from EDA Instruments (Toronto), RGM-2 by Eberline (U.S.A.), and radon gas monitors/data logger system Model 601/650 by Alpha-NUCLEAR (Toronto). In addition, data were obtained by means of an automated grab-sampler, WL-1000C, manufactured by Pylon Electronics (Ottawa). Other data were collected by conventional grab-sampling instrumentation requiring a great deal of manual operations.

The WLM-300 was used to gather WL(Rn) data. The WLM-300 is a gross α-count continuous monitoring system, that operates on time integrating principles. It operated quite reliably over the period of U/G tests. Because the WLM-300 cannot differentiate α-particles from radon daughters and thoron daughters, the instrument overestimated WL(Rn) somewhat. The filter in the sampling head was changed weekly as dust loading produced energy degradation and absorption of α-particles, thereby reducing the α-counting efficiency of the system.

The RGA-400 was used to gather data on WL(Rn) and WL(Tn). Although the RGA-400 has also capabilities for measuring Rn-222 and Rn-220 by means of a second system operating on electrostatic deposition principles, the gas system was humidity dependent, and as factory manufactured, it did not operate reliably.

The RGA-400 is a continuous monitoring system that operates on α-spectroscopy principles. It was found that the instrument underestimated WL(Rn) and WL(Tn) substantially. Some of the reasons for this discrepancy may be attributed to the following:

a) misalignment of the energy windows of the detection system;

b) partial overlapping of the α-energy spectrum corresponding to the radon daughters and thoron daughters:

c) α-energies corresponding to RaA and ThC are practically identical and hence not distinguishable. Alpha-count separation for these radioisotopes is done analytically;

d) loading of filter dust shifts α-energy of the spectrum toward lower energies, and hence, affects the accuracy of the readings (see items a, b, and c).

In addition to the above items, it was later found that the conversion factor to convert thoron daughter α-count to WL(Tn) was wrongly implemented in firmware, i.e., wrong factor, and hence difficult to change.

The performance of the RGA-400 is shown in Figures A-1 to A-5. The instrument underestimates WL(Rn) substantially as compared with the WLM-300 (see Figure A-1), and WL(Rn) and WL(Tn) as compared with grab-sampling data shown in the Tables and in other Figures in the text (see also Figures 14 and

15).

The Alpha-NUCLEAR system is a continuous monitoring system of the passive kind intended for Rn-222 measurements. Its response partly depends on the radon daughter and thoron daughter barrier used to separate the sensitive volume, where a diffused-junction detector is located, from the environment. The response of the instrument without this barrier will depend on the Working Level Ratio (WLR), defined by the relationship: WLR = (WL(Rn)/[Rn-222]) x 10^2, where [Rn-222] is given in $pCiL^{-1}$. The Alpha-NUCLEAR system was quite susceptible to electrical noise, surge currents, and the like. Erroneous readings could be seen when operating a conventional sampling pump nearby. The Alpha-NUCLEAR system did not perform reliably enough under U/G environmental mine conditions.

The [Rn-222] fluctuations recorded by the Alpha-NUCLEAR monitors could not be verified by the Eberline RGM-2 continuous monitoring system or by grab-sampling. Monthly average values for [Rn-222] obtained with the Alpha-NUCLEAR monitoring system did not, however, differ dramatically from average values obtained by other systems or methods. Figures A-6 and A-7 show examples of the response of the system under relatively constant environmental conditions. Figure A-8 shows the difference in response between two monitors, one with a radon (thoron) barrier, i.e., foam, and the other without one.

The Eberline RGM-2 is a radon gas continuous monitoring system. The effect of Rn-220 on the response of the instrument cannot be ascertained at this moment because no calibration tests were conducted with mixtures of Rn-222 and Rn-220. Notwithstanding the above, the RGM-2 was found to be a highly reliable and dependable instrument.

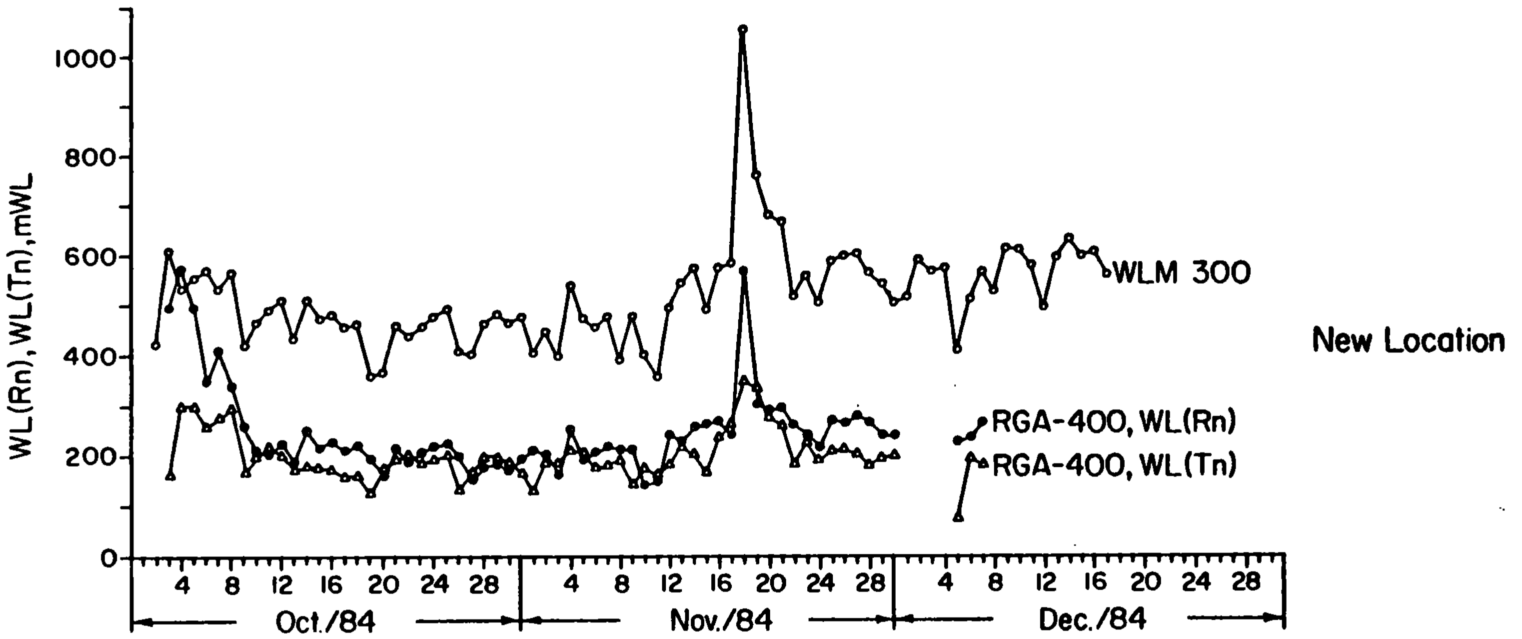
As a continuous monitoring system the Eberline RGM-2 by Eberline (radon gas) and the WLM-300 by EDA(WL(Rn)) clearly outperformed the other systems by a large margin.

