HIGH ELEVATION EXPERIMENT WITH ELECTRET RADON MONITORS

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ABSTRACT

In recent performance testing of large numbers of electret radon monitors (E-PERMs, trade name of Rad Elec. Inc.) in exposure devices known as S-chambers, systematic discrepancies between our own and client's radon measurements were noticed. The differences amounted to about minus 3%. One client pointed out that our elevation at Lakewood appeared to be about 6% low, as compared with his topographic information. Thus, about half of the elevation error appeared to enter as a radon error. The sensitivity of S-chamber accuracy with respect to the elevation correction in well-controlled work appeared to be about 100 feet, equivalent 0.05 pCi/l at 6 pCi/l radon concentration or near 1%. Therefore, the need for good elevation correction in the interest of high measurement accuracy is evident.

Apparently, no exposure of electret radon monitors (E-PERMs) at high elevations has been performed and documented. Therefore, Radon QC tested about a dozen electrets in Colorado at 10,620 feet (Echo Lake) and 14,130 feet (Mount Evans), as well as at 5,590 feet (home base). The results showed the surprising versatility of the well-researched electret product, while the prime monitors (CRMs) of different manufacture need more factory documentation and development work to be equally applicable.

ACKNOWLEDGEMENTS

The idea for this paper came from William Alexander, Colorado Radon Engineering, Fort Collins (1). His primary electret lab showed up a minor elevation correction error at our chamber as significant (Fig.1). Michael Ferraro of Radon Detection Systems, Boulder, made available two CRMs to be used in the mountain measurements, and Dr.Robert Holub of the Colorado School of Mines made possible the gamma correction measurements needed. Carolyn Allen of Rad Elec Inc. made available ref. (4).

INTRODUCTION

A general examination of a topographic map of the United States (2) shows that about half of the contiguous land mass may exceed 3,000 feet in elevation. The respective contour runs out of Canada from North and South Dakota through Nebraska, Kansas and the Western portion of Texas, until it crosses the Rio Grande into Mexico. Eastern high ground may compensate for low portions of the West Coast and the Southwest - and then there is Alaska!

Yet, in general electret radon work in America, people appear to develop a "flat Earth" mentality. The data reduction equations supplied by Rad Elec, Inc., do not contain a correction factor for elevations. To be sure, such corrections are enclosed separately (Table 1), but this procedure gives the elevation correction a sense of being "optional". The handbook (3) assures the user that there is no need to correct for elevation in S-chamber work unless one's location exceeds 4,000 feet. For L-chambers, the large volume, high sensitivity layout, correction factors are given for every 1000 feet, however (Fig.2), and the corrections commence at 1,000 ft. The correction table for the widely used S-chambers covers the range from 4,000 feet to 8,000 feet. In a recent paper (1992), Kotrappa and Stieff (4) simulated the elevation range up to 8,000 feet (2,440 m) in a pressure tight device which included a NIST radon source. They essentially confirmed their earlier data from their laboratory in Maryland (Table 1). There was no need for gamma corrections in their experiment, and their primary monitors were not affected by either elevation or cosmic flux.

Since Radon QC moved from Northbrook, Illinois, to Colorado, we have become aware of the greater rigors of elevated land with respect to measurement. And when Bill Alexander pointed out (1) that according to his data reduction program, our lab elevation was about 100 feet off the mark, we decided that it was time to look into the "third dimension" of radon, the elevation factor, and how well we are able to control it. We were in for a huge surprise ! - It turns out that the simpler the device or method, and the better researched and documented it is, the more usefully can it be applied and understood at higher elevations. With increasing complexity and finesse, equipment becomes increasingly useless when taken to greater elevations.

Perhaps the most sobering realization in this investigation is that our knowledge of measurement is still in its infancy. There is need for large investments of effort and R&D to come to grips with many unknowns - unless we are willing to settle for a "flat earth" mentality in the radon field.

Table 1: Elevation Correction Factors for E-PERM Results (Table 4, E-PERM System Manual, Rad Elec Inc. (3))

Elevation in Feet	"S" chamber c.f.	"L" chamber c.f.
0.000	1.00	1.00
1.000	1.00	1.05
2.000	1.00	1.09
3.000	1.00	1.14
4.000	1.03	1.18
5.000	1.09	1.22
6.000	1.15	1.28
7.000	1.21	1.33
8.000	1.27	1.39

(Table 2, Kotrappa and Stieff (4), Elevation corrections for E-PERM radon monitors, Comparison of correction factors (C) and pressure ratios (P))

elevation (m)	pressure (kPa)	pressure (cm Hg)	C for "S" chb	P for "S" chb
000	101.3	76.0	1.04	-
305	97.7	73.3	1.02	-
610	94.4	70.8	0.97	-
915	91.0	68.3	1.01	1.00
1220	87.7	65.8	1.03	1.04
1525	84.4	63.3	1.07	1.07
1830	81.0	60.8	1.17	1.12
2134	77.7	58.3	1.22	1.17
2440	74.4	55.8	1.27	1.22

