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APLICATIONS OF CONTINUOUS RADON MONITORS: SUB-SLAB DEPRESSURIZATION DUTY CYCLE ANALYSIS

By: Carl J. Kershner, Ph.D.
femto-TECH, Inc.
325 Industry Drive
Carlisle, Ohio 45005

A two month study was carried out during the early spring heating period of 1989, on a slab-on-grade home with an active sub-slab depressurization system to evaluate the required characteristics of a continuous radon monitor/controller. A pulsed ion chamber type radon monitor was used to measure the radon concentrations and a personal computer was used as data logger/controller. Radon levels in the house were monitored for four months in the summer and fall of 1988; prior, during, and after mitigation. Based on these analyses, a 37 Bq/m^3 (1 pCi/l) control band width was chosen for the active controller with 111 and 74 Bq/m^3 (3 and 2 pCi/l) on/off switching points, respectively. Data compiled over a two month period demonstrated the efficacy of the continuous monitor controller system in maintaining an average radon concentration of 78 Bq/m^3 (2.1 pCi/l) with an average fan on time of 29.3%. A 60 day composite summary of the controller data revealed a diurnal modulation on the fan duty cycle requirements. The minimum counting statistics and precision requirements for continuous radon monitors in controlling applications are presented.

INTRODUCTION

Sub-slab depressurization (SSD) has become one of the most commonly employed techniques for mitigating radon levels in residential and other indoor environments. This is a consequence of the relatively low installation, operating and maintenance costs and the proven efficacy of the technology (Henschel et al. 1990). Most SSD systems in use today operate on a continuous duty cycle. Although this is a safe and conservative approach, it can result in unnecessary energy consumption in powering the suction fan and from exhausting of conditioned air (Clarkin et al. 1990). Other active radon mitigation systems (such as heat recovery ventilation and pressurization) would benefit even more from an on demand controlled duty cycle - especially in schools and large building applications.

To evaluate the feasibility and to determine the radon detector requirements of a mitigation system control device, a field study was conducted in a typical slab-on-grade house in Dayton, Ohio.

EXPERIMENTAL

The house used in this study was a slab-on grade single-story structure with 190 m^2 (2050 ft^2) living area situated in Dayton, Ohio. The slab construction consisted of a poured foundation and a 0.1 m (4 in.) aggregate layer between a compacted clay pad and the slab floor. The forced air heating and air conditioning system had in-slab supply ducts and attic cold air returns.

In the year prior to mitigation, radon levels were measured with a continuous radon monitor in the family room and in bedroom No. 3 (See Fig. 1) for periods of from 24 hours to as long as 30 days. The average annual radon level for the house was found to be 207 Bq/m^3 (5.6 pCi/l) with a peek level of 1014 Bq/m^3 (27.4 pCi/l). The highest radon levels were observed in the summer months under "closed-house" conditions with the air conditioning system in operation. The annual average reflects considerable periods of "open-house" conditions in spring and fall. A pre-mitigation diagnostic survey of the house using a femto-TECH TRACKER revealed no localized radon entry points. However, radon levels of 370 to 740 Bq/m^3 (10 to 20 pCi/l) were observed in the in-slab duct system during blower operation.

A 10 cm (4 inch) diameter sub-slab suction system was installed in a walk-in closet as shown in Fig. 1. This was the most centrally located non-obtrusive location on the floor-plan. The system was activated with full-time fan operation in July, 1988. The SSD system was a straightforward vertical pipe installation with a Kanafalkt, Inc. Model K-4XL4 (5 m^3/min, 179 CFM) centrifugal in-line duct fan housed in the attic and exhausted through the roof (See Fig. 2 for details).

Area monitoring prior, during, and after mitigation was carried out with femto-TECH, Inc. Model R210F continuous radon monitors equipped with recording and printing data acquisition systems. The seven day radon concentration plot encompassing the SSD system start-up is presented in Fig. 3. These data represent closed-house conditions with the air-conditioning system in operation, except for the construction period (Day four in Fig. 3) when open-house conditions prevailed. The SSD system was operated for eight months in continuous mode until the fan control was installed in march of 1989. The radon levels averaged 59 Bq/m^3 (1.6 pCi/l) during this period.