Some difficulties were experienced with the WL-1000C by Pylon. Although on most occasions it seemed to operate reliably, erroneous readings were observed when compared with manual grab-sampling (see Table 1). For instance, the ratio [ThC]/[ThB] was greater than unity on several occasions. As the instrument was calibrated before the U/G tests for flow rate, discriminator alignment and α-counting efficiency, the reason for this erratic behaviour is not known. However, it has been observed that the accuracy of the instrument is reduced significantly in relatively 'rich' thoron atmospheres.

The more reliable measurements for Rn-222, WL(Rn) and WL(Tn) available to us are those taken by grab-sampling. The accuracy of Rn-222 measurements using Terradex detectors cannot be determined because they represent average values derived from a one-week exposure period at a time.

From the above discussion one may surmise that the performance of instrumentation under hostile environmental conditions was not always satisfactory. However, some systems clearly outperformed others.

It is recommended that periodic calibration tests be conducted before, during, and after any long-term underground test to promptly correct any unwanted deviation from expected reliable performance. The problem of accuracy and reliability is compounded in some mines because of the presence in mine atmospheres of thoron and its decay products. There is no question that there is room for much improvement in instrumentation development. In general, the overall performance of the instrumentation used in these tests could be ranked as fair. For precise measurements, however, the ranking under field conditions for some instrumentation would be fair to poor.



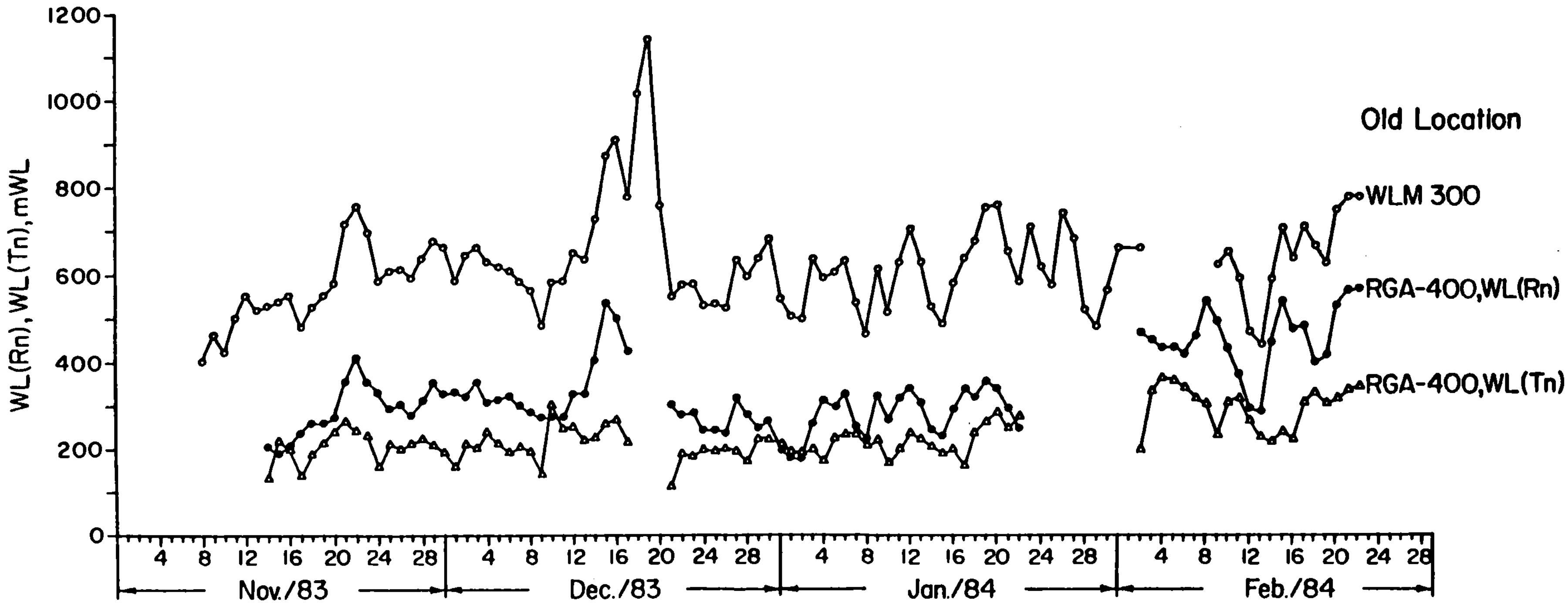


Fig. A-1 - WL(Rn) and WL(Tn) as a function of time for the old and new locations.