Table 2. Gamma Correction Factors for E-PERM Readings (Rad Elec handbook (3), Appendix 3, Table 2)

State	BG (micro-R/hr)
Delaware (lowest value)	6.81
New Jersey - low elev.	6.9
Colorado	13.05
Wyoming (highest value)	13.33

DESCRIPTION OF THE EXPERIMENT

In order to conduct meaningful electret work, one needs to observe several peculiarities that come with this technology.

1. "Constants" A and B in calibration factor calculation - these change all the time, and are sometimes hard to keep up with. Ten percent variations (1.88 to 1.69 for A) are not uncommon, so it pays to check on the latest determination (4).
2. Radon equation depends on the correct choice of electret AND chamber, so one has to be sure that no error in selection was made.
3. Gamma correction factors are given in the handbook (Table 2), and the correction is to be applied to the raw radon value calculated. There are differences in the gamma background readings of different makes of survey meters, depending on the definition of the gamma sensitivity. Dr. Kotrappa of Rad Elec Inc. at one time made available his Bicron survey meter to us to establish chamber backgrounds in Illinois. Tissue gamma sensitivity may vary from total gamma sensitivity as presumably defined by other manufacturers (Eberline). Thus, the biologically significant gamma radiation may be less than the total gamma spectrum.
4. Elevation correction factors are also given in the handbook (Table 1), but are not made a compulsory part of the radon equation. As for some elevations this correction may equal or exceed the gamma correction, it must be considered equally significant It is advisable to check the elevation of the measurement site with the local city engineer's office who will cheerfully provide documentation of applicable benchmark information.
5. The electret reader must be well checked, with a fresh battery, and the electrets must be applied to the reader with a constant orientation convention. The operator must carry out a good number of readings per E-PERM to be measured, and must be free from bias.
6. Handling of electrets and chambers require a certain discipline and experience, otherwise faulty readings or accidental discharge of voltages are possible.
7. It is important that sufficient stock of sufficiently charged electrets are on hand, otherwise the major advantage of the method - its instantaneous readout - becomes illusionary.
8. In designing a survey, it is important to project the expected voltage drain over the duration of the measurement, so as to achieve the minimum drain for a reliable readout - about 10 volts - without draining down some or all electrets beyond their capacity. With 500 volts available capacity and 2 volts per day per pCi/l a short term electret can be subjected to about 250 pCi/l x days before reaching the expiration level of 200 volts (Fig.4).
9. Regarding temperature and humidity, we normally operate our chambers at "ambient" levels, and avoid excesses. During the operation in Northbrook, there was evidence of irregularity in some high humidity work. The role of humidity may well be another area of worthy research in radon before its case should be closed, and electrets as well as other active and passive devices are eligible.

In preliminary work at Lakewood, a sealed radon source was identified that would impart a sufficient radon concentration upon a contained air volume of several 10s of gallons so as to drain electrets of several 10s of volts in a matter of 6-8 hours. We used a soil source from an EPA superfund site in Illinois. The equipment container was a sealable plastic garbage can equipped with a sturdy baking grill and a small, battery powered air mixing fan. There was room for a dozen S-chamber electrets and two each of different makes of primary, battery-powered CRMs for "primary monitoring" (Fig.3)

Elevation control was in Lakewood through documentation at the City Engineer's office (two bench marks, T 405 at 5,602.935 ft and S 405 at 5,591.885 ft), at Echo Lake through the published lake level at 10,598 ft, and at Mt. Evans through a bench mark at 14,128 ft. The linear elevation correction factors provided by Rad Elec were extrapolated beyond 8,000 feet (1.27) to the 10,600 ft. elevation (1.42) and the 14,128 ft elevation (1.65) (Fig.2).

Gamma correction information was found through a separate survey with a Geiger counter, and the Lakewood correction (13 micro-R/h) was found to about double at 10,600 ft (28 micro-R/h) and to double again at the Mt. Evans elevation (58 micro-R/h). Thus, the gamma correction ontop of Mt. Evans is nearly ten times the East Coast/ NJ correction of about 6 micro-R/h (Fig.6).

Each experiment lasted 6.5 hours. While the build-up of radon at Lakewood (inside a building) was nearly linear, high winds in the field reduced the level of radon build-up, even in a sealed container, as shown in Table 3 and Fig.4. Yet the electret voltage drain per average pCi/l radon concentration was significantly stable, varying slightly around 0.5, from 0.47 to 0.53, with respect to CRM "A". This indicates that CRM "A" may be in need of slight elevation correction (for work in elevations beyond 6,000 ft only). For the other CRM, the efficiency of voltage loss per pCi/l was more severely affected, indicating a need for greater corrections at elevations beyond 6,000 feet.

