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THE EFFECT OF PASSIVE CIGARETTE SMOKE ON WORKING LEVEL EXPOSURES IN HOMES

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ABSTRACT

Numerous studies have evaluated the combined effects of cigarette smoke and inhalation of radon decay products on the risk of lung cancer to smokers. In 1988 the National Academy of Sciences concluded that the risk of lung cancer is about 10 times greater for smokers than for nonsmokers at the same Working Level exposures. However, very little attention has been given to the effects of passive cigarette smoke and radon decay product exposures to nonsmokers. Preliminary studies (presented by the authors at the annual conference of the American Association of Radon Scientists and Technologists - Oct. 4 - 6, 1990) showed that even a single cigarette drastically increased the Working Level exposures in homes. Consequently, a cigarette smoker not only increases his/her own risk, but may also increase the risk to all occupants of the same dwelling due to an increase in Working Level exposures.

This paper presents the results of additional measurements to evaluate the effects of typical cigarette smoking patterns in a home. The study simulated the smoking habit of approximately a one pack a day smoker. Continuous measurements were made on radon gas levels, Working Levels, and corresponding equilibrium ratios. Working Levels were found to increase rapidly after lighting of cigarettes and to remain elevated for several hours. Cigarette smoke provides a significant source of aerosols for attachment of radon decay products in homes. Furthermore, the airborne particles from cigarette smoke remain in the air for many hours after the visible smoke has dissipated. Consequently, the increase in Working Levels and equilibrium ratios persists long after the smoking stops.

Since the risk of exposure to radon decay products is also significantly affected by the fraction of unattached polonium-218, then additional studies are recommended to evaluate unattached fractions, as well as aerosol concentrations and particle size distributions. This paper confirms the potential risks to nonsmokers from increases in Working Levels due to passive smoke in homes and points to needs for further studies to document other risk factors.

INTRODUCTION

The connection between exposure to radon decay products and subsequent lung cancers in uranium miners has been studied since the early 1950's. Continuing studies of uranium miners in the United States, Czechoslovakia, Sweden, and Canada have confirmed that uranium miners develop more lung cancers than other types of miners or the general population according to a 1984 report by the National Committee on Radiation Protection and Measurements (1). These studies indicate that about 10 additional lung cancers occur per year for each Working Level Month (WLM) exposure to one million persons. The 1988 report of the Committee on the Biological Effects of Ionizing Radiation (BEIR IV) concluded that lifetime exposures to radon decay products could result in an additional 350 lung cancer deaths for each million person WLM (2). The Environmental Protection Agency estimates that 20,000 lung cancer deaths a year may be caused by exposures to radon decay products in homes (3).

The connection between cigarette smoking and lung cancer is also well documented. Kabat (4) shows that, among lung cancer deaths in five countries, 83 - 94% are due to cigarette smoking by men and 57 - 80% by women. In the United States the Surgeon General reported 106,000 lung cancer deaths among smokers in 1986. The National Academy of Sciences (5) also evaluated the risk to nonsmokers from passive exposure to tobacco smoke, usually from a smoking spouse. This study found an increase in risk of about 34% compared to nonsmokers without exposure to tobacco smoke. Cigarette smoking is clearly the primary cause of lung cancer in the U.S.

Since radon decay products are also clearly a cause of lung cancer, the question arises on how these two causes may combine. BEIR IV concluded that smokers have about 10 times greater risk than nonsmokers for the same WLM exposures. This study determined that the combined effect of cigarette smoke and radon decay products is synergistic. The two effects combine multiplicatively rather than additively. This means the combined effects are worse than the sum of the two risks alone. Recognizing that cigarette smoke drastically increases the radon lung cancer risk to smokers also raises questions about the combined effects on nonsmokers who are passively exposed to environmental tobacco smoke.

EFFECT OF CIGARETTE SMOKE ON INDOOR AIR

A review of studies done by A.C. George (1) indicates that even one cigarette will profoundly increase the concentration of airborne particles. In fact, any human activity will increase the particle concentration several fold over the normal quiescent value. The fumes from cooking, burning of candles or incense, spraying of aerosols, ultrasonic humidifiers, or other similar activities will also increase the concentration of particles in air (1). Conversely, air conditioning or air cleaning systems that remove particulates by filtration or electrostatic precipitation will reduce indoor aerosol concentrations. For example, Moeller (6) indicates that a fan to circulate the air plus a positive ion generator will reduce aerosols and the airborne concentration of radon decay products by 90 to 95 percent. The lowest concentration of airborne particles likely to exist in homes is in the order of 1,000 to 10,000 particles per cubic centimeter.

Any activity that changes aerosol concentrations will also affect the equilibrium ratio between radon gas and radon decay product concentrations. The quantity of decay products in the air and the equilibrium ratio go up as the aerosol concentration goes up. This is because airborne radon decay products are mostly attached to aerosols. Decay products that do not attach to aerosols (the unattached fraction) tend to quickly plateout on walls and other surfaces and are removed from the air. As the aerosol concentration goes up, there are more particles for attachment of radon decay products which then remain in the air longer that those that are unattached.

