Design and Application of a Continuous, Digital-Output, Environmental Radon Measuring Instrument

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INTRODUCTION

A radon measuring instrument has been developed which can continuously measure environmental concentrations of radon in the atmosphere without employing any air movers or pumps. The unit is entirely passive in design and relies upon the diffusion of radon for sample collection. Since radon is an inert noble gas it will follow the classical theory of motion and diffuse in a direction dependent upon the concentration gradient existing between the atmosphere and the sensitive portion of the detector. A porous foam filter allows radon, but not its daughters, to enter the detector where an electrostatic field is maintained to facilitate collection of the decay products of radon, i.e., initially the positive ions of RaA (Po-218). Alpha particles from RaA and RaC' (Po-214) within the sensitive volume are detected using a ZnS scintillator and photomultiplier tube with the usual complement of electronics.

The radon detector, once installed at a measuring site, prints the number of alpha particle events occurring in the sensitive portion of the detector during sequential preset periods of time continuously throughout the day. Typically, a 40 to 60 minute interval is used. Since radon diffusion is a continuous process the detector is always functioning and

therefore produces information concerning the variation of radon at the measuring site.

INSTRUMENT DESIGN

The detector portion of the instrument, Figure 1, is a hemispherical region 15.24 cm (6 in.) in diameter with a 0.85 cm radius spherical electrode, Figure 2, located at the center. A wire mesh screen provides the outer structural support for the porous foam and functions as the anode for the electrostatic field. The central electrode (cathode) is made from an extruded lucite rod, one end of which is machined into a hemisphere. A ZnS(Ag) scintillant is sprayed onto the hemispherical portion of the lucite.

In order for the alpha particles from Po-218 and Po-214 to be detected scintillation in the ZnS(Ag) must be observed by the photomultiplier tube which is in contact with the central electrode light pipe. Due to the geometry of the detector only a certain fraction of the alpha particles will deposit their energy in the ZnS. Therefore, the amount of scintillant must be sufficiently thick to allow maximum energy transfer from the alpha particle and, at the same time, be transparent to the resulting photon emission. By fabricating several central electrodes with different scintillant densities it was observed that, according to Figure 3, approximately 25 mg of ZnS was the most efficient. Since the surface area of the electrode is 4.54 cm^2 the optimum scintillant density is 5.5 mg/cm^2.

Originally scintillant was sprayed using a glue and acetone matrix. This method proved inadequate since the glue contained some trace alpha-emitting material which increased the instrument background. To alleviate this condition, the glue was omitted entirely from the matrix and the scintillant was mixed only with acetone. Since acetone is a solvent for

the plastic it was seen that the ZnS would simply bind to the surface of the electrode.

A conductive coating must be placed over the ZnS on the central electrode so that the positive RaA ions will be electrostatically collected on the surface. The metalized material must be as thin as possible since the range of alpha particles in most materials is very small. Pure aluminum foil, with an effective density of approximately 1 mg/cm^2, is used in the recent instrument design.

Greater than 80% of the Po-218 produced in the sensitive volume of the detector exists as the positive ion and will therefore be accelerated toward the cathode. The collection efficiency will depend upon the external electrostatic field. The optimum magnitude of the field depends primarily upon the radius of the sensitive volume since the electrostatic field varies as the inverse square of the radius of the detector. The efficiency of the detector is shown in Figure 4 as a function of the collection voltage and indicates that, above 300 volts, the response of the detector is independent of potential. This "plateau" value is, however, strongly dependent upon the radius of the sensitive volume.

The detector operates as either a continuous or integrating instrument and counts the alpha particles from the decay of RaA and RaC' collected on the central electrode. A block diagram of electronic configuration is given in Figure 5. The number of events in any preset interval of time is displayed on the scaler and recorded by the serial printer. Thus, it is possible to determine the fluctuations of Rn-222 in the atmosphere by analyzing the continuous digital output from the monitor or, by integrating the decay events over long periods of time, the average concentration of Rn-222 can be calculated.

The response time of the instrument was measured by installing the detector into a constant Rn-222 concentration and observing the time increase in count rate. An equilibrium condition was achieved after approximately 30 minutes indicating that the ingrowth of RaC' was sufficient, along with the production of new RaA, to provide a constant response. Eventhough the build-up time for RaC' is long relative to RaA, an effective equilibrium is established within approximately 30 minutes since diffusion is providing new RaA while the RaC' approaches equilibrium. Figure 6 shows the response of the detector due to a stepwise increase in the Rn-222 concentration.

FIELD MONITORING

The continuous radon measuring instrument was employed in a monitoring program to simultaneously measure indoor and outdoor concentrations of Rn-222 in a typical residential structure in New Jersey. In addition to characterizing the spatial and temporal variations of the Rn-222 concentration measured at this site, it would also be possible to calculate the radon source term from a knowledge of the structure's air exchange rate (ventilation) and the mean indoor and outdoor radon concentrations.

A typical result of the monitoring for radon is shown in Figure 7 for the period of 29 January to 2 February, 1976. From Figure 8 it is seen that a readily identifiable diurnal variation was measured in the basement and on the second floor. The maximum radon concentration occurred in the early morning and the minimum appeared in the mid-afternoon. The average concentration of radon in the basement was approximately 1.1 pCi/l,

about three times greater than that measured on the second floor. Linear regressions between barometric pressure and windspeed with radon concentration were performed to examine if any causal relationships could be predicted. Figure 9 indicates that a qualitative correlation does exist when large scale meteorological changes occur in the environment.