DISCUSSION OF LAKEWOOD CHAMBER RESULTS

As far as the elevation correction is concerned, and in keeping with the message given by the electret manufacturer's handbook, we at Radon QC have handled the E-PERM elevation information inadequately. We assumed that a reading off a Lakewood city limits sign would suffice. Yet as Fig.1 shows, a five to six percent elevation error will reflect itself in a three percent radon error, using the experimental data of Kotrappa and Stieff (4). Though this may be appear insignificant to some - Bill Alexander of Colorado Radon Engineering has demonstrated to us that he will not give up even one percent of radon accuracy through the faulty observance of site elevation, as this appears to be the accuracy limit of his work.

Radon QC will therefore observe its elevation of 5,590 feet, 12.935 feet below the benchmark elevation at T405 in Lakewood (twelve point nine three five feet).- Our sharpening the elevation correction has already benefitted several clients, whose E-PERM readings could be brought within one decimal place of the target value between 5 and 10 pCi/l .

The careful examination of electret readings at the Lakewood, Colorado location and comparison with our primary monitors, as well as frequent comparison with other CRMs and other passive devices, suggest that radon gas (as well as progeny) readings are well in hand at the "base level" in Lakewood.

Yet the E-PERM elevation correction table suggests that elevation may have an effect on other monitors and instruments as well, because of the thinning of the air and decreasing ionization targets, and because of increasing cosmic flux which is known to double with every 5,000 feet of elevation increase (J. Morse, CSM, pers. comm.). Therefore, Radon QC used the freshly gained knowledge of E-PERM reliability to take the electret devices to new heights. But in contrast to the Rad Elec simulation of elevation with laboratory equipment, we preferred to employ America's highest automobile road and take the equipment to Mount Evans, within easy driving range from Denver off Idaho Springs. This access offered a second measuring point at Echo Lake, halfway up Mt. Evans, and about halfway in elevation between Lakewood and the peak.

DISCUSSION OF THE HIGH ELEVATION RESULTS

Table 3 gives the raw and computed results of three measurements of 6.5 hours each with the use of 11 E-PERMs at Mt. Evans (14,130 ft), Echo Lake (10,620 ft) and Lakewood (5,590 ft). Three of the E-PERMs used were long term (red), and gave insignificant readings for this study. Graphic depiction of Table 3 is in Fig. 7.

Though the sealed source in the sealed container was the same, sustained radon levels in the three exposures varied significantly, from 30 (Mt.Evans) to 62 pCi/l (Lakewood), with about 39 pCi/l at the halfway lake. Voltage drain ranged from 11.7v to 15v to 29 v, which denotes the considerable significance of "correction factors" such as gamma background and elevation when one goes to higher elevations.

Of course, we were aware of the major predicament of this experiment - the lack of a reliable primary radon source to measure the electrets against. Out of the combination of the results of one CRM type A and the electrets, we believe that we have, at least within a reliability of about 10%, a sufficiently adequate measure of "absolute" radon levels to be comfortable with.

The ratio of raw, average voltage loss per electret divided by CRM pCi/l reading (uncorrected) is highest at Mt. Evans and lowest at Lakewood. For one set of CRMs (A) the ratios are 0.53 (Mt.Evans), 0.50 (Echo Lake) and 0.47 (Lakewood), respectively. For CRM "B" the ratios are 0.65, 0.52 and 0.42. (Fig.5).

This seems to indicate that CRM "A" may function similar to the electret, and that similar corrections may apply. More severe corrections may be in need for CRM "B".

For Lakewood, corrected E-PERM readings and CRM A agree at 63 and 62 pCi/l, while CRM B runs a little higher, at 65 pCi/l. Without elevation correction, the E-PERMs would be 56 pCi/l.

The following Figure 7 depicts the interesting relationships of E-PERM readings and primary CRMs both in the light of raw, gamma corrected and gamma as well as elevation corrected results.

For electret measurements at high altitude, the data suggest that Rad Elec's correction factors for elevation can well be extrapolated from 8,000 to 14,000 feet. The data also seems to suggest that the gamma correction term remains valid, even at extreme elevation. Gamma readings were obtained in a separate survey (Fig.6).

For the CRMs used, it appears that an elevation correction term similar to the E-PERM correction term would be appropriate both for the 10,000 feet and 14,000 feet locations. As the situation stands, the E-PERMs compare well with both CRMs, as long as the elevation correction at high elevations beyond Denver is dropped. Therefore, all systems should compare well again if corrected for elevations throughout. The extent of the variations is different between the two systems used, which should be expected as CRM A and B are using different design and operating principles.