The quantity of radon decay products in the air is normally measured in terms of Working Levels. Working Levels are commonly measured by collecting airborne dust and associated radon decay products on a filter and measuring the collective alpha particle emissions. Consequently, for a given radon concentration, the measured Working Levels tend to increase with increasing aerosol concentrations and increasing equilibrium ratios, both of which are likely to increase with the introduction of cigarette smoke into the air as noted above. Since Working Levels are the primary measure of exposure to radon decay products and corresponding lung cancer risk, anything that affects Working Levels may also affect estimates of lung cancer risk. Therefore, increases in Working Levels due to cigarette smoke could increase risk of lung cancer for any concentration of radon.

EFFECT OF CIGARETTE SMOKE ON WORKING LEVELS

Initial studies of the effect of cigarette smoke on Working Levels were conducted by Eric Geiger at Radon QC in 1988 (7). A single cigarette was burned in a radon chamber while Working Levels were measured hourly. The Working Levels were found to increase significantly while the radon gas concentration remained about the same. These

observations confirmed the work of other investigators. Namely, cigarette smoke increases aerosol concentrations and Working Levels. Discussion of these observations among the authors in the spring of 1990, however, led to several questions. First of all, what do we know about levels of cigarette smoke and Working Levels in homes? Secondly, what is known about the lung cancer risk to occupants in homes where the Working Levels are affected by cigarette smoke?

Numerous studies are reported that evaluate the combined effects of cigarette smoke and exposure to radon decay products in terms of risk to the smoker. However, little research has been done that considers the effects on nonsmoking occupants of homes due to increased Working Levels attributed to cigarette smoke.

PURPOSE OF THIS STUDY

This paper has three purposes. One is to highlight the fact that cigarette smoking may increase the lung cancer risk from exposure to radon decay products for all occupants of a smoker's home. The second is to present preliminary findings on Working Level measurements related to cigarette smoke in a radon chamber and in typical homes. Thirdly, this paper identifies several needs for further research to answer questions about risks to all occupants related to cigarette smoking in the home or other buildings.

MEASUREMENT TECHNIQUES

This paper presents the results of four sets of measurements. One study was conducted in a radon chamber at Radon QC, two studies were done in the basements of typical homes; one in Nazareth, PA and the other in Bethlehem, PA., a final study was done in the living room of a home in Rockville, MD.

Radon Chamber - The study was conducted in the Red Chamber at Radon QC. This chamber has the highest radon levels of the three chambers available for radon and radon decay product calibrations at Radon QC. The Red Chamber is a walk-in room about five feet by nine feet with an eight-foot ceiling. It is equipped with calibration ports and a viewing window. This chamber normally runs at radon levels from 200 to 600 pCi/L. The radon and decay product levels are constantly monitored with a continuous radon monitor, continuous working level meter, and an alpha spectrometer. The chamber is operated at slight negative pressure and cigarette smoke was drawn in through one of the calibration ports.

Nazareth House - This is a 50 year old wood frame house with a full basement. The basement is approximately 31 feet by 26 feet with concrete walls and a concrete floor. One corner of the basement, about 19 feet by 12 feet, is partitioned off leaving an open L-shaped area where the experiment was conducted. No one in this house smoked cigarettes.

Bethlehem House - This is a one year old house with an open basement area of about 43 feet by 15 feet. The basement has concrete floors and walls. A person in this house is a heavy smoker.

Rockville House - This is a two story colonial all masonry house (cinder block and brick) on a concrete slab without a basement. The experiment was conducted in the living room, which is about 15 feet by 20 feet. The living room is connected by an open archway to an adjoining dining room. The open area of the two rooms is about 15 feet by 35 feet. Entrances to both rooms were closed with bifold doors.

INSTRUMENTATION

In each study measurements of radon gas and radon decay products were made hourly. Working Level measurements were made with an Eberline model WLM-1A. This detector draws an air sample through a filter at a flow rate of 0.10 to 0.18 liters/minute. Alpha particle emissions from the aerosols trapped on the filter are measured with a silicon diffused junction alpha detector. Both radon (radon-222) and thoron (radon-220) decay products are measured. The thoron contribution is estimated by observing the decay rate after the sampler is shut off. Equilibrium between radon and decay products was calculated assuming that only radon-222 was measured. Accuracy of this detector is related to the sampling time, calibration of the flow rate, and calibration of counting efficiency.

Radon gas samples were measured with an Eberline model RGM-3 continuous radon monitor. Air is drawn at 6 liters/minute through a filter to remove particulates before counting alpha emissions with a zinc sulfide phosphor. This instrument will measure alpha emissions from both radon and thoron. However, the 56 second half-life of thoron should prevent very much getting into the detector. We calculated the radon/decay product equilibrium assuming that all the alpha emissions came from radon-222.

Since both the radon gas and decay product monitors are used primarily for determining levels in the radon chambers at Radon QC, these instruments are intercalibrated quarterly with the Environmental Measurements Laboratory (EML) of the Department of Energy.