The detector/controller used in this study consisted of a Model R210F radon monitor, an Apple II Plus (Registered trademark of Apple Computer, Inc.) computer, and a BSR (Registered trademark of BSR, Ltd.) wireless remote controller. The component lay out is presented in Fig. 2. In addition to the usual floppy disk drives, video display, and printer peripherals; a clock/calander board, a modem/BSR controller board, and a direct memory access peripheral interface adaptor (PIA) board was required to provide the data acquisition and controlling functions unique to this application. Due to the use of a transistor-transistor-logic (TTL) PIA, the interface between the pulse output of the R210F radon monitor and the computer was implemented with nothing more than a 10k ohm pull-up resistor on the signal line.

The transmitter module of the BSR control was plugged into a line receptacle at the computer location and the receiving module was plugged in at the SSD fan location. Because the BSR control system uses the house AC service lines to communicate between transmitter and receiver, multiple receivers can be used. In this case an additional receiver programmed with the same unit code as the fan receiver was located in the kitchen to activate a light when the fan was operating. This type of remote control proved to be quite a useful feature in providing complete flexibility in locating the radon monitor and indicator light without the need for running interconnecting wires.

The operating software consisted of machine level and compiled BASIC routines. The machine level portion of the program handled the set up and operation of the BSR controller and the reading and counting of the pulses from the radon monitor. The pulse counting program operated on a one minute count interval with a 1 kHz signal-line sample rate. The 20-50 msec ion chamber pulses from the R210F radon monitor were easily resolved with this counter. The BASIC portion of the program served as the foreground operating system; performing arithmetic processing data display, data storage, and control logic functions. Thus, at one minute intervals, the screen display information was up-dated and a fan control decision performed. Print-outs were performed on an hourly cycle and whenever an SSD controller command was executed. The screen displays and print-outs consisted of: the date, the time, the elapsed time, the present concentration, the average concentration, and the status of the BSR controller.

The controller algorithm was based on a digital model of an analog rate meter with a 0.05 min^{-1} time constant. The practical and statistical basis for this time constant is presented in the ANALYSIS section below. The program statement used to implement the rate meter function was,

$$R(1) = R(0)+(S-R(0))*k,$$

where S is the rate computed for the present sample interval, k is the rate constant, R(1) is the present integrated rate, and R(0) is the integrated rate at the end of the previous sample interval.

ANALYSIS

A control transducer must have a response time and sensitivity sufficient to follow the variations in the signal being measured and to perform an unambiguous decision on the information. Moreover, because all radiation counting techniques require a finite integration interval to collect statistically significant information, a control response based on such information is inextricably related to the sensitivity of the radiation detector. Thus, the modulation frequencies and levels of the signal, detector sensitivity, and the radon level the SSD system is capable of achieving, must all be considered in selecting a response time, a control band width, and a high and low control point for an SSD controller.

Inspection of the hourly concentration data collected over the year prior to mitigation, revealed that there were distinct features to the amplitude and period of variation for the radon concentrations in this test house - similar to those reported by Scott, 1988. The results of these observations are summarized in Table 1 and examples can be seen in Fig. 3. The hourly concentration data plotted in Fig. 3 have the classic diurnal modulations in the first three days as well as a considerably dampened effect for the two days after mitigation. A meteorogically related modulation can be seen on top of the diurnal variation in days three and four. As noted by Scott, 1988, many of these variations have steep leading edges, rising within an hour or two and trailing off for periods of hours or days. Smaller variations, designated as "Other" in Table 1, have periods of from two to six hours and are probably caused by operation of exhaust fans, the clothes dryer, the heating and air conditioning system, and other occupant related activities. On the basis of these observations and because the SSD system was found to be capable of maintaining radon levels below 74 Bq/m^3 (2 pCi/l), a control band-width of 37 Bq/m^3 (1 pCi/l), a high control point of 111 Bq/m^3 (3 pCi/l), and a low contol point of 74 Bq/m^3 (2 pCi/l), were selected for this study.