It may be pointed out that the barometric pressure indicators in both CRMs also gave very different results. CRM "A" showed a 20% difference between 5600 and 14000 feet, while CRM "B" essentially stalled at 6,000 feet elevation - it gave a 5% barometric difference to 14,000 feet, and that in three instruments independently. Therefore, the peripheral measurement devices, especially the barometric ones, should be treated with great caution when using them outside of the "flatland".

CONCLUSIONS

1. The available electret (E-PERM) literature which provides correction factors for both gamma and elevation corrections in the range from 4,000 feet to 8,000 feet is applicable even under extreme elevation situations up to at least 14,000 feet. However, regardless of the elevation, the respective correction term should be included in the radon equation to increase awareness and for mathematical correctness.

2. In applications at elevations beyond 6,000 feet, good agreement in radon readings between E-PERMs and CRMs can be achieved by leaving out the elevation correction for E-PERMs. This agreement is best demonstrated by the rather constant ratio of raw voltage losses and radon readings, at least with some types of CRMs.

3. With elevation corrections for E-PERMs applied, agreement with the "primary" CRMs can again be obtained by applying modest correction factors to the "primary" CRMs, of the order of 1.3 for 10,000 feet, and slightly higher for 14,000 feet elevations.

4. "Simpler" devices of passive or active nature appear to be easier "adaptable" than more sophisticated monitors. This appears to hold also for the peripheral sensors, such as barometric pressure indicators.

5. This study appears to suggest that more work may be needed also in the near-flat elevation range around 3,000 feet, where a 3% correction is suggested by the electret manufacturer at 4,000 feet, but none at lesser elevations. Some radon services will no longer accept a 3% sacrifice in accuracy, as proven by Colorado Radon Engineering, Bill Alexander. In any event, the manufacturer should be congratulated for the existence of this "problem".

6. This study also suggests that there are many facets of radon measurement that are by no means "completed chapters". Radon QC calls on the radon industry to keep on sharpening our tools and our understanding of our enigmatic subject. This suggestion also is made for the benefit of the CRM manufacturers, who are obviously far from having created the "perfect mouse trap" just as yet.

7. A video record of this survey is available from Radon QC for those interested.

REFERENCES

1. Colorado Radon Engineering, William Alexander, E-PERM report 4/22/96, with remark: The topo map that I have indicates your elevation to be closer to 5,500 ft. (It is actually within 10' of 5,600 ft).
2. United States Contour Map, Geological Survey, scale 1/7 million, Reston, VA 1975
3. E-PERM Systems Manual (ring binder), Rad Elec Inc. Frederick MD, May 12, 1993
4. Kotrappa and Stieff (1992), Elevation Correction Factors for E-PERM Radon Monitors, Health Physics, Jan, 1992, vol.62, no.1, p.82-86

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Figure 1. SENSITIVITY OF RADON READINGS AT LAKEWOOD, WITH RESPECT TO ELEVATION CORRECTION