CIGARETTE SMOKE

Cigarette smoke was introduced into each room by lighting a 100 mm filtered cigarette and allowing it to burn in a cup or ashtray. The cigarettes were not smoked by anyone, but simply allowed to burn by themselves. The cigarettes required about 10 minutes to burn. The burning cigarettes were placed about three feet from an outside wall and were about 12 to 15 feet from the measuring instruments. In the Nazareth and Bethlehem houses a single cigarette was burned each 24 hours. In the Rockville house an attempt was made to simulate a typical smoking pattern of a one pack a day smoker. Approximately two packs of cigarettes were burned in this house between a Friday night and Sunday night of the experiment.

RESULTS

RADON CHAMBER STUDY

The data on the effect of cigarette smoke in the Red Chamber at Radon QC are shown in Figure 1 and Table 1. Two readings collected before introducing cigarette smoke into the chamber showed radon at about 310 pCi/L and Working Levels at about 0.4. This gave an equilibrium of about 14%. After burning one cigarette, the Working Levels went up to 2.2 and the equilibrium went up to 71%. These increases took about four hours due to the time needed for ingrowth of decay products to reach a new equilibrium. The increases also persisted for many hours, such that even 24 hours later the Working Level was still at 1.14 (more than double the original level) and the equilibrium was at 24% (nearly double the initial level). The burning of a second cigarette caused the Working Levels to move up to about 2.4 and stay there for several hours.

The main observation from this radon chamber study was that the smoke from a single cigarette drastically increased the concentration of radon decay products in the air as measured by Working Levels. Furthermore, the increased levels persisted for more than 24 hours, long after any visible evidence of cigarette smoke was gone. Two factors could account for these observations. One is that the radon chamber has a relatively low ventilation rate. Secondly, the air in this chamber is relatively low in aerosol concentration as indicated by the low percent equilibrium before starting the experiment. Since both of these factors could be substantially different in typical homes, the next part of the study was to repeat the cigarette experiment in homes.

NAZARETH HOUSE

The data gathered on the effects of passive smoke in this house are shown in Figure 2 and Table 2. As observed in the radon chamber, after a cigarette was burned the Working Levels and percent equilibrium both increased for several hours. After about six hours both of these effects began decreasing. Presumably these decreases are due to dilution from the normal ventilation in the basement area. Two other observations were noted in this house. One was the normal diurnal variation in radon gas concentrations. The other was that the percent equilibrium increased substantially in the six hours before the burning of a cigarette. This would indicate that some other source of aerosol was introduced into the basement air prior to the cigarette experiment. Since this increase occurred between 9 a.m. and 3 p.m., it follows the typical pattern related to normal daytime activities in a home, although we cannot attribute a specific cause to the increase.

The Working Level monitor in this house also recorded an 8% contribution of thoron decay products to the Working Level measurements. This would account for percent equilibrium values greater than 100%. This observation confirms a 1988 report by the NCRP which notes that indoor air can have significant amounts of the thoron decay product, lead-212 (4).

BETHLEHEM HOUSE

Two cigarettes were burned in the basement of this house at a 24 hour interval as noted in Figure 3 and Table 3. After the first cigarette, both the Working Levels and the percent equilibrium increased as noted in the Nazareth House. However, the Working Levels began decreasing within three hours. The percent equilibrium continued to increase for six hours. After burning a second cigarette on the next day the Working Levels dropped, although there was a general increase in the percent equilibrium. The decrease in Working Levels may be attributed to the decrease of radon concentration by a factor of two in the twelve hours following the cigarette burning.

This house also had a 13% contribution from thoron decay products to the Working Level measurements. Therefore, the lowest equilibrium value was 62%. Several times the equilibrium ratio went over 100%. The data in Table 3 (Continued) show that during the night of July 3-4, 1990, the equilibrium went up to 121%. We cannot account for this increase, although it would appear to be related to an increase in aerosol concentration. The overall high levels of percent equilibrium in this home could be due to regular cigarette smoking by an occupant. Since the percent equilibrium began increasing after 6 p.m., the increase could be due to smoking in the early evening hours.

ROCKVILLE HOUSE

The first observation of note in this house is that the radon gas levels varied widely during the 65 hours of the study, as shown in Figure 4 and Table 4. Initial levels of about 8 pCi/L at midday on Friday, January 11, 1991, rose to a high of about 22 pCi\L on Saturday morning and gradually decreased again to about 2.1 pCi\L on Sunday afternoon. We believe this ten-fold variation in radon levels was likely due to changes in weather conditions. On Friday morning a new wet snow fell on already snowcovered and frozen ground. The wet snow then changed to heavy rain during the day on Friday, while the outdoor temperatures increased from about 30 up to 40 degrees Fahrenheit. The clouds cleared on Saturday with cooler temperatures and sunshine through Sunday.