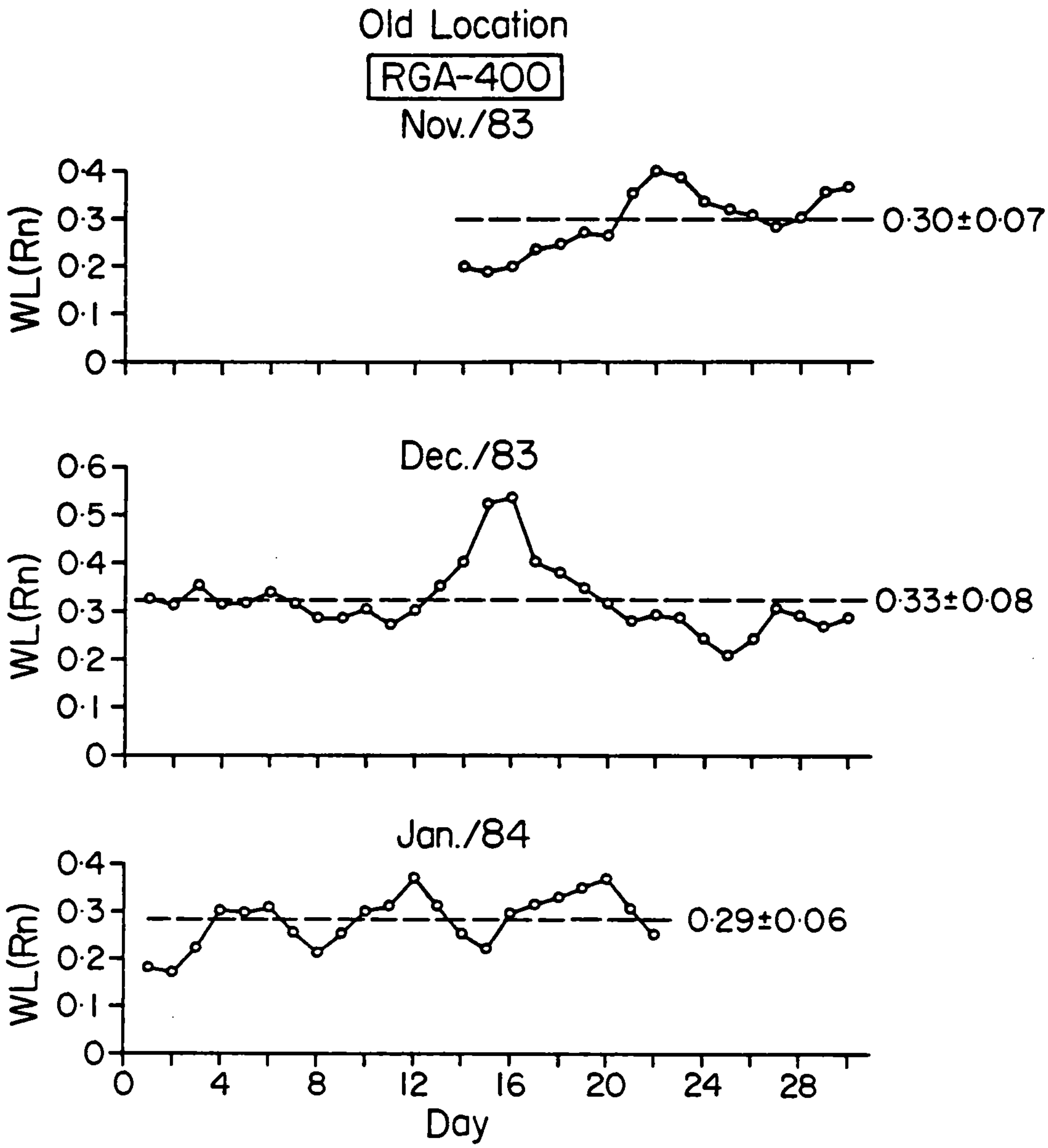


Fig. A-2 - WL(Rn) as a function of time (old location). Also shown is the monthly average value.

