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Cigarette Smoking Increases Radon Working Level Exposures To All Occupants of the Smoker's Home

By

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Abstract

The 1988 National Academy of Sciences report on radon health risks evaluated the combined effects of radon exposures and cigarettes on the lung cancer risk to smokers. This report showed that the risk of lung cancer is about 10 times greater for smokers than for nonsmokers at the same Working Level exposures. In 1986, the Surgeon General reported that 106,000 lung cancer deaths occurred among smokers. Therefore, the health risks of cigarettes alone or in combination with radon exposures are well recognized.

What has not been studied is the effect of cigarette smoke on the Working Levels in homes that increases the exposure to radon decay products to all occupants, both smokers and nonsmokers. Preliminary studies in a radon chamber at Radon QC showed that the smoke from a single cigarette increased the Working Levels by a factor of five within four hours. Furthermore, the Working Levels remained at an elevated level for more than 24 hours. The equilibrium ratio of radon decay products to radon gas also went from about 14% up to 71%, with a slow decrease over 24 hours. Similar studies in the homes of a smoker and nonsmoker confirmed the laboratory observations. The studies in homes also showed the effects of thoron decay products.

The data from these preliminary studies indicate that the smoke from even a single cigarette drastically increases the quantity of radon decay products in the air and the Working Level exposure to all occupants of the home. Therefore, cigarette smoking not only increases lung cancer risk to smokers, but may also increase the risk to children and other nonsmokers in the home. Further research in typical homes is proposed to examine the effects of cigarette smoke on Working Levels, equilibrium ratios, ventilation rates, aerosol concentrations, particle size distribution, and unattached fractions of radon decay products.

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 (NCRP 1984). 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 - 1988) concluded that lifetime exposures to radon decay products could result in an additional 350 lung cancer deaths for each million person WLM. The Environmental Protection Agency estimates that 20,000 lung cancer deaths a year may be caused by exposures to radon decay products in homes.

The connection between cigarette smoking and lung cancer is also well documented. Kabar 1989 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 (NAS 1986) 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 (NCRP 1984) indicated that one cigarette will profoundly affect 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 (NCRP 1988). Conversely, air conditioning or air cleaning systems that remove particulates by filtration or electrostatic precipitation will reduce indoor aerosol concentrations. 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 increases 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. 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, not a single reference could be found that considered 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 three sets of measurements. One study was conducted in a radon chamber at Radon QC and two studies were done in the basements of typical homes; one in Nazareth, PA and the other in Bethlehem, PA.

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 lady in this house is a heavy smoker.

In each study measurements of radon gas and radon decay products were made hourly. The effects of burning a single 100 mm filtered cigarette were observed for 24 hours. 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.

Results and Discussion

Radon Chamber Study

The data on the effect of cigarette smoke in the Red Chamber at Radon QC are shown in Fig. 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 Fig. 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 aersol 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 report by NCRP 1988 which notes that indoor air can have significant amounts of the thoron decay product, lead-212.

Bethlehem House

Two cigarettes were burned in the basement of this house at a 24 hour interval. 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(Cont.) 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.

Conclusions

Both the radon chamber experiment and measurements in the basements of typical homes showed that cigarette smoke leads to an 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 significant 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. These studies also highlighted the need to consider other sources of lung cancer risk in homes, namely the contribution from thoron decay products.

Need for Further Study

These studies were intended to demonstrate that passive cigarette smoke affects home occupants 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, aersol

concentration, particle size distribution, and unattached fractions, as well as radon gas concentration, Working Levels, and percent equilibrium.

References

National Academy of Sciences, Health Risks of Radon and Other Internally Deposited Alpha-Emitters; Committee on the Biological Effects of Ionizing Radiation, BEIR-IV; National Academy Press, Washington, D.C. 1988.

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National Council on Radiation Protection and Measurements, Radon, Proceedings of the 24th Annual Meeting, March 30-31, 1988; 7910 Woodmont Ave., Bethesda, MD; August 1, 1989.

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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
5/19/90	0000	1.78	457	39
	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 3 (Cont.)

Effect of Passive Smoke on Working Levels

Bethlehem House

	Time	Radon Daughters WL	Radon Gas pCi/l	Equilibrium %
7/2/90	1837	0.034	4.20	81
	1937	0.032	3.70	86
	2037	0.029	3.49	83
	2137	0.029	3.25	89
	2237	0.028	3.46	81
	2337	0.029	3.43	85
7/3/90	0037	0.032	3.62	88
	0137	0.033	3.87	85
	0237	0.036	4.14	87
	0337	0.043	4.65	92
	0437	0.043	5.16	83
	0537	0.046	5.68	81
	0637	0.049	5.85	84
	0737	0.049	6.30	78
	0837	0.048	6.30	76
	0937	0.050	5.75	87
	1037	0.051	5.32	96
	1137	0.048	5.30	91
	1237	0.044	4.86	91
	1337	0.040	4.28	93
	1447	0.035	3.69	95
	1537	0.033	3.14	105
	1637	0.030	2.89	104
	1737	0.027	2.81	96
	1837	0.022	2.70	81
	1937	0.023	2.18	106
	2037	0.023	2.02	113
	2137	0.023	2.05	112
	2237	0.024	1.99	121
	2337	0.027	2.32	116
7/4/90	0037	0.029	2.78	104
	0137	0.033	3.30	100
	0237	0.035	3.59	97
	0337	0.040	3.98	100
	0437	0.044	4.56	96
	0537	0.045	4.45	101

Figure 1

Effect of Passive Smoke on Working Levels

Red Chamber - Radon QC