The femto-TECH pulsed ion chamber instrument used in this study had a detector sensitivity of 0.49 counts-per-hour per Bq/m^3 (18 CPH/pCi/l) and was operated in a passive sampling mode with a 1.0 h^{-1} air exchange rate to the sensor. An instrument with this detection sensitivity has a counting standard deviation of less than ±25% for a 40 minute count interval at the low control point radon concentration of 74

Bq/m^3 (2 pCi/l). This can be shown to be statistically equivalent to a counting-rate meter with a 0.05 min^{-1} time constant (Friedlander and Kennedy, 1957).

The counting statistical errors for a controller based on a detector sensitivity of 0.49 $CPH/Bq/m^3$ (18 CPH/pCi/l), a detector response time constant of 0.05 min^{-1}, and control points of 74 and 111 Bq/m^3 (2 and 3 pCi/l) are summarized in Table 2. The standard deviations (S.D.) in column five were computed using $(N+1)^{\frac{1}{2}}$ rather than the usual rule-of-thumb $N^{\frac{1}{2}}$, due to the small number of counts involved (Friedlander and Kennedy, 1957). The relative cumulative frequency (r.c.f.) columns in Table 2 represent the probabilities of confounding controller errors due to counting statistics. In this case, it is the probability of obtaining fewer than 24 counts while at the 36 count control point and of obtaining more than 36 counts while at the 24 count control point. It can be seen from these data that the probability of confounding controller errors, due to counting statistics, is quite small. Thus, a radon count-rate meter with these design characteristics should be quite capable of performing as the radon detector for the SSD control system in the test house.

RESULTS AND CONCLUSIONS

The SSD control system was activated in March of 1989. A summary of the data collected in the first two months of operation are presented in Fig. 4 and a typical 24 hour operation is shown in Fig. 5. The vertical axis of the graph in Fig. 4 represents relative number of times the SSD fan was on for a particular hour-of-the-day over the entire 67 day test period. The conclusions that can be drawn from these data are:

1. Because the SSD was only required to operate for 29.3% of the time, the system was more than adequate to maintain the radon levels between the control set-points in the test house.

2. As would be expected, the familiar diurnal modulation on indoor radon levels clearly effects SSD fan duty cycle demand.

3. Because the average radon concentration for the 67 days of controlled SSD operation was slightly less than the mid-point of the control band, there were some periods where the "natural" radon concentrations were below the "on" set-point of the controller.

4. The data clearly demonstrate the feasibility of controlling an active SSD system and the efficacy of the controller design used in this study.

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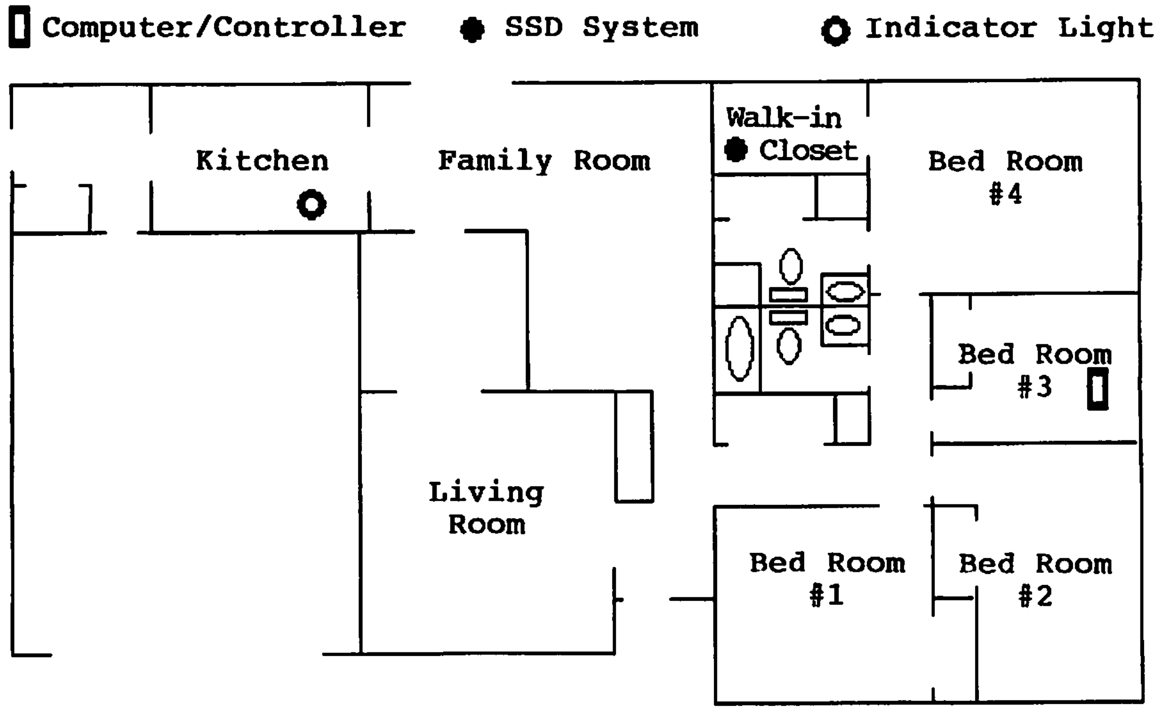
LIST OF CAPTIONS