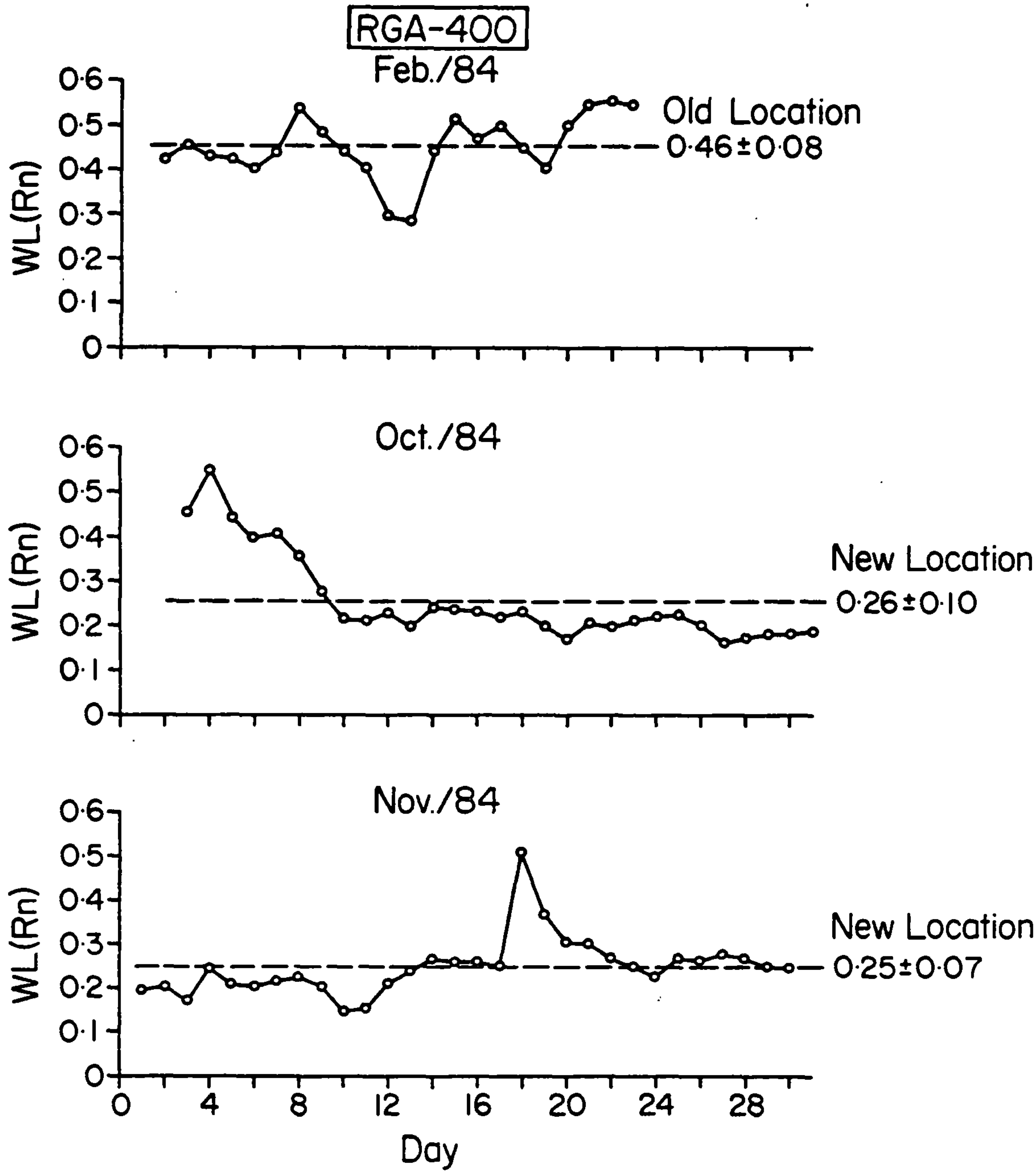


Fig. A-3 - WL(Rn) as a function of time (old and new locations). Also shown is the monthly average value.

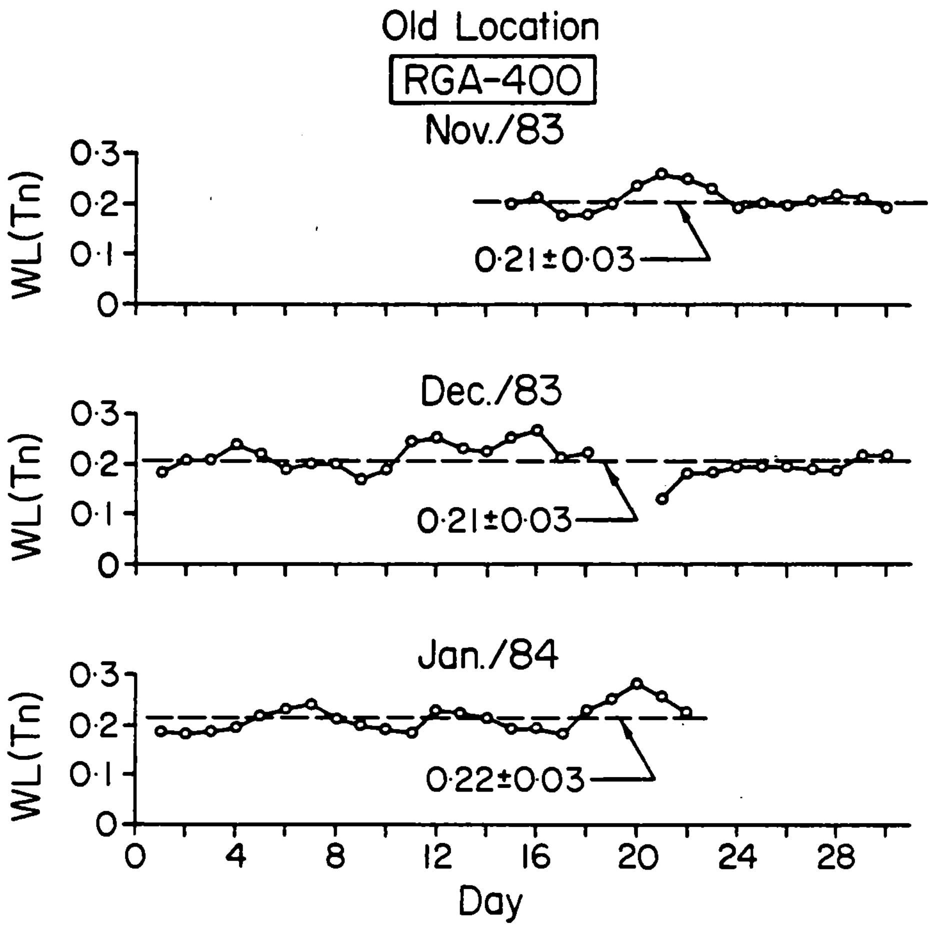


Fig. A-4 - WL(Tn) as a function of time (old location). Also shown is the monthly average value.