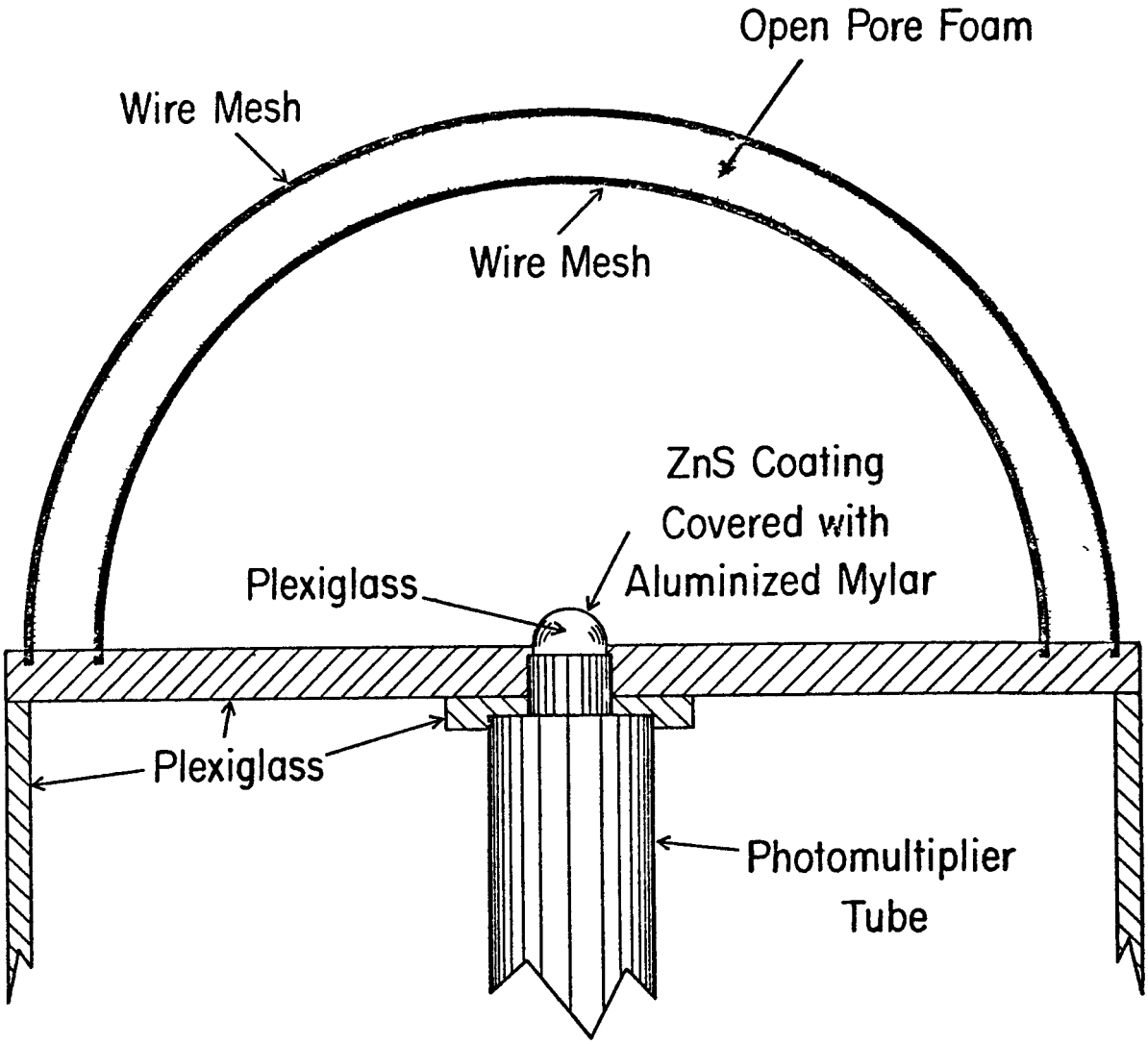
Unlike most other investigations, where several locations were surveyed on a short-term "grab sample" basis, the present program concentrated on a single dwelling and measured Rn-222 simultaneously in the basement, on the first floor, and outside the structure. The house is heated with a recirculated air system and was operating during the monitoring period. Figures 10 and 11 show a portion of the monitoring results. The first floor Rn-222 concentration was a factor of three greater than that measured outdoors. This fact is reasonable since radon will emanate from the foundation due to the trace amounts of Ra-226 in the soil and materials of construction. The basement concentration was a factor of fourteen greater than the outside air concentration and a factor of five greater than that measured on the first floor.

CONCLUSION

Indoor and outdoor Rn-222 concentrations in air have been measured simultaneously in a typical residential structure in New Jersey using the New York University continuous, digital readout, radon monitoring instrument. The indoor concentration is not uniform in that the basement tends to be higher than the other floors. Assessing indoor exposure to Rn-222 in the atmosphere must rely upon a continuous measurement rather than a grab sample of air since the fluctuations and spatial changes in concentration encountered in a structure are large and variable.

Acknowledgement

The authors greatfully acknowledge the cooperation of Mr. and Mrs Albert Spitz who have lived with several radon measuring instruments in their home for many months.