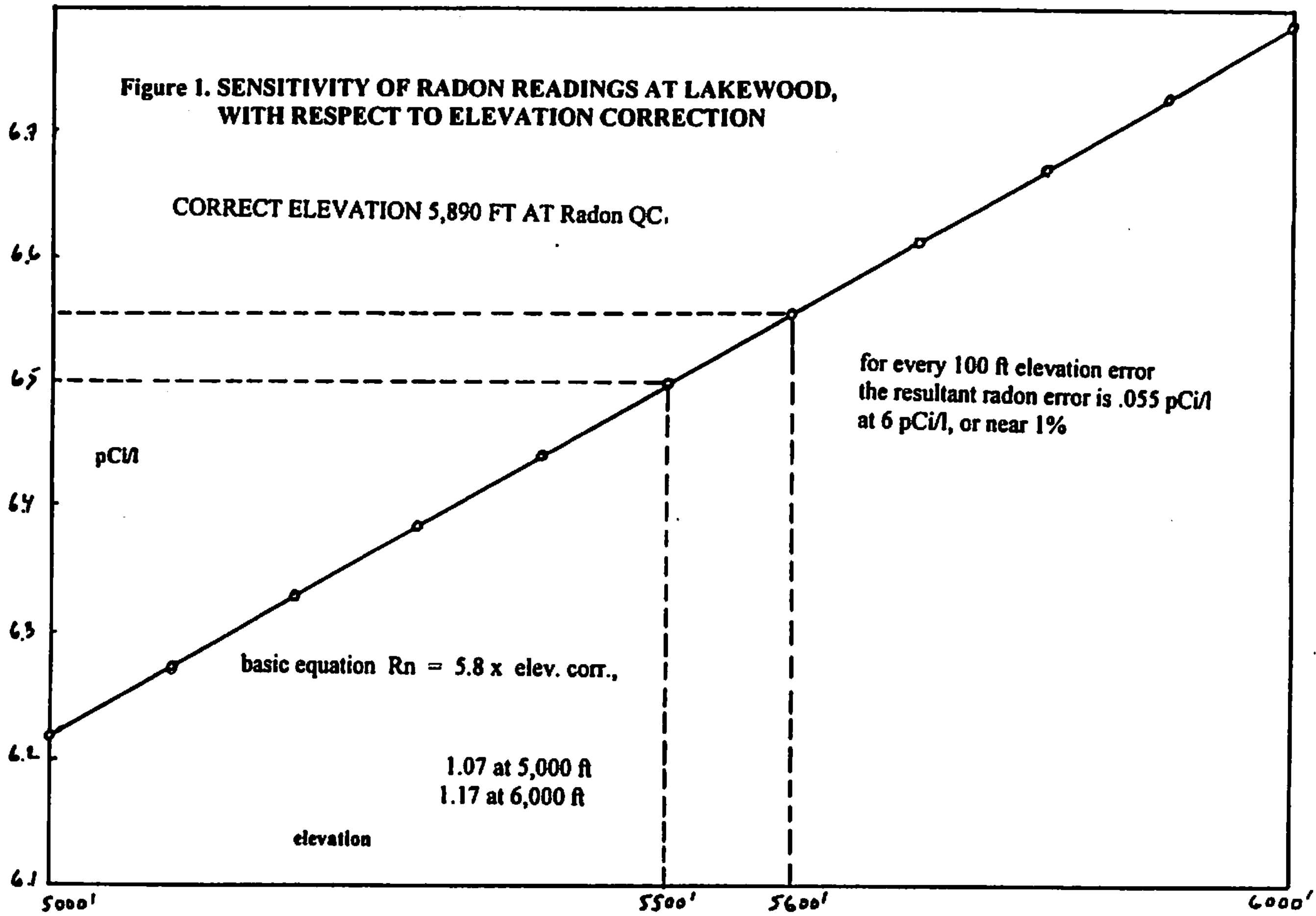


Figure 2. ELEVATION CORRECTION FROM TABLE 1
extrapolating from the 4000-8000 ft range to 10,000 and 14,000 ft