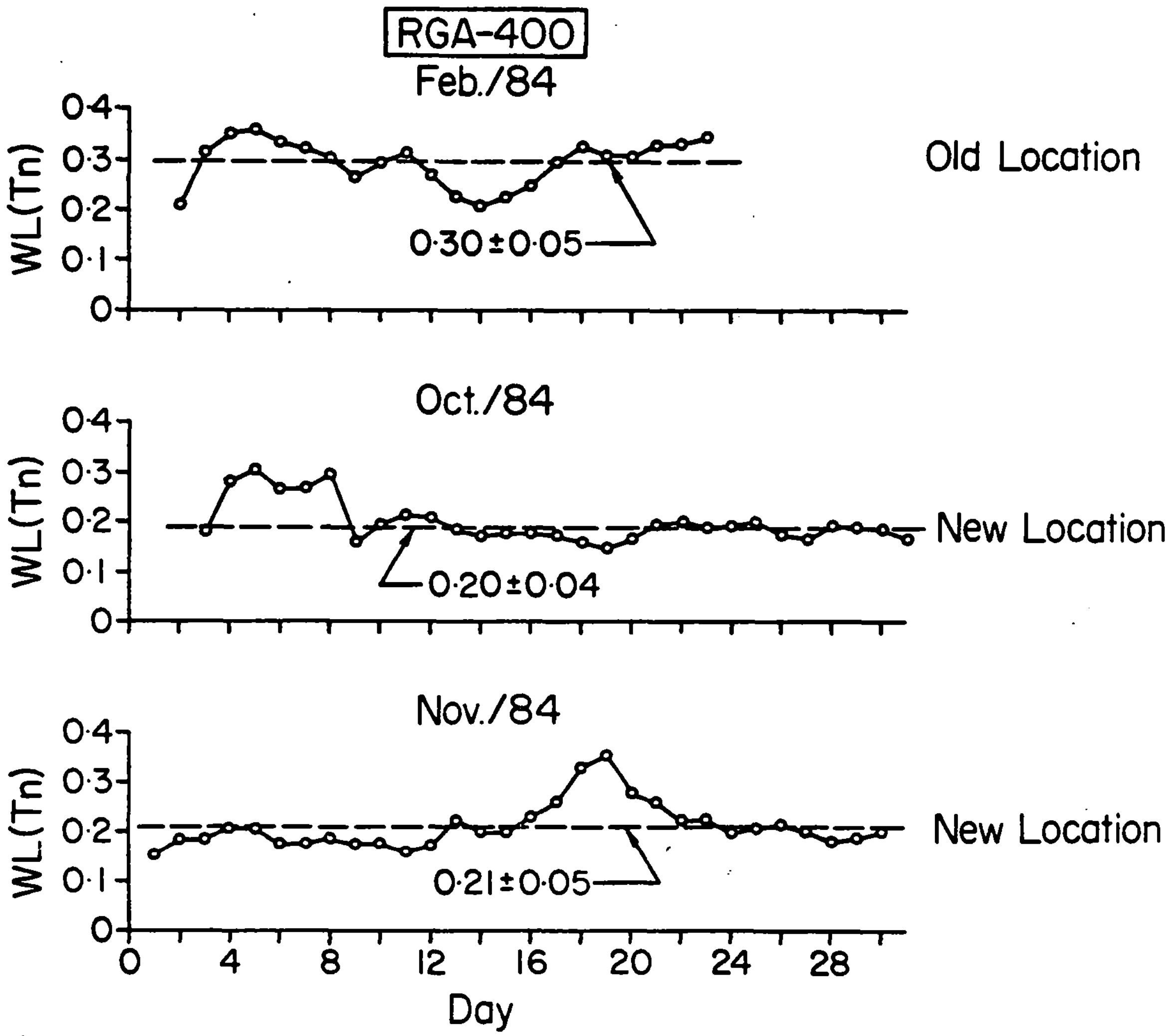


Fig.A-5 - WL(Tn) as a function of time (old and new locations).
Also shown is the monthly average value.