The wide variation in radon levels during this experiment also serve to highlight two other factors regarding radon measurements. One is that any readings taken during the day on Friday would have shown unusually high radon levels that are probably not typical for this house. This is another indication that short term measurements of a few hours, or even 24 hours, may give radon levels that are not representative of average conditions. The other factor has to do with how well charcoal canisters measure radon when the levels vary widely during the exposure period. Eight open-face charcoal canisters were placed in pairs around the living room for 72 hours to measure radon during the same time as the continuous radon monitor. The two canisters next to the continuous monitor gave an average reading of 4.4 pCi/L compared to an average of hourly readings of 7.69 pCi/L. Apparently, the canisters were affected more by the radon levels at 2 to 4 pCi/L during the last 24 hours of exposure than the levels of 8 to 20 pCi/L during the first day of exposure. Another observation of note also was that the six canisters placed nearer to the outside walls of the living room gave readings of 12 to 27 percent higher than the canisters near the inside wall next to the continuous monitor. Therefore, placement of canisters can also affect the readings substantially.

The times and the number of cigarettes burned are given in Table 4. We began lighting cigarettes on Friday evening to represent smoking after dinner and during the evening such as might occur while watching television. One or two cigarettes were lighted in the morning as typical of someone having a cigarette after breakfast. No other cigarettes were burned during the day on Saturday. Eight cigarettes were burned between 7:15 pm and 9:15 pm that night. On Sunday, six cigarettes were burned near noontime and another ten that evening to conclude the experiment. At most times, two cigarettes were burned at the same time to represent two people smoking together.

As in the other homes, both the Working Levels and the percent equilibrium increased significantly following the burning of each cigarette. These parameters remained

elevated for three to six hours after each group of cigarettes. The effects persisted longer when more cigarettes were lighted in a short time, such as was done in the evenings during this study. The percent equilibrium values varied from a low of about 20 up to a high of about 70 after the introduction of cigarette smoke into the air. The lowest equilibrium values occurred in the morning hours around five or six am. The Working Level values also increased after each cigarette lighting even though the radon levels were falling for most of the study after midnight on Friday.

DISCUSSION AND CONCLUSIONS

Both the radon chamber experiment at Radon QC and the measurements in the basements and living areas of typical homes showed that cigarette smoke leads to a significant increase in Working Levels and percent equilibrium. To the extent that Working Levels are an indicator of health risk from exposure to radon decay products, the increases observed in this study raise important questions about the increased risk to nonsmokers due to the presence of passive cigarette smoke. Most studies have focused on the increased risk to smokers related to combined effects of cigarette smoke and radon decay products. We suggest that further studies also consider the possibility of increased risk to nonsmokers in the home of a smoker. The risk to occupants of a home with radon at EPA's guideline level of 4 pCi/l could be quite different in the home of a smoker in comparison to a home with no smokers.

The question also arises about the increased risk to smokers. Since cigarette smoke significantly increases Working Levels and percent equilibrium, then wherever a person is smoking these parameters are affected. That is to say that smokers create an environment around them of increased Working Levels wherever they are. Therefore, smokers not only inhale cigarette smoke, with corresponding risks, but also they inhale an atmosphere of increased radon decay product concentrations at the same time. Perhaps this is a contributing factor to the increased risk of lung cancer to smokers.

For those who conduct Working Level measurements, these studies also indicate that technicians making such measurements should not smoke. Otherwise, the Working Level readings may reflect smoking habits of the technician, or other occupants of a home, rather than natural Working Levels. These studies also highlighted the need to consider other sources of lung cancer risk in homes, namely the contribution from thoron decay products.

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NEEDS FOR FURTHER STUDY

These studies were intended to demonstrate that passive cigarette smoke affects home occupant's exposures to radon (and thoron) decay products. We understand that increases in aerosol concentration may also reduce the unattached fraction of polonium-218 and that may reduce the intake and retention of decay product alpha energy. We did not measure unattached fractions. We also did not measure aerosol concentrations or particle size distribution. For a better assessment of potential health risks from passive smoke further studies should consider measurements of home ventilation rates, aerosol concentration, particle size distribution, and unattached fractions, as well as radon gas concentration, Working Levels, and percent equilibrium.