FIGURES

TABLES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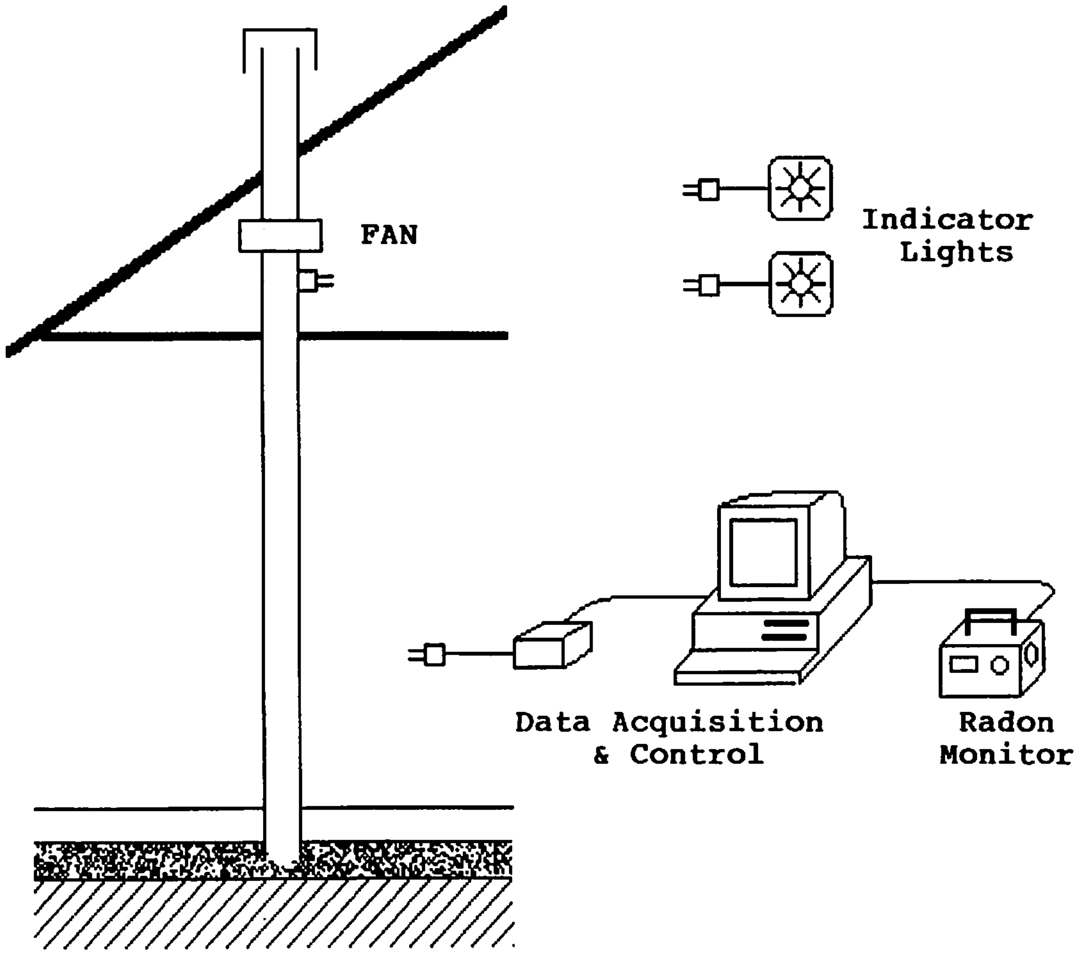
Indicator Light
Kitchen
Family Room
Walk-in