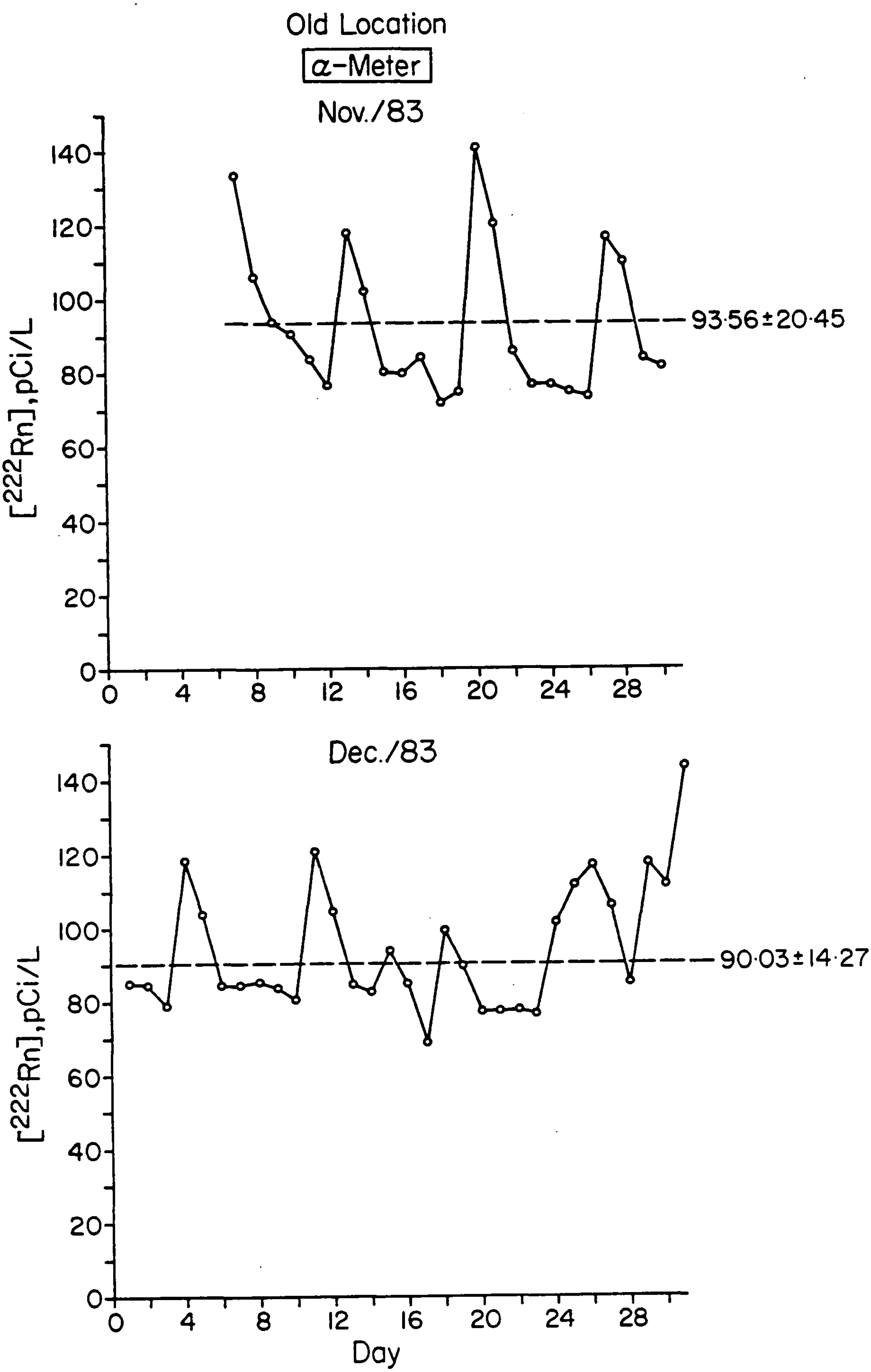


Fig. A-6 - Radon gas concentration (old location) versus time. Also shown are the monthly average values.

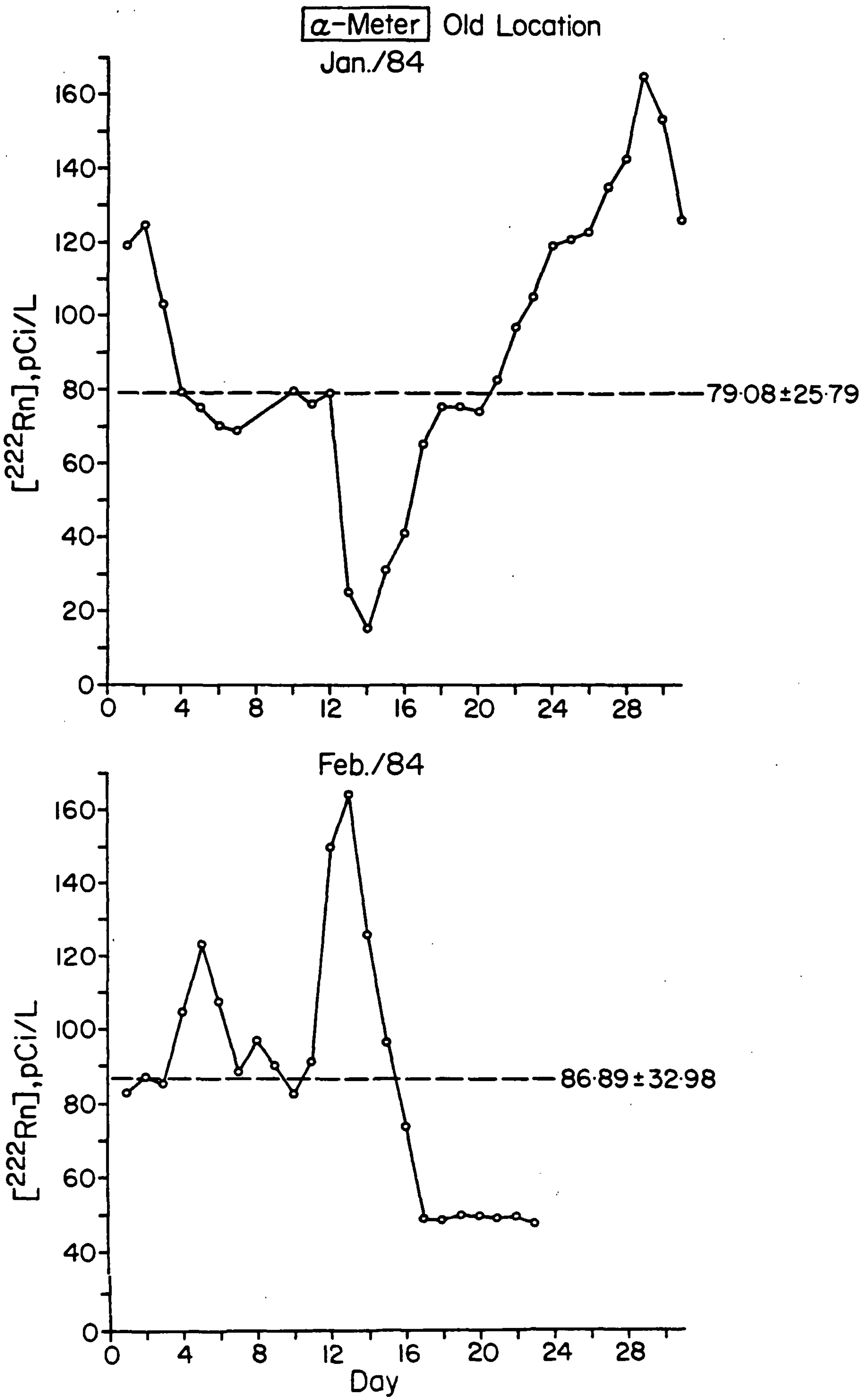


Fig. A-7 - Radon gas concentration (old location) versus time. Also shown are the monthly average values.