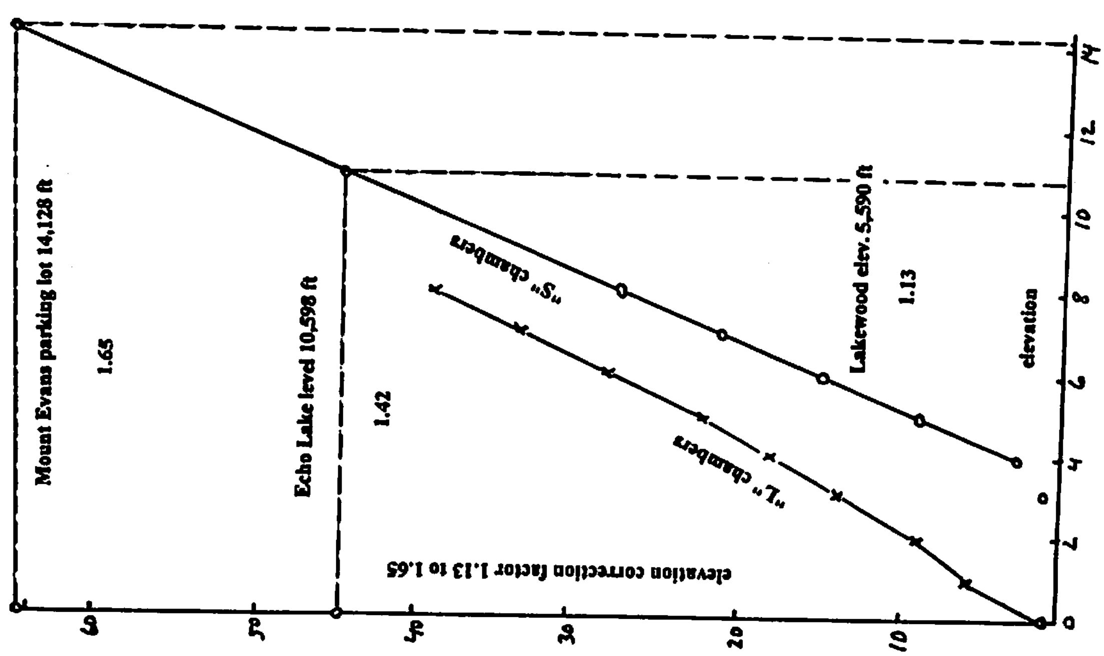


Table 3. **RESULTS OF HIGH ELEVATION E-PERM TEST**

	AVERAGE OF EIGHT E-PERMS			TWO CRM"A"		TWO CRM "B"	
	voltage loss v	radon w/o elev. comp. pCi/l	radon with elev.comp. pCi/l	pCi/l	ratio $\frac{\text{v E-Perm}}{\text{pCi/l CRM"A"}}$	pCi/l	ratio $\frac{\text{v E-Perm}}{\text{pCi/l CRM"B"}}$
MOUNT EVANS elev. 14,130 ft.	11.7	21.1	29.4	22 x 1.34 corr.	0.47	18 x 1.63 corr.	0.42
ECHO LAKE elev. 10,620 ft.	19.13	29.6	38.6	30 x 1.29 corr.	0.5	29 x 1.33 corr.	0.52
LAKEWOOD elev. 5,590 ft.	29.13	55.8	62.7	62	0.53	65	0.65