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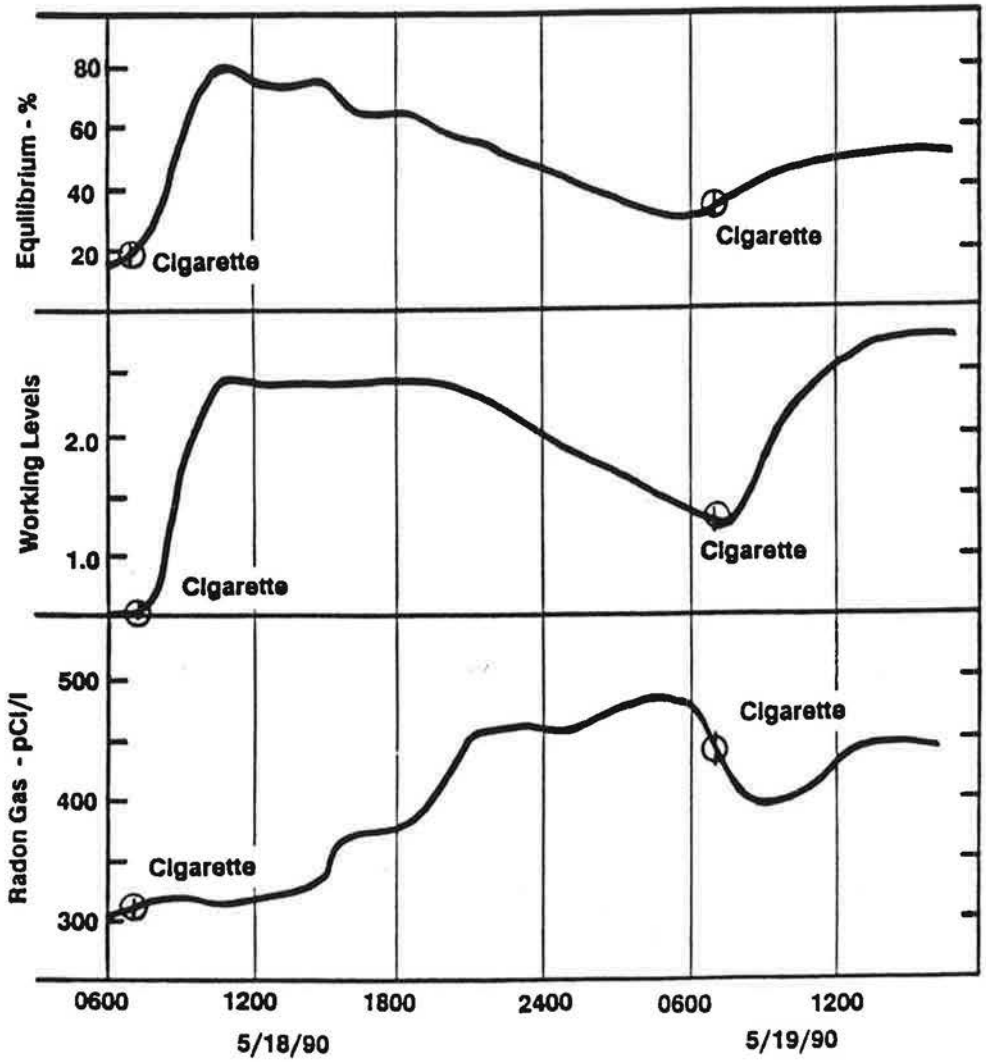