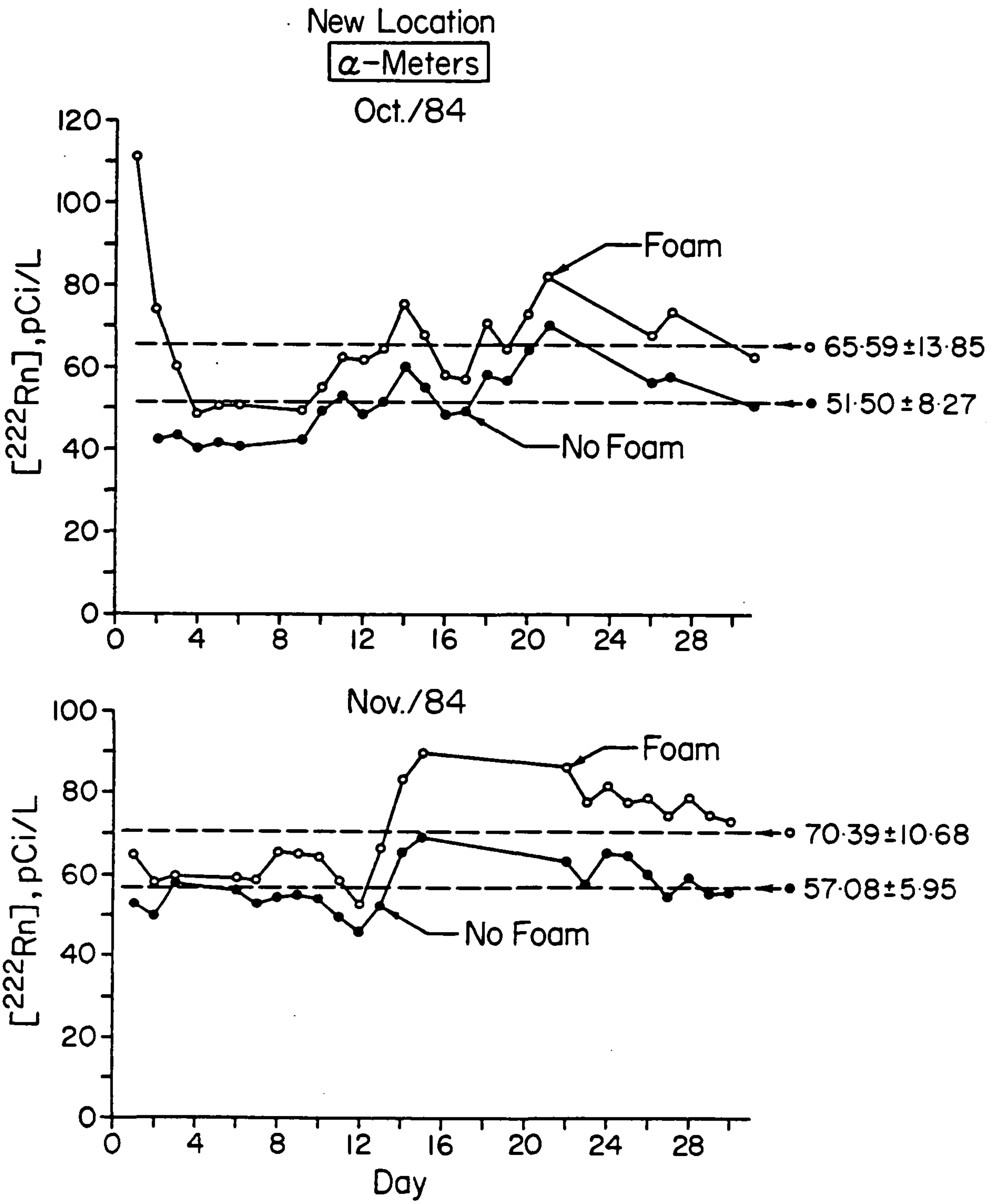


Fig. A-8 - Radon gas concentration (new location) versus time. Also shown are the monthly average values.

APPENDIX B

CONTRIBUTION TO THE RADIATION LEVEL FROM RADON EMANATING MINE WALLS

Comparison of radiation levels before and after backfill operations is necessary to determine the contribution from radioactive backfill material.

Underground experimentation and monitoring was complicated by the fact that only one sampling station was originally operational (old location) and, as previously indicated, other sampling stations (new location) were necessary because of relocation of the backfill area.

Because the old and new locations were situated about 300 m apart, determination of the contribution to the radiation level from backfill material was complicated by the following factors. Firstly, mine layout, i.e., branching, and hence air flow patterns, between the new location and the old location was quite complex (see sampling points 1 to 12 in Figure 2). Secondly, mining operations and activities other than backfill took place during the monitoring program. Thirdly, the contribution to the radiation level from mine walls was not known.