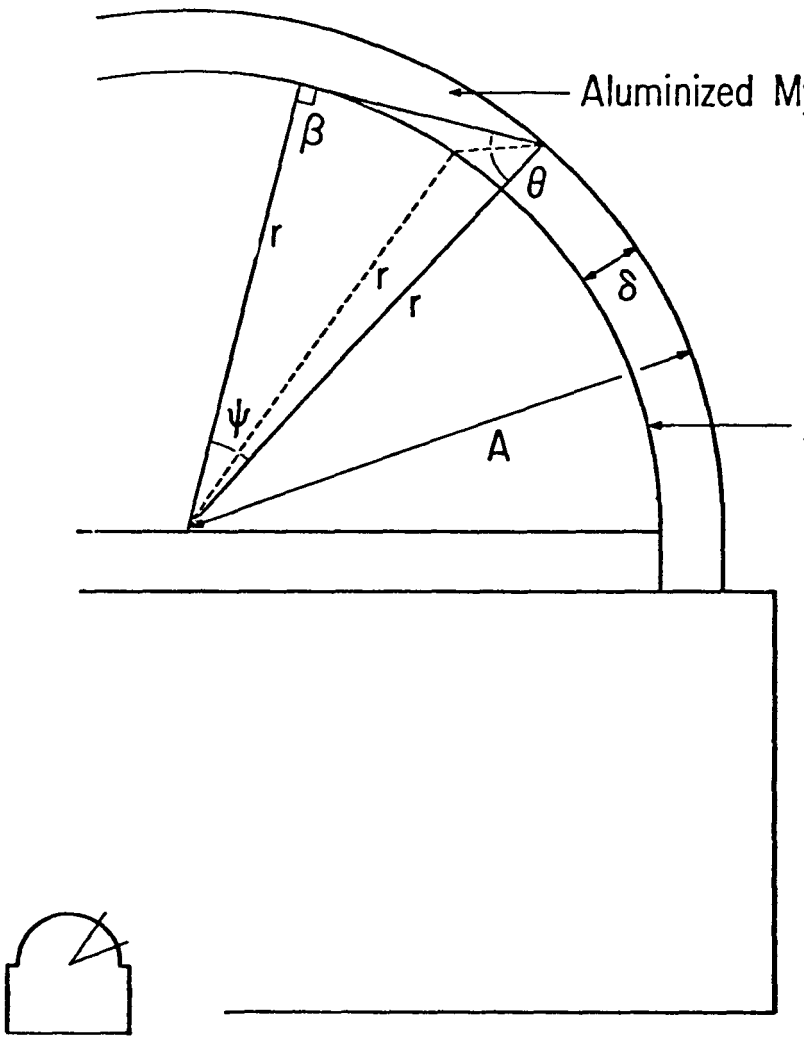


DETECTOR CROSS-SECTION

Figure 1

Central Electrode and Light Pipe Detail

Geometric Detection Efficiency



Geometry

$\theta_{max} \geq \theta \geq 0$

$\pi \geq \beta \geq \pi/2$

Mylar

$\sigma = 1.1\ mg/cm^2$

$(1.1\text{-}1.8\ mg/cm^2)$

$\delta = 0.0013\ cm$

$(0.0005\ in)$

Light Pipe

$A = 0.8513\ cm$

$r = 0.8500\ cm$

Figure 2

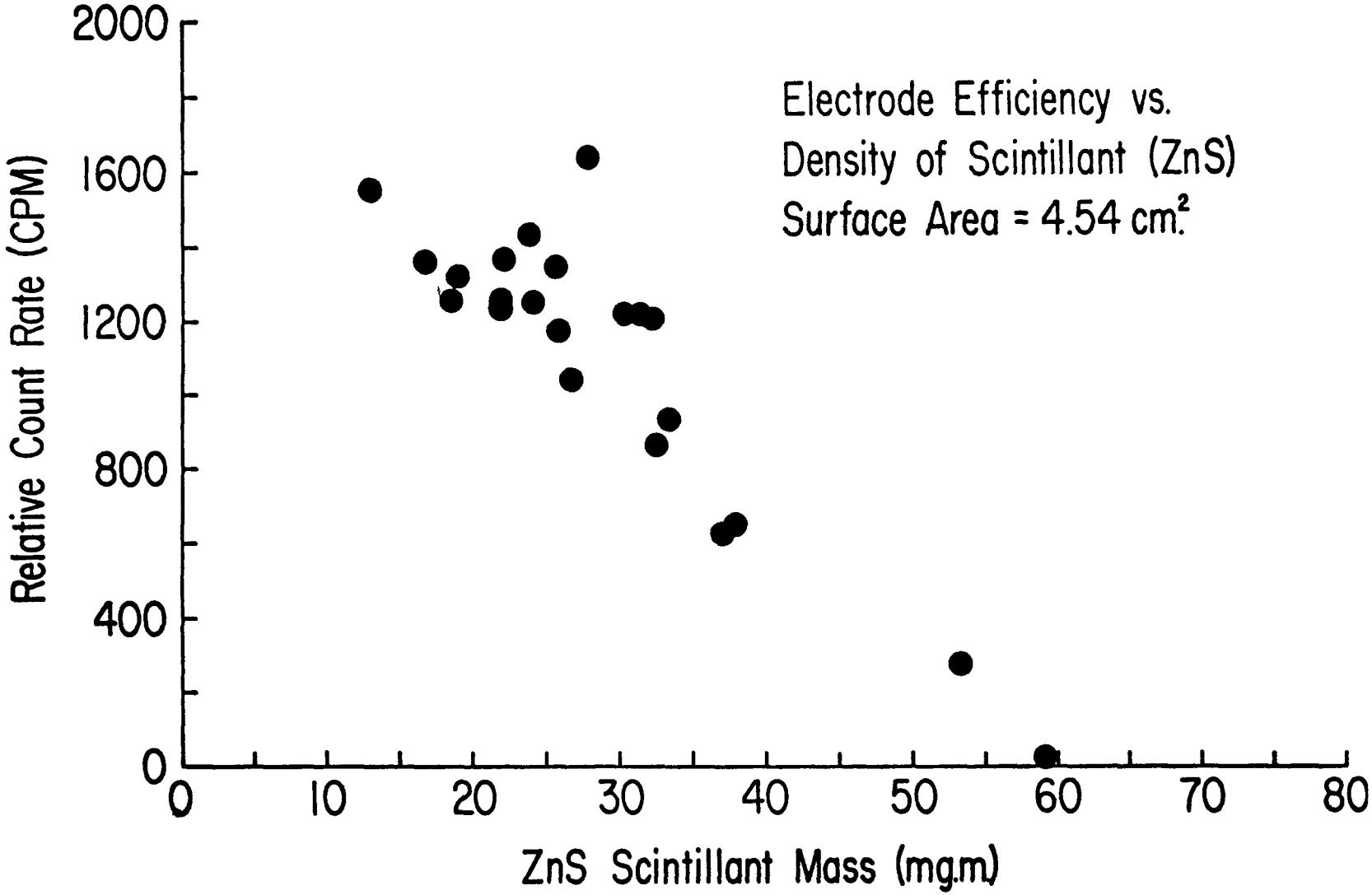

Electrode Efficiency vs.
Density of Scintillant (ZnS)
Surface Area = 4.54 cm²
Relative Count Rate (CPM)
2000
1600
1200
800
400
0
0
10
20
30
40
50
60
70
80
ZnS Scintillant Mass (mg.m)