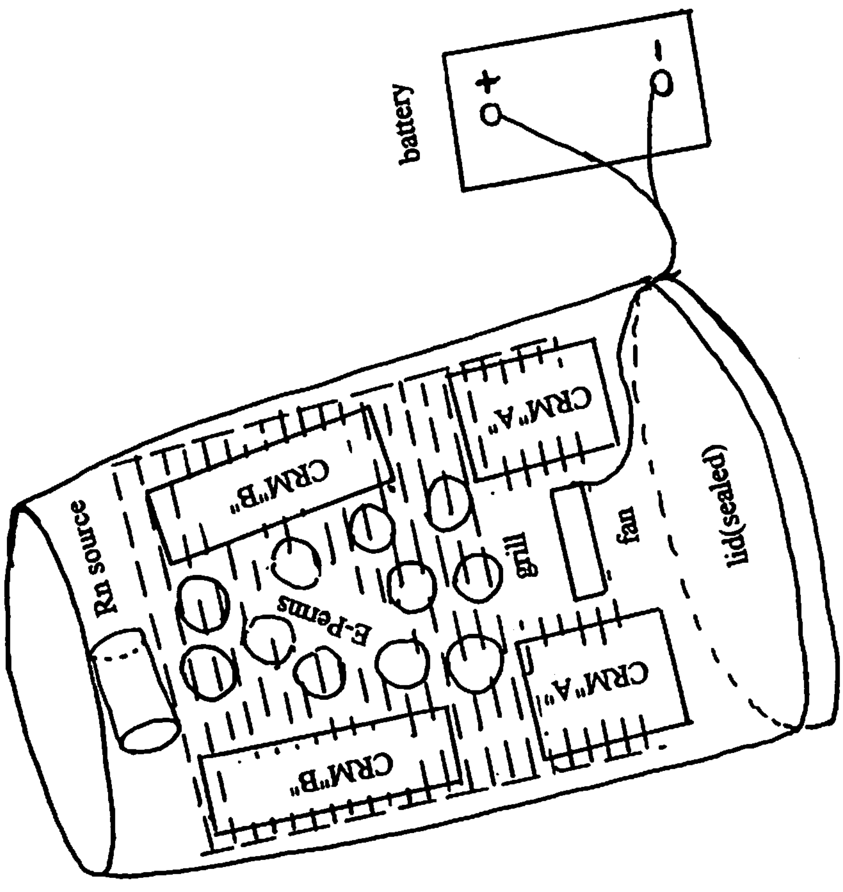


Figure 3. LAYOUT OF THE E-PERM EXPERIMENT USING A GARBAGE CAN AND Rn-SOURCE

Figure 4. RADON CONCENTRATION (apparent) IN VESSEL

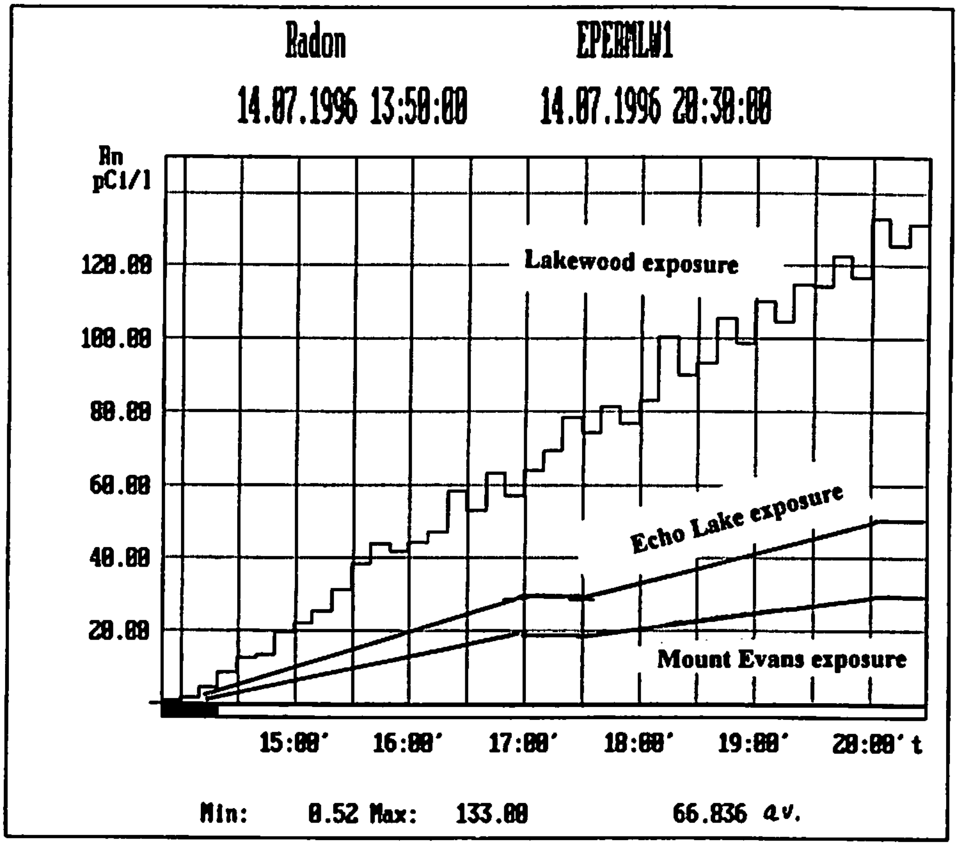
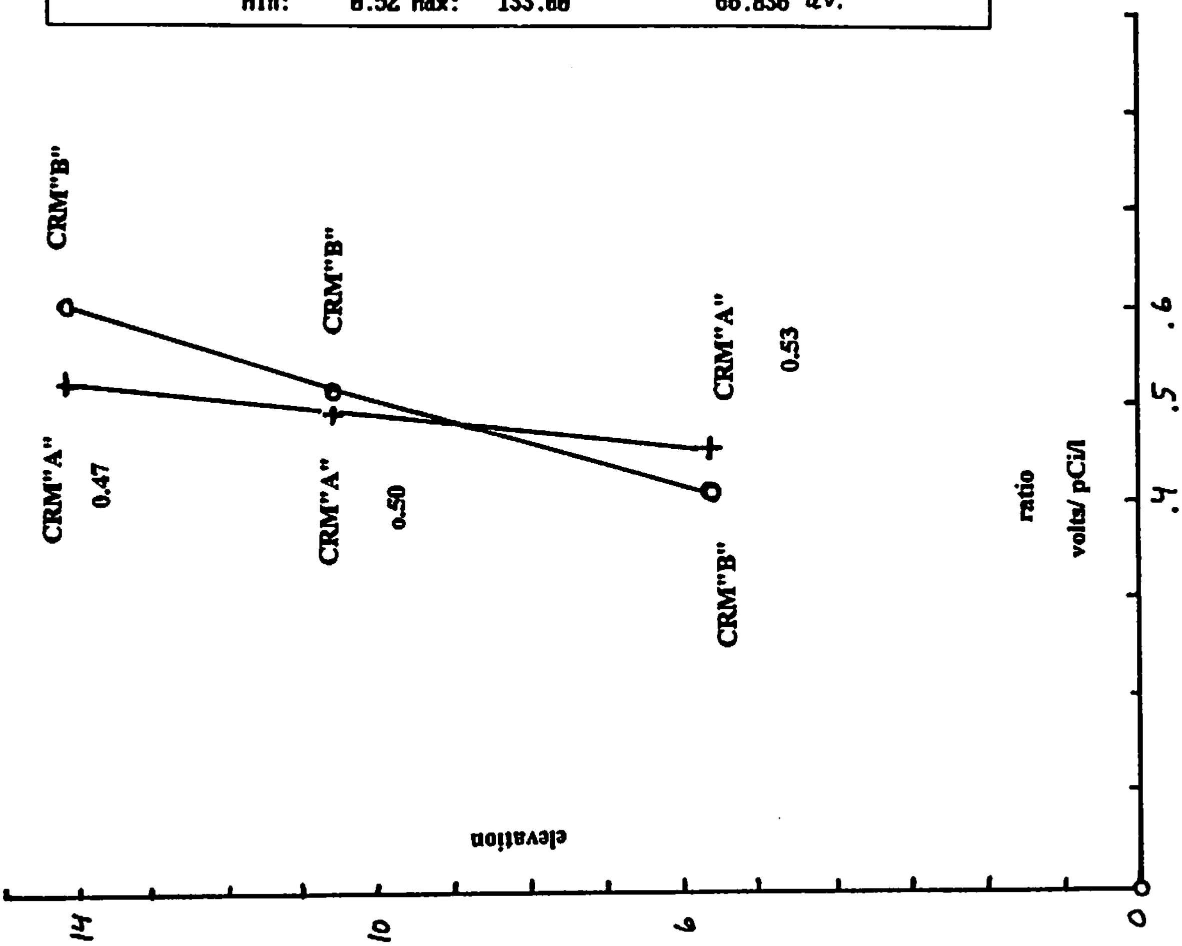