Theoretical estimates regarding the latter item can be made. The effect of the other two items is quite difficult to calculate. For simplicity, no change in air flow pattern and air quantity will be assumed. Furthermore, the effect of mining operations, and activities other than backfill operations, on the radiation level will not be considered here, or will be considered negligible. However, the reader should be cautioned that the above assumptions hardly apply in this study. They are simply made for lack of adequate information and/or because of the inability to adequately control experimental conditions to suit the needs of the experiment.

To aid in the calculations, a mine model has been developed to predict environmental radiation levels in underground uranium mines, and to estimate the contribution to the radiation level from mine walls between any two given arbitrary locations of, say, a mine drift. Hence, from experimental data collected at the sampling stations, before and after backfill operations, in conjunction with theoretical predictions by the mine model, it is possible to determine the net contribution to the mine radiation level from backfill material.

Theoretical prediction of radiation data can be made provided certain conditions, and physical and geometrical factors, are known. The above include air flow, radon flux from mine walls, the geometry and physical dimensions of the section of the mine under consideration, and the initial conditions at a point of interest.

Calculations have been made between sampling locations 1 (new location) and 12 (old location) (see Figures 2 and 16). Experimental radiation data for location 1 were: WL(Rn) = 0.20 and [Rn-222] = 1924 Bq/m^3 (52 pCi/L). These data will be taken at the initial conditions for the mine model in order to calculate the 'final conditions', i.e., values at location 12.

Experimental radiation data at location 12 were: WL(Rn) = 0.46 and [Rn-222] = 2664-3330 Bq/m^3 (72-90 pCi/L). Theoretical predictions are to be compared with these experimental data. The two values given for the radon gas concentration have been taken from Figures 21 and 22. The different values (~25%) have been obtained by different techniques and methods, as indicated.

Other experimental data of interest are as follows:

L = 286 m, Q = 35 m^3/s, S ~30-120 m^2, and J ~0.44 Bq/m^2s (~12 pCi/m^2s). where L represents the distance between locations 1 and 12, Q stands for air flow (see Figures 1 and 2). S is the mine drift cross-section area, and J represents the radon flux from mine walls. The value for J is uncertain and calculated from indirect measurements (10). The actual value of J is probably lower than that taken in present calculations.

Accurate prediction of radiation data by the mine model used here is rather difficult because the cross-sectional area of the section of the mine of interest varied considerably from location to location. At location 12 (old location), S was about 30 m^2. This value increased substantially, and quite irregularly, between location 12 and 1 (new location) to values in excess of 120 m^2. Hence, calculations have been made for different values of S, namely: 30, 60, 90 and 120 m^2 (see below). The average cross-sectional area is most probably between 60 and 90 m^2, but it was not possible to estimate it experimentally because of practical reasons.

Theoretical radiation data calculated by the mine model for location 12 (old location) from experimental data at location 1* (new location)

S m^2	WL(Rn)	[Rn-222] Bq/m^3	WLR^+	Remarks
30	0.23	1994	0.42	Theoretical values
60	0.25	2023	0.46	" "
90	0.28	2045	0.50	" "
120	0.30	2064	0.54	" "
	0.46	2664-3330	0.58	Experimental values at location 12

*Calculated using the following boundary (initial) conditions: WL(Rn) = 0.20, and [Rn-222] = 1924 Bq/m^3 (52 pCi/L).

$^+$Stands for Working Level Ratio defined as WL(Rn) x 10^2/[Rn-222], where [Rn-222] is given in pCi/L.

Assuming an average cross-section of 90 m^2, the theoretical WL(Rn) is 0.28 (see above table), a value which is about 60% lower than that determined experimentally. The above table also shows that the theoretical radon gas concentration is lower than the experimental value (30-60% for S=90 m^2).

A more reliable comparison between experimental and theoretical values should take into consideration:

a) the geometry of the section of the mine in more detail;

b) contributions from side branching;

c) precise determination of air residence times; and

d) more realistic, and hence complex (radiation) mine models.

The difference between experimental and theoretical data for WL(Rn) and [Rn-222] provides an approximate estimate of the contribution to the mine radiation level from radioactive backfill material. This (theoretical) contribution, although not unduly high, is significant and should be monitored periodically were backfill operation practices to increase dramatically. It should be noted that because of the variability and complexity of the section of the mine where the study was conducted, radioactivity contributions from side branching have not been included. These contributions may be quite significant; if so, the contribution from backfill material would be correspondingly lower than that calculated above. However, in order to ascertain the radiological impact of continuing backfill operations in underground uranium mines with sufficient confidence, much more experimentation will be necessary.

Finally, and for illustration purposes, the radiation levels at position 12 (see Table above) have been recalculated assuming this time J ~9.6 Bq/m^2s (~260 pCi/m^2s). This value for the flux corresponds to backfill material. The results are given in the Table below and demonstrate that a 20-fold increase in J doubles [Rn-222] and increases WL(Rn) by ~50%, at worst, for S = 120 m^2 and L = 286 m.

Theoretical radiation data calculated by the mine model for location 12 (old location) from experimental data at location 1* (new location)

S m^2	WL(Rn)	[Rn-222] Bq/m^3	WLR+	Remarks
30	0.24	3444	0.26	Theoretical values
60	0.29	4073	0.27	" "
90	0.35	4557	0.28	" "
120	0.40	4964	0.30	" "
	0.46	2664-3330	0.58	Experimental values at location 12

*calculated using the following boundary (initial) conditions: WL(Rn) = 0.20, and [Rn-222] = 1924 Bq/m^3 (52 pCi/L).

+stands for Working Level Ratio defined as WL(Rn) x 10^2/[Rn-222], where [Rn-222] is given in pCi/L.