Figure 3

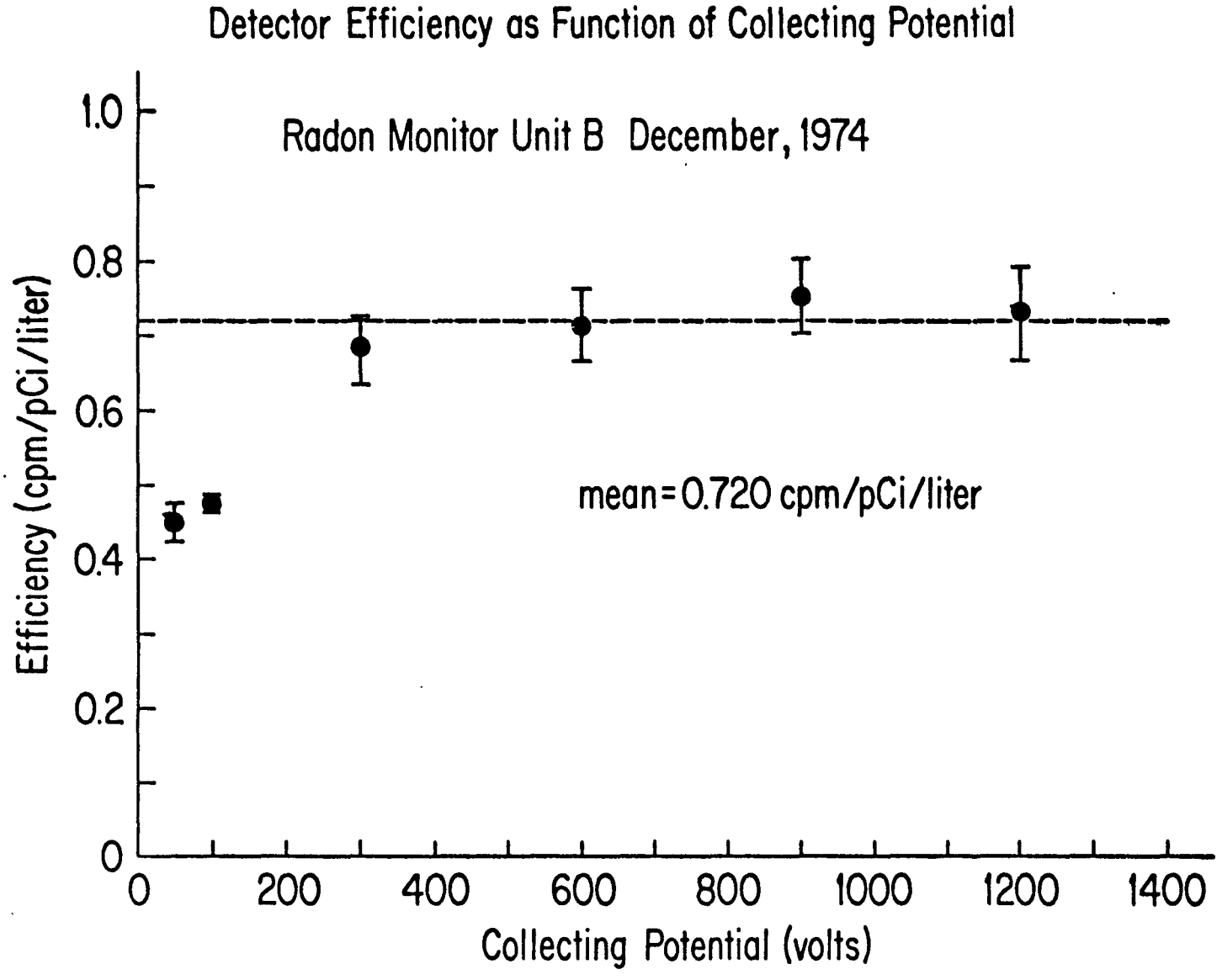

Detector Efficiency as Function of Collecting Potential
Radon Monitor Unit B December, 1974
mean=0.720 cpm/pCi/liter
Efficiency (cpm/pCi/liter)
1.0
0.8
0.6
0.4
0.2
0
0
200
400
600
800
1000
1200
1400
Collecting Potential (volts)