Figure 1. Effect of passive smoke on working levels - Red Chamber, Radon QC

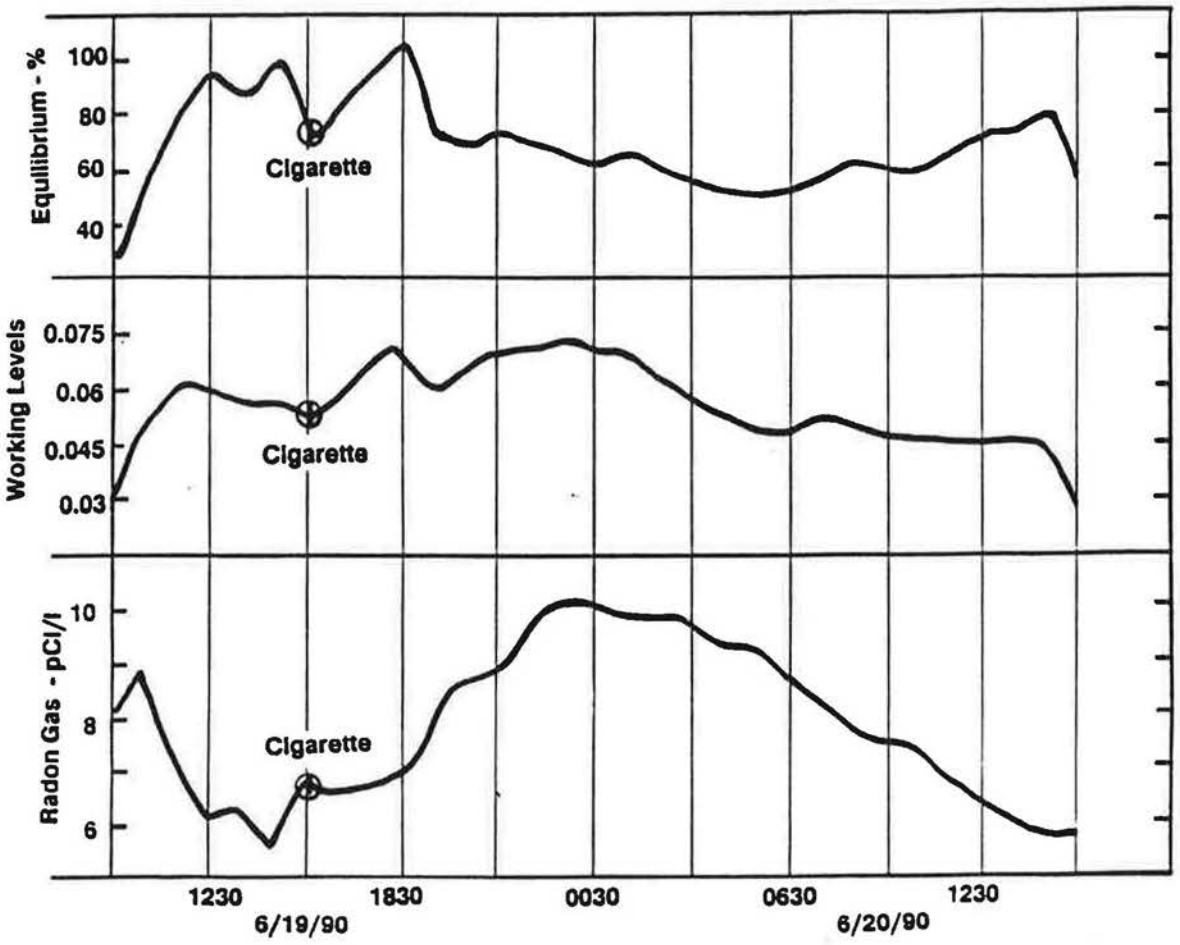

Figure 2. Effect of passive smoke on working levels - Nazareth House

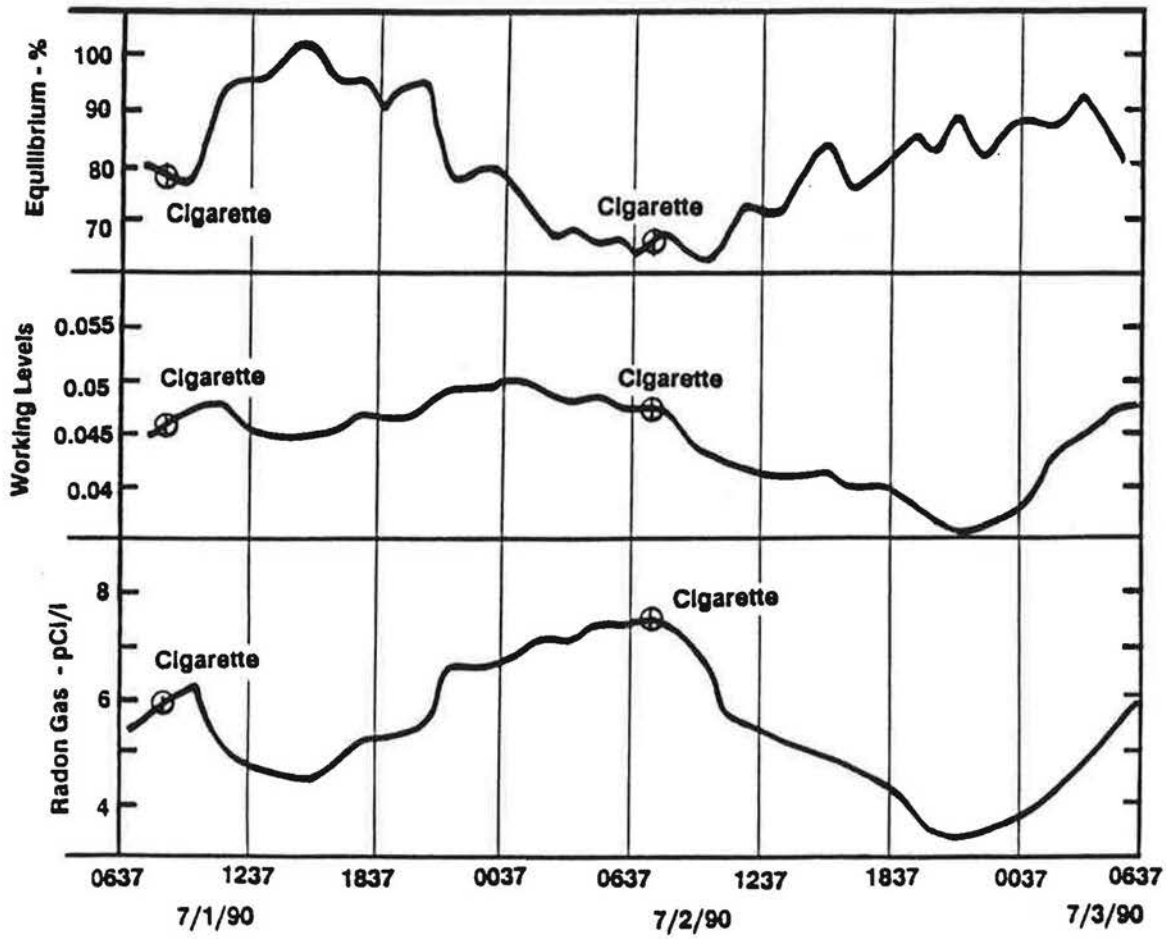

Figure 3. Effect of passive smoke on working levels - Bethlehem House

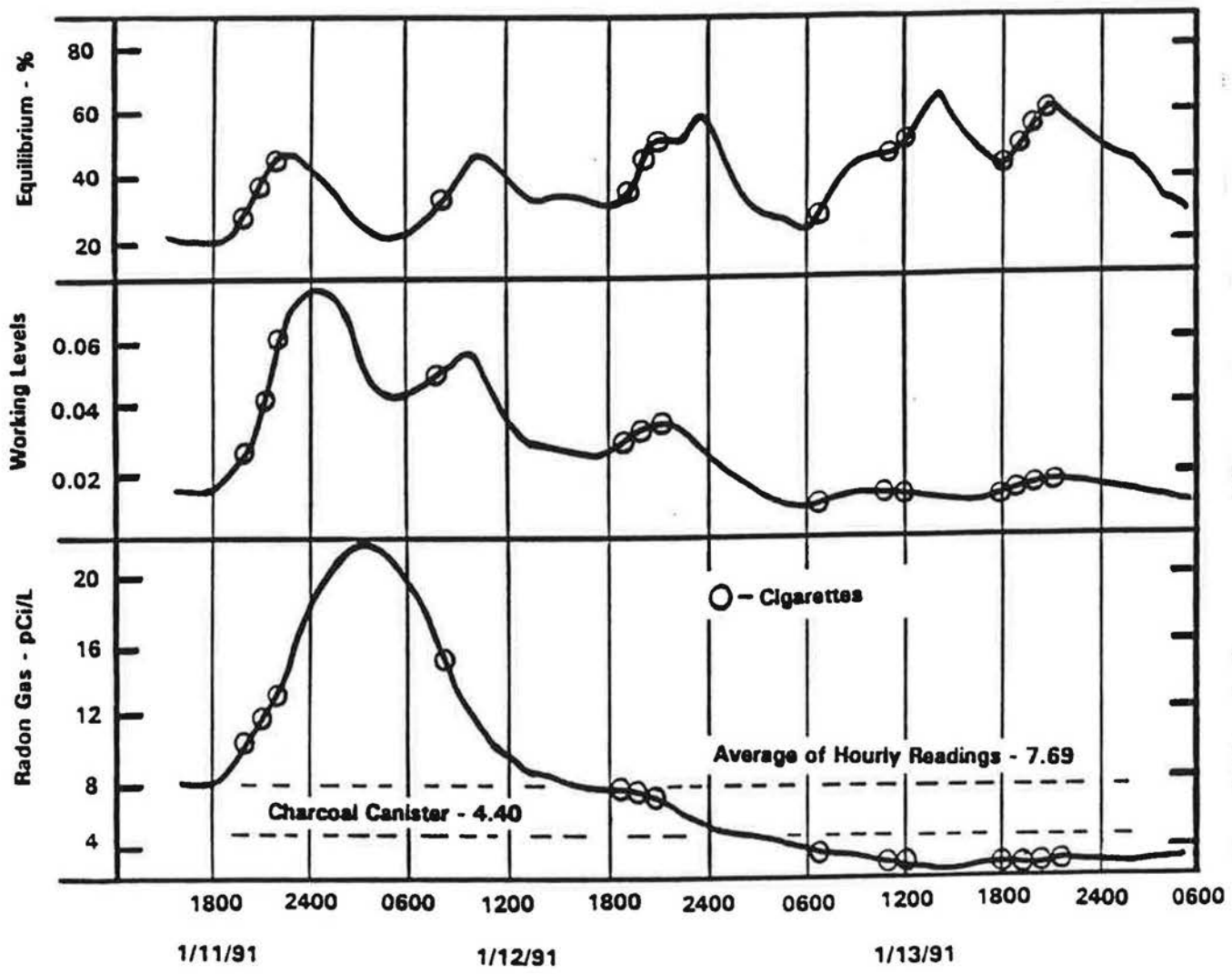

Figure 4. Effect of passive smoke on working levels - Rockville House

TABLE 1. EFFECT OF PASSIVE SMOKE ON WORKING LEVELS - RED CHAMBER - RADON QC

	Time	Radon Daughters WL	Radon Gas pCi/L	Equilibrium %
5/18/90	0600	0.45	304	15
	0700	0.44	317	14
	0705	Burned One Cigarette*		
	0800	0.57	318	18
	0900	1.34	323	41
	1000	2.02	319	63
	1100	2.23	314	71
	1200	2.13	320	67
	1300	2.17	328	66
	1400	2.14	322	66
	1500	2.10	328	64
	1600	2.11	382	55
	1700	2.14	374	57
	1800	2.14	376	57
	1900	2.14	378	57
	2000	2.14	432	50
	2100	2.09	455	46
	2200	2.01	457	44
	2300	1.90	455	42
	2400	1.78	457	39
5/19/90	0100	1.67	457	37
	0200	1.58	465	34
	0300	1.48	469	32
	0400	1.39	473	29
	0500	1.30	476	27
	0600	1.22	479	25
	0700	1.14	473	24
	0705	Burned One Cigarette*		
	0800	1.13	409	28
	0900	1.52	397	38
	1000	2.92	398	48
	1100	2.11	410	51
	1200	2.23	423	53
	1300	2.34	442	53
	1400	2.42	440	55
	1500	2.42	450	54
	1600	2.45	451	54