Closet
Bed Room
#4
Bed Room
#3
Living
Room
Bed Room
#1
Bed Room
#2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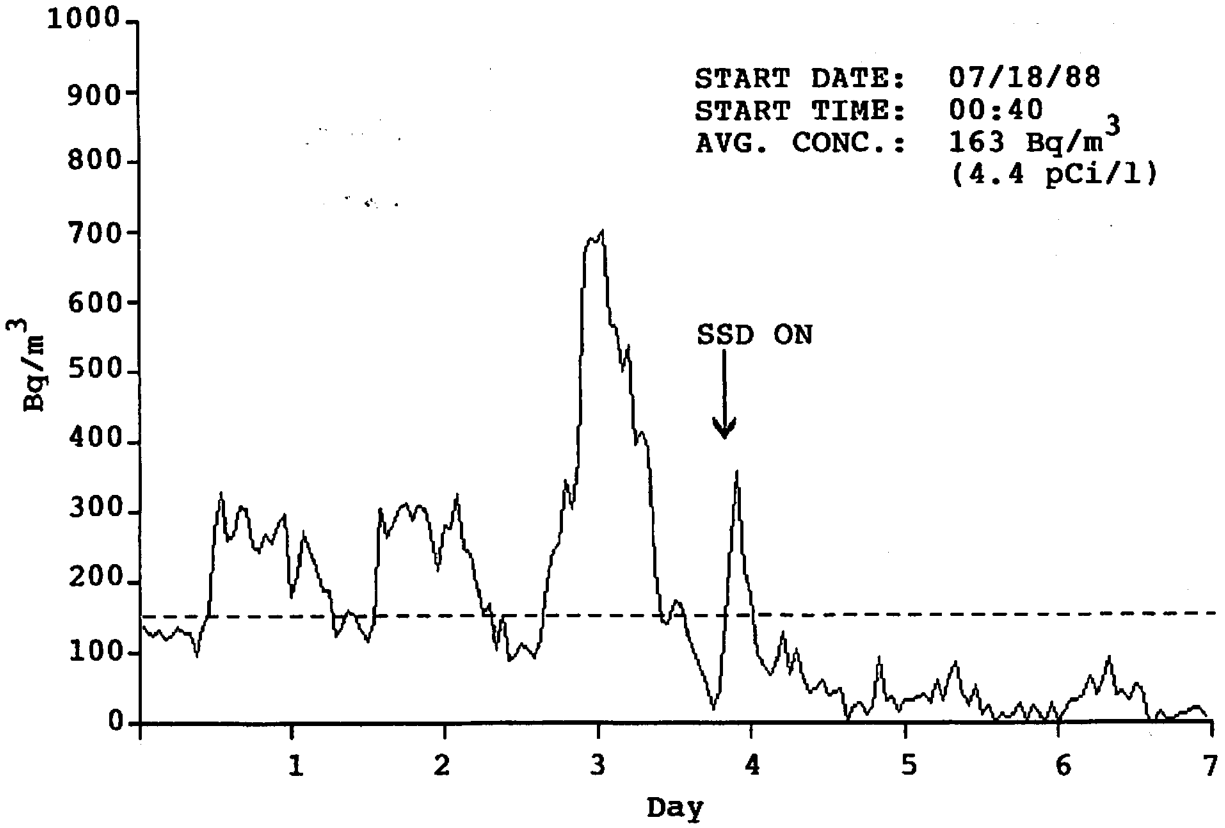