Figure 4

Radon Monitoring Instrument
Schematic Diagram

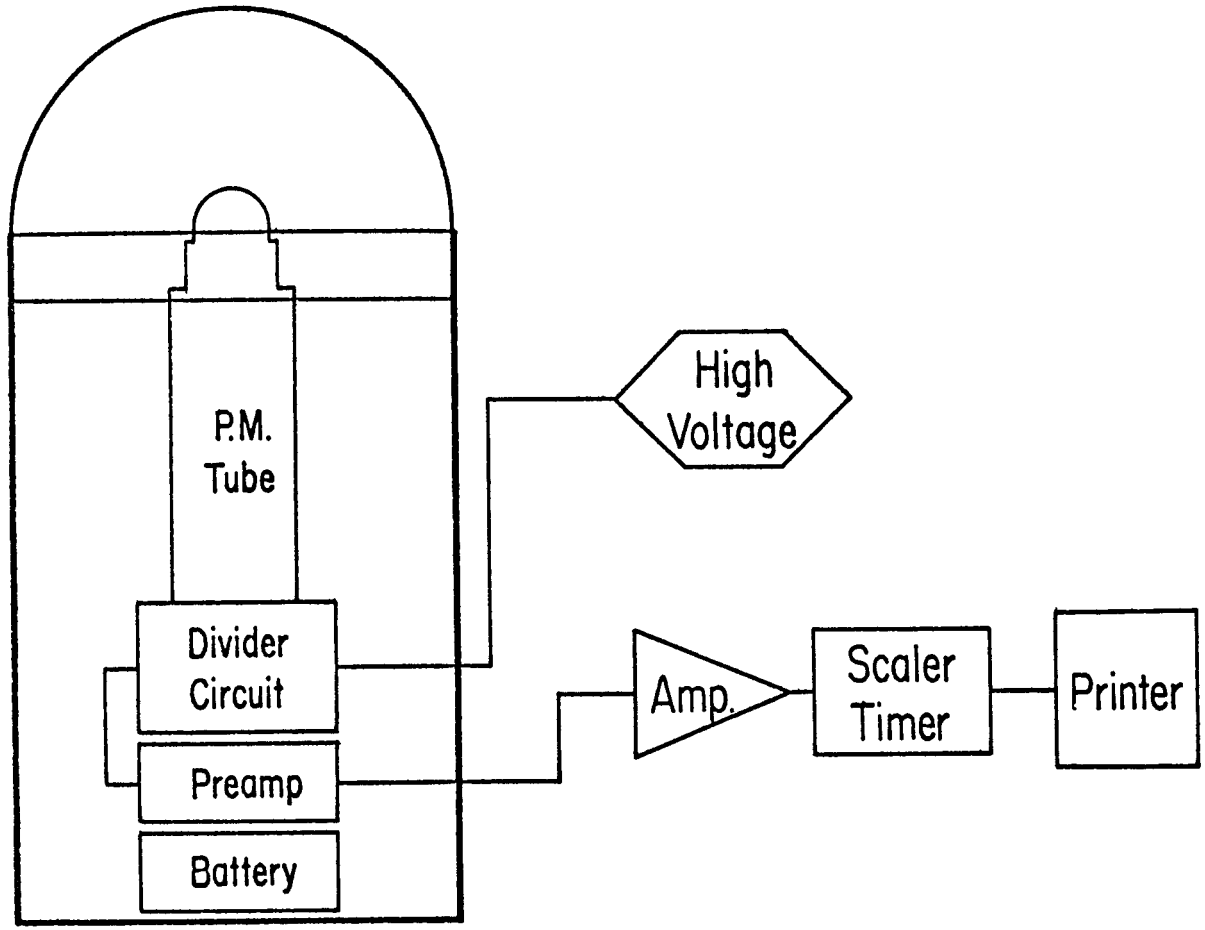


Figure 5

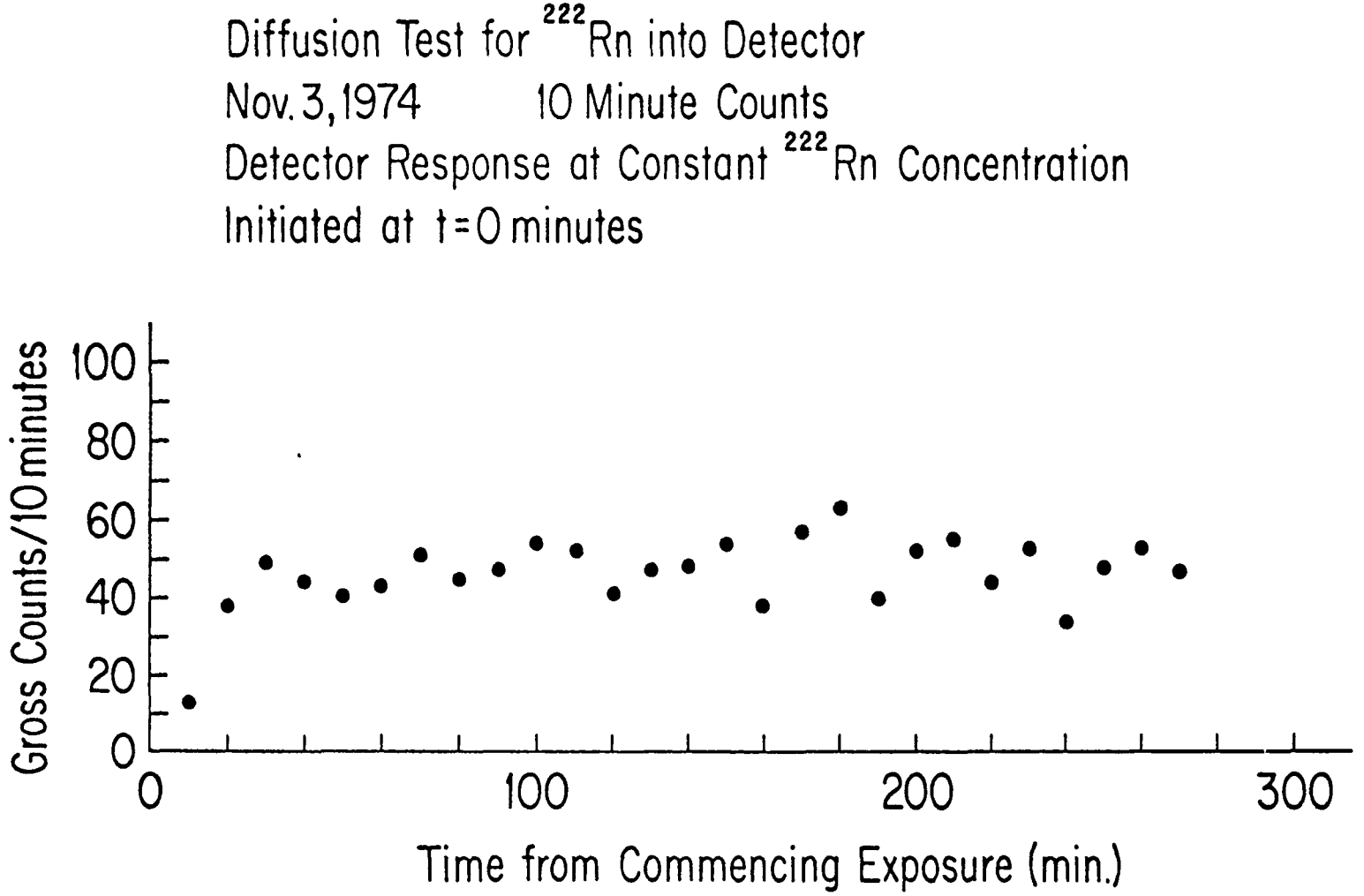

Diffusion Test for ^{222}Rn into Detector
Nov. 3, 1974 10 Minute Counts
Detector Response at Constant ^{222}Rn Concentration
Initiated at t=0 minutes
Gross Counts/10 minutes
0
20
40
60
80
100
0
100
200
300
Time from Commencing Exposure (min.)

Figure 6

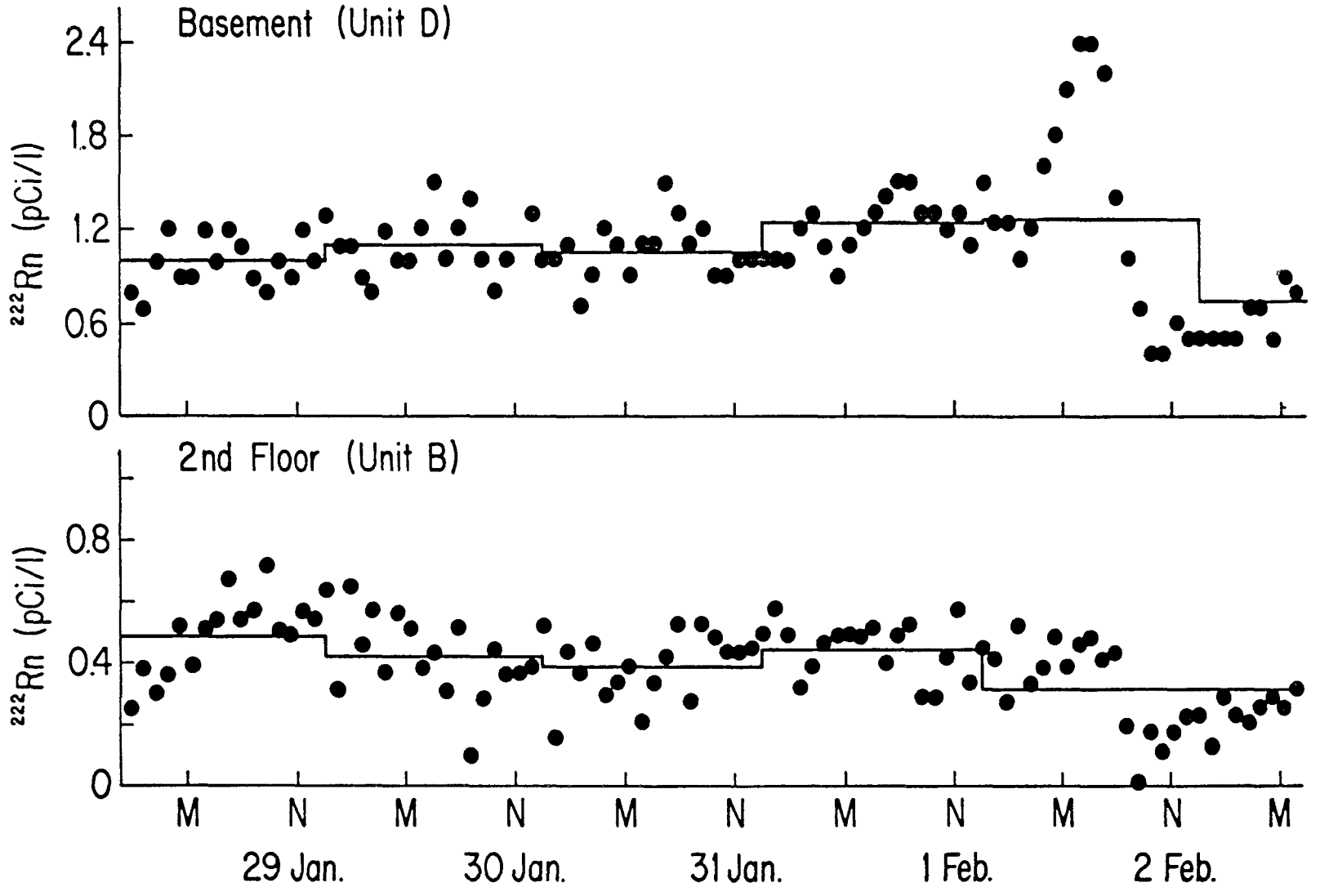

Basement (Unit D)
^{222}Rn (pCi/l)
2.4
1.8
1.2
0.6
0
2nd Floor (Unit B)
^{222}Rn (pCi/l)
0.8
0.4
0
M N M N M N M N M N M
29 Jan.
30 Jan.
31 Jan.
1 Feb.
2 Feb.

Figure 7

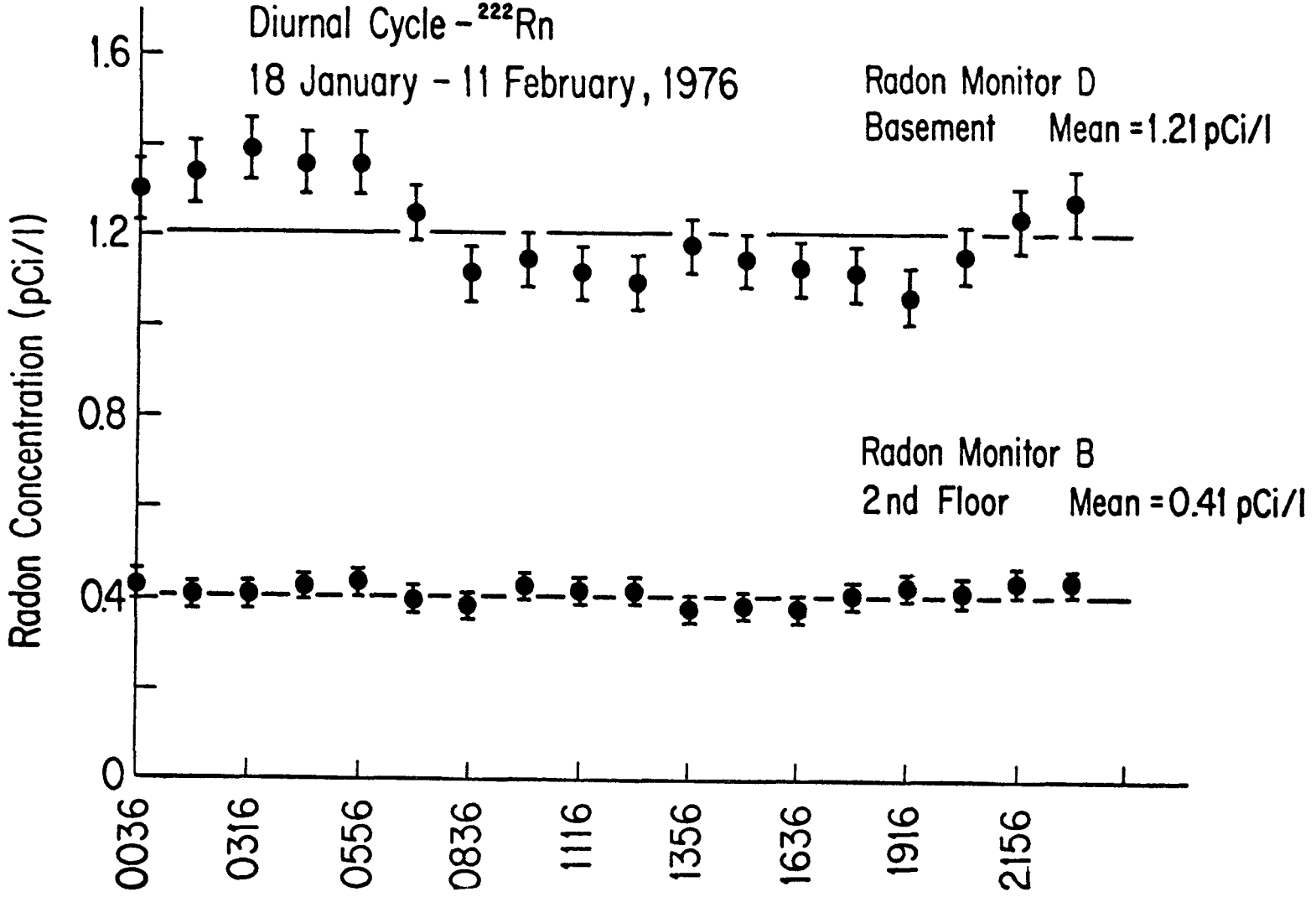

Diurnal Cycle - ^{222}Rn
18 January - 11 February, 1976
Radon Monitor D
Basement Mean = 1.21 pCi/l
Radon Monitor B
2nd Floor Mean = 0.41 pCi/l
Radon Concentration (pCi/l)
1.6
1.2
0.8
0.4
0
0036
0316
0556
0836
1116
1356
1636
1916
2156

Figure 8

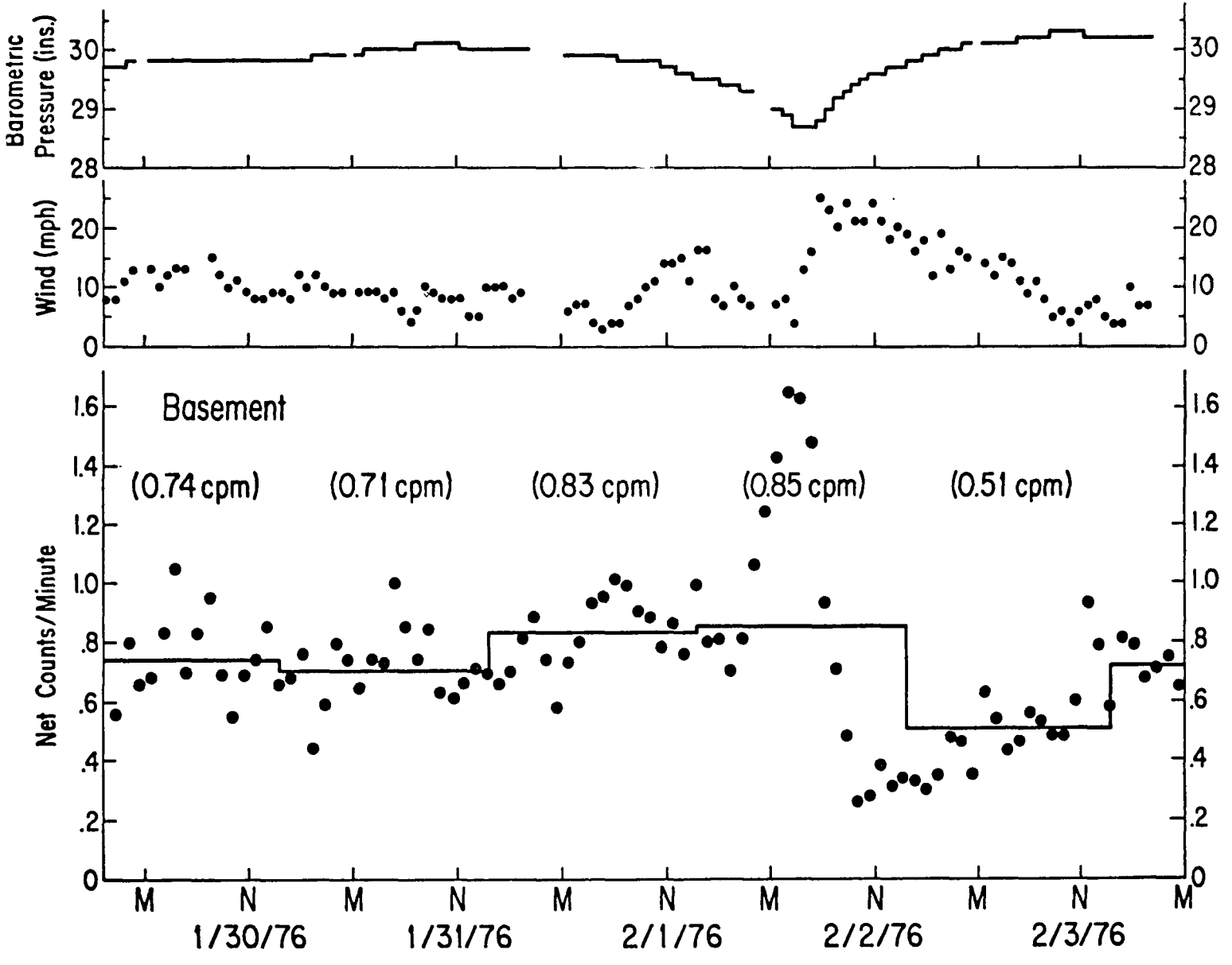

Barometric Pressure (ins.)
30
29
28
Wind (mph)
20
10
0
Basement
(0.74 cpm)
(0.71 cpm)
(0.83 cpm)
(0.85 cpm)
(0.51 cpm)
Net Counts/Minute
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
M
N
1/30/76
1/31/76
2/1/76
2/2/76
2/3/76

Figure 9

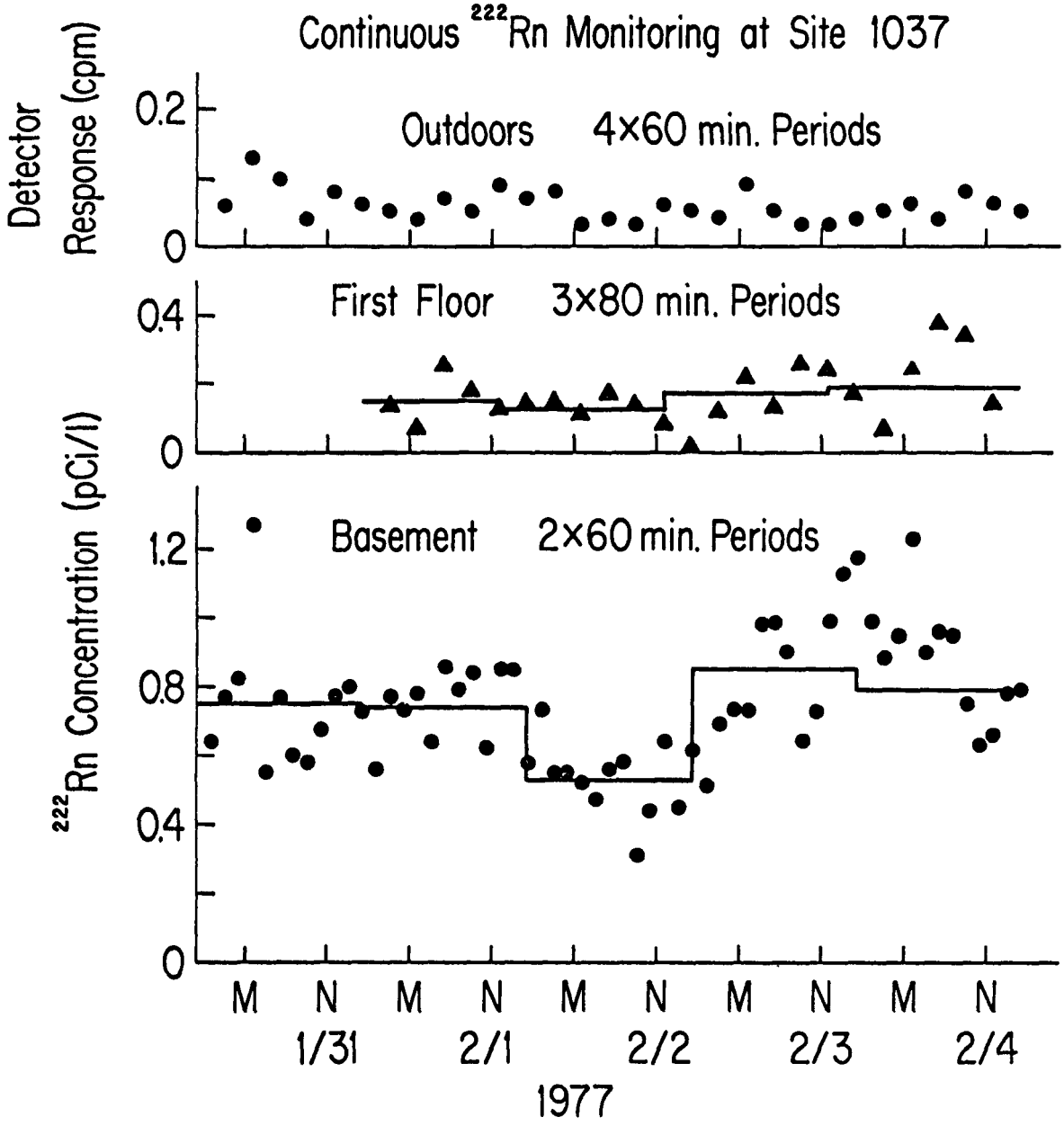

Continuous 222Rn Monitoring at Site 1037
Detector Response (cpm)
Outdoors 4×60 min. Periods
0.2
0
First Floor 3×80 min. Periods
0.4
0
222Rn Concentration (pCi/l)
Basement 2×60 min. Periods
1.2
0.8
0.4
0
M N M N M N M N M N
1/31 2/1 2/2 2/3 2/4
1977

Figure 10

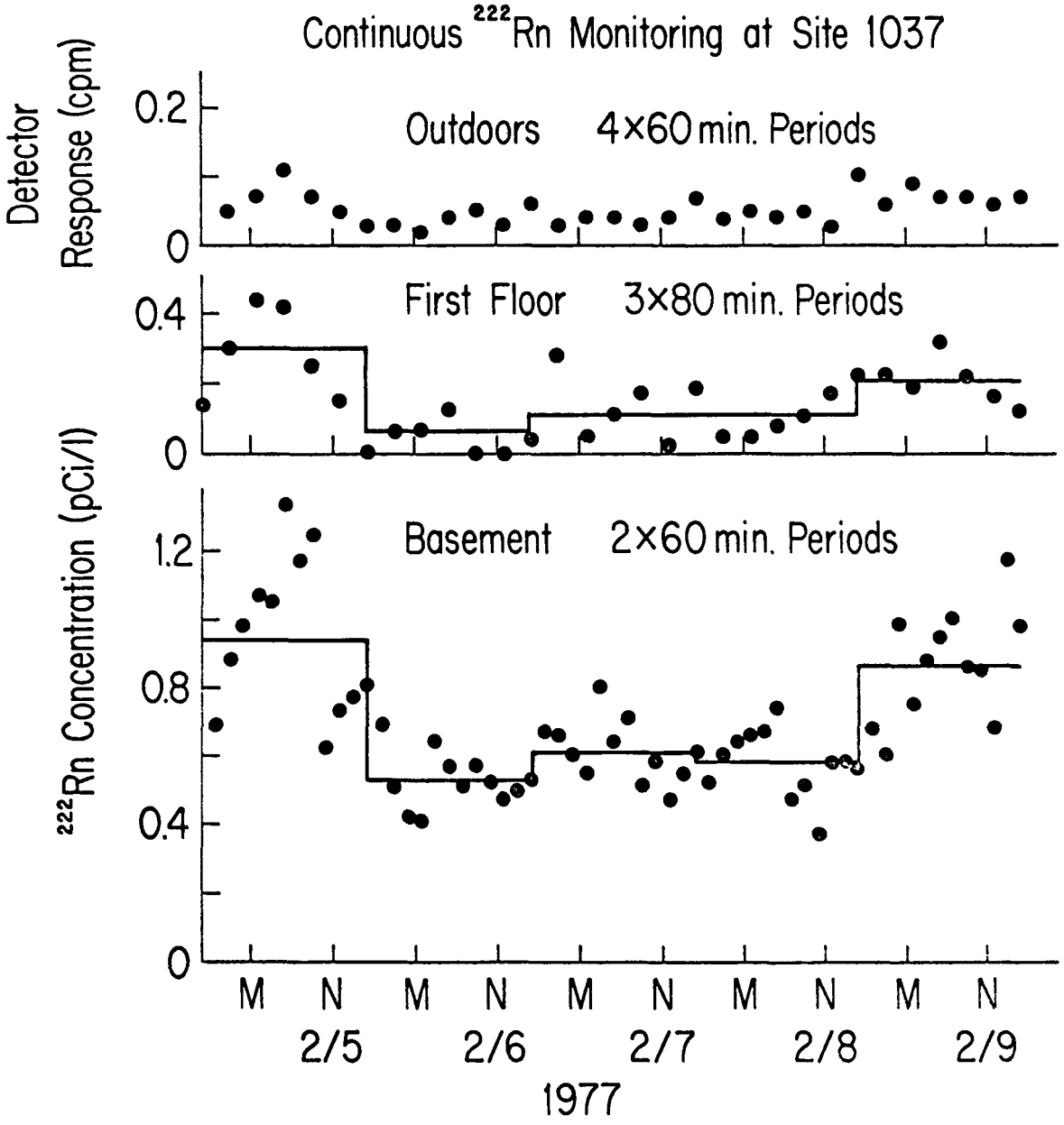

Continuous 222Rn Monitoring at Site 1037
Detector Response (cpm)
Outdoors 4×60 min. Periods
First Floor 3×80 min. Periods
Basement 2×60 min. Periods
222Rn Concentration (pCi/l)
0.2
0
0.4
0
1.2
0.8
0.4
0
M N M N M N M N M N
2/5 2/6 2/7 2/8 2/9
1977

Figure 11