* Marlboro 100 Filter Cigarette

TABLE 2. EFFECT OF PASSIVE SMOKE ON WORKING LEVELS - NAZARETH HOUSE

	Time	Radon Daughters WL	Radon Gas pCi/L	Equilibrium %
6/19/90	0930	0.021	7.43	28
	1030	0.050	8.87	56
	1130	0.058	7.01	82
	1230	0.058	6.13	95
	1330	0.053	6.24	85
	1430	0.054	5.48	99
	1530	0.050	6.86	73
	1530	Burned One Cigarette*		
	1630	0.054	6.59	82
	1730	0.063	6.66	95
	1830	0.069	6.72	103
	1930	0.057	7.77	73
	2030	0.061	8.61	71
	2130	0.066	8.74	76
	2230	0.067	9.59	70
	2330	0.071	10.13	70
6/20/90	0030	0.066	10.16	65
	0130	0.066	9.66	68
	0230	0.060	9.74	62
	0330	0.057	9.66	59
	0430	0.052	9.24	56
	0530	0.049	9.24	53
	0630	0.049	8.70	56
	0730	0.050	8.33	60
	0830	0.050	7.77	64
	0930	0.047	7.48	63
	1030	0.046	7.40	62
	1130	0.047	6.70	70
	1230	0.046	6.24	74
	1330	0.045	6.07	74
	1430	0.046	5.69	81
	1530	0.030	5.74	52

* Marlboro 100 Filter Cigarette

TABLE 3. EFFECT OF PASSIVE SMOKE ON WORKING LEVELS - BETHLEHEM HOUSE

	Time	Radon Daughters WL	Radon Gas pCi/L	Equilibrium %
7/1/90	0537	0.044	5.17	85
	0637	0.044	5.56	79
	0737	0.046	5.66	81
	0837	0.047	6.16	76
	0837	Burned One Cigarette*		
	0937	0.048	6.26	77
	1037	0.050	5.99	83
	1137	0.049	5.14	95
	1237	0.045	4.80	94
	1337	0.045	4.67	96
	1437	0.045	4.48	100
	1537	0.045	4.48	100
	1637	0.045	4.76	95
	1737	0.049	5.14	94
	1837	0.048	5.35	90
	1937	0.048	5.20	92
	2037	0.051	5.40	94
	2137	0.052	6.64	78
	2237	0.051	6.57	78
	2337	0.053	6.64	80
7/2/90	0037	0.053	6.80	78
	0137	0.052	7.00	74
	0237	0.050	7.40	68
	0337	0.050	7.06	71
	0437	0.050	7.42	67
	0537	0.050	7.31	68
	0637	0.048	7.46	64
	0737	0.050	7.41	67
	0737	Burned One Cigarette*		
	0837	0.048	7.30	66
	0937	0.042	6.81	62
	1037	0.041	6.13	67
	1137	0.041	5.48	75
	1237	0.038	5.30	72
	1337	0.038	5.16	74
	1437	0.037	4.84	76
	1537	0.039	4.64	84
	1637	0.035	4.59	76
	1737	0.035	4.47	78

* Marlboro 100 Filter Cigarette

TABLE 4. EFFECT OF PASSIVE SMOKE ON WORKING LEVELS - ROCKVILLE HOUSE

Time	Radon Daughters WL	Radon Gas pCi/L	Equilibrium %	Cigarettes* Burned
1/11/91				
1600	0.016	8.10	20	
1700	0.016	7.83	20	
1800	0.016	7.64	21	
1900	0.017	9.00	19	
2000	0.026	10.3	25	1
2100	0.044	11.0	40	3
2200	0.061	13.1	47	3
2300	0.074	14.9	50	
2400	0.077	17.5	44	
1/12/91				
0100	0.076	21.0	36	
0200	0.073	22.2	33	
0300	0.057	22.0	26	
0400	0.044	22.1	20	
0500	0.044	21.5	20	
0600	0.043	20.0	22	
0700	0.042	17.5	24	
0800	0.048	14.7	33	2
0900	0.057	12.9	44	
1000	0.055	11.3	48	
1100	0.048	10.2	47	
1200	0.036	9.40	39	
1300	0.028	9.20	31	
1400	0.029	8.49	34	
1500	0.026	7.99	33	
1600	0.027	7.84	35	
1700	0.026	7.75	33	
1800	0.023	7.85	29	
1900	0.027	7.97	33	3
2000	0.034	7.50	45	3
2100	0.035	7.00	52	2
2200	0.033	6.49	51	
2300	0.030	5.42	56	
2400	0.028	4.83	58	

* Winston 100 Filter Cigarette