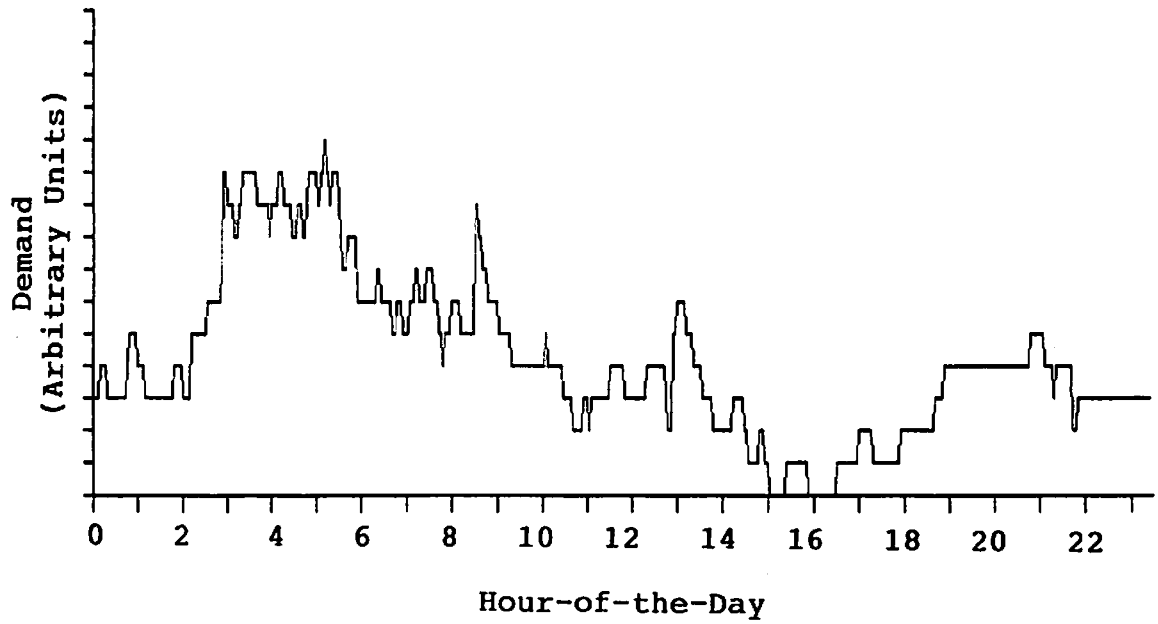
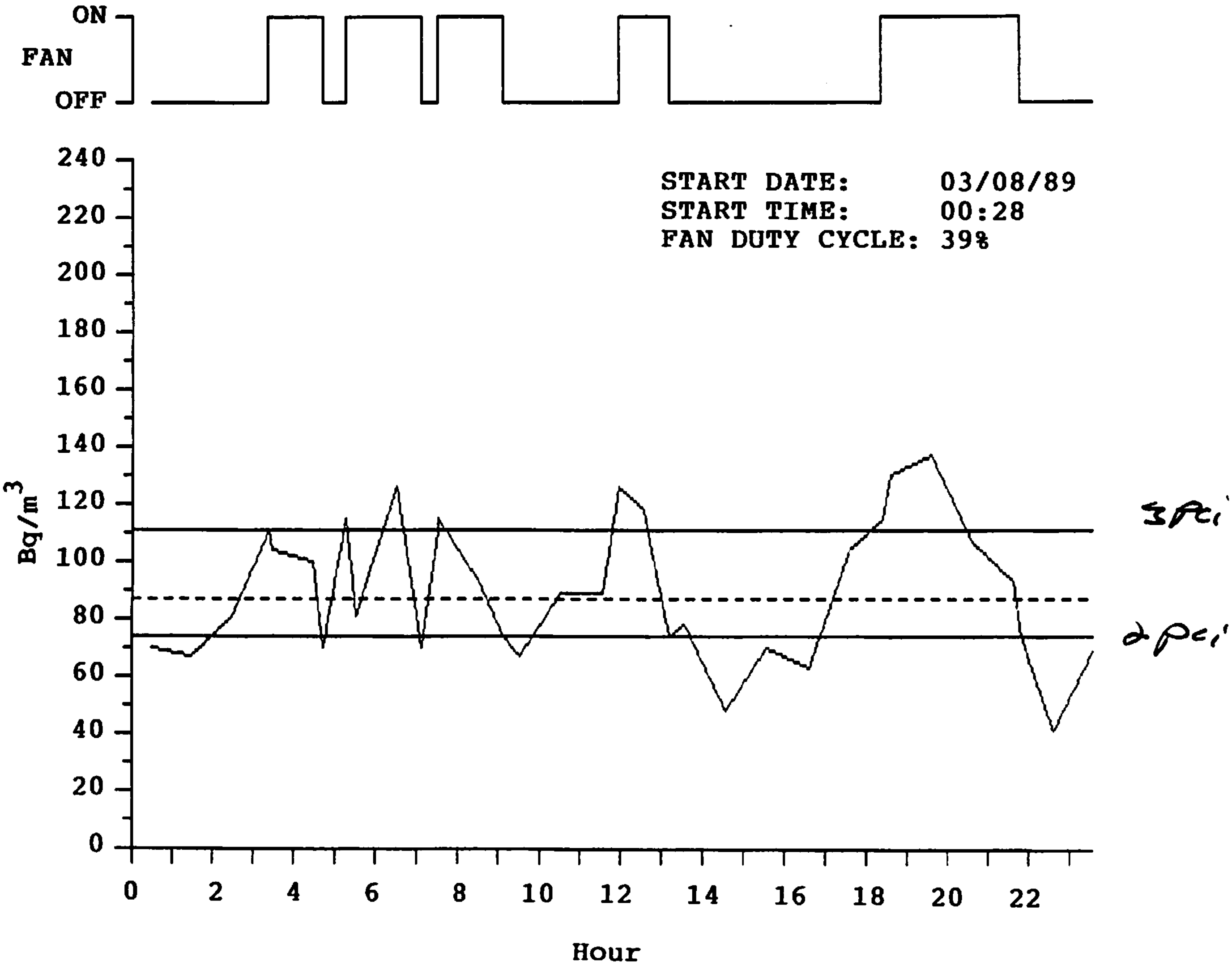
Indicator
Lights
Data Acquisition
& Control
Radon
Monitor