Figure 5. RATIO OF RAW E-PERM V-LOSS OVER pCi/L FROM CRM "A"



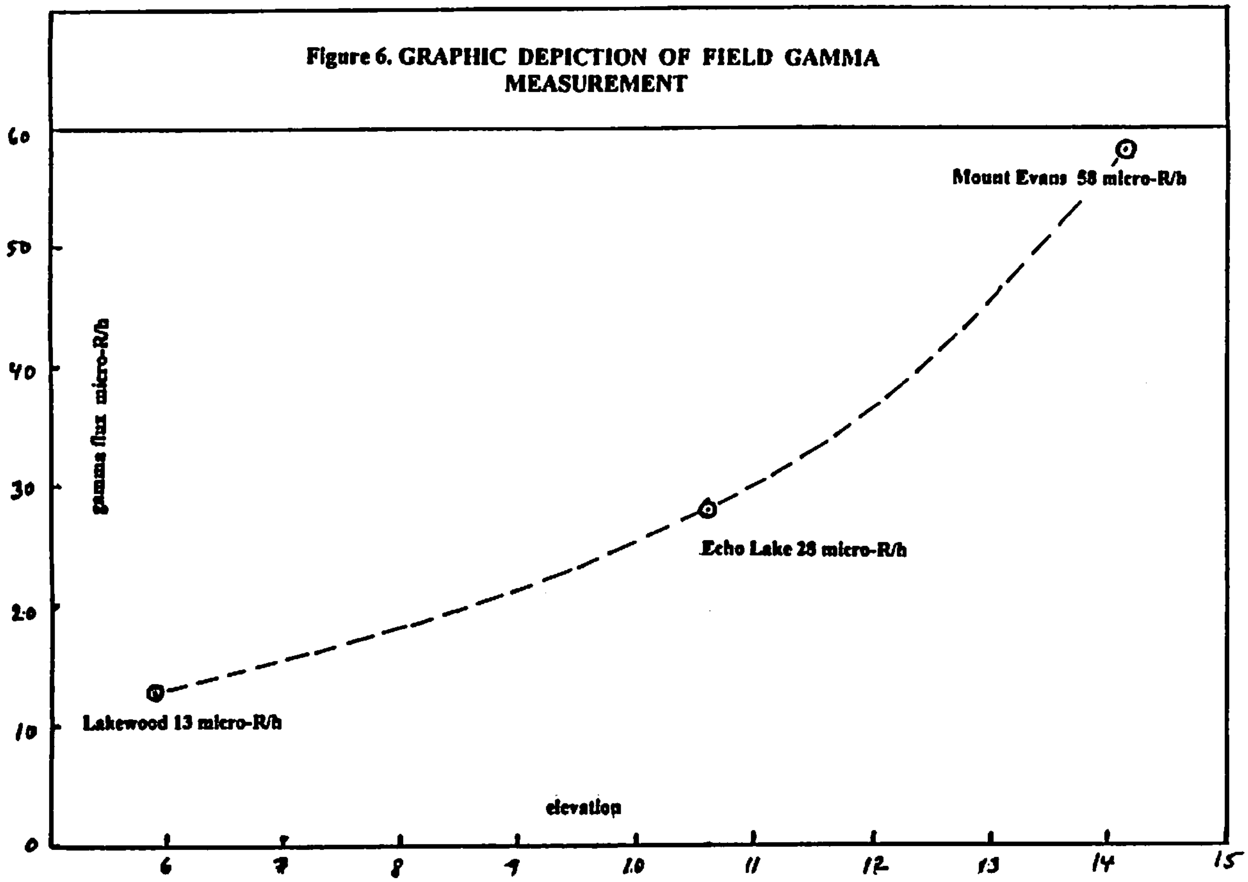


Figure 6. GRAPHIC DEPICTION OF FIELD GAMMA
MEASUREMENT
gamma flux micro-R/h
elevation
Mount Evans 58 micro-R/h
Echo Lake 28 micro-R/h
Lakewood 13 micro-R/h
60
50
40
30
20
10
0
6
7
8
9
10
11
12
13
14
15

Figure 7. GRAPHIC OF THE RESULTS OF THE TEST