START DATE: 07/18/88
START TIME: 00:40
AVG. CONC.: 163 Bq/m3
(4.4 pCi/l)
SSD ON
Bq/m3
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
Day

AVERAGE CONCENTRATION = 78 Bq/m^3 3/3/89 to 5/9/89
MAXIMUM CONCENTRATION = 211 Bq/m^3 67 Days
MINIMUM CONCENTRATION = 7 Bq/m^3
MAXIMUM ON TIME = 436 min 7 hrs.
MINIMUM ON TIME = 9 min
MAXIMUM OFF TIME = 703 min 11 hrs
MINIMUM OFF TIME = 52 min
AVERAGE FAN DUTY CYCLE = 29.3%




ON
FAN
OFF
240
220
200
180
160
140
120
100
80
60
40
20
0
Bq/m3
START DATE: 03/08/89
START TIME: 00:28
FAN DUTY CYCLE: 39%
0
2
4
6
8
10
12
14
16
18
20
22
Hour
3pci
2pci

CAUSE	AMPLITUDE Bq/m^3 (pCi/l)	PERIOD (hr)
Diurnal	100-200 (3-5)	24
Meteorological	200-1000 (5-25)	12-48
Other (Exhaust fans, etc.)	40-100 (1-3)	2-6

POINT	CONC. Bq/m^3 (pCi/l)	CPH	COUNTS (40 min)	S.D.	r.c.f. (high<low)	r.c.f. (low>high)
Low	74 (2)	36	24	5.0	--	0.0082
High	111 (3)	54	36	6.1	0.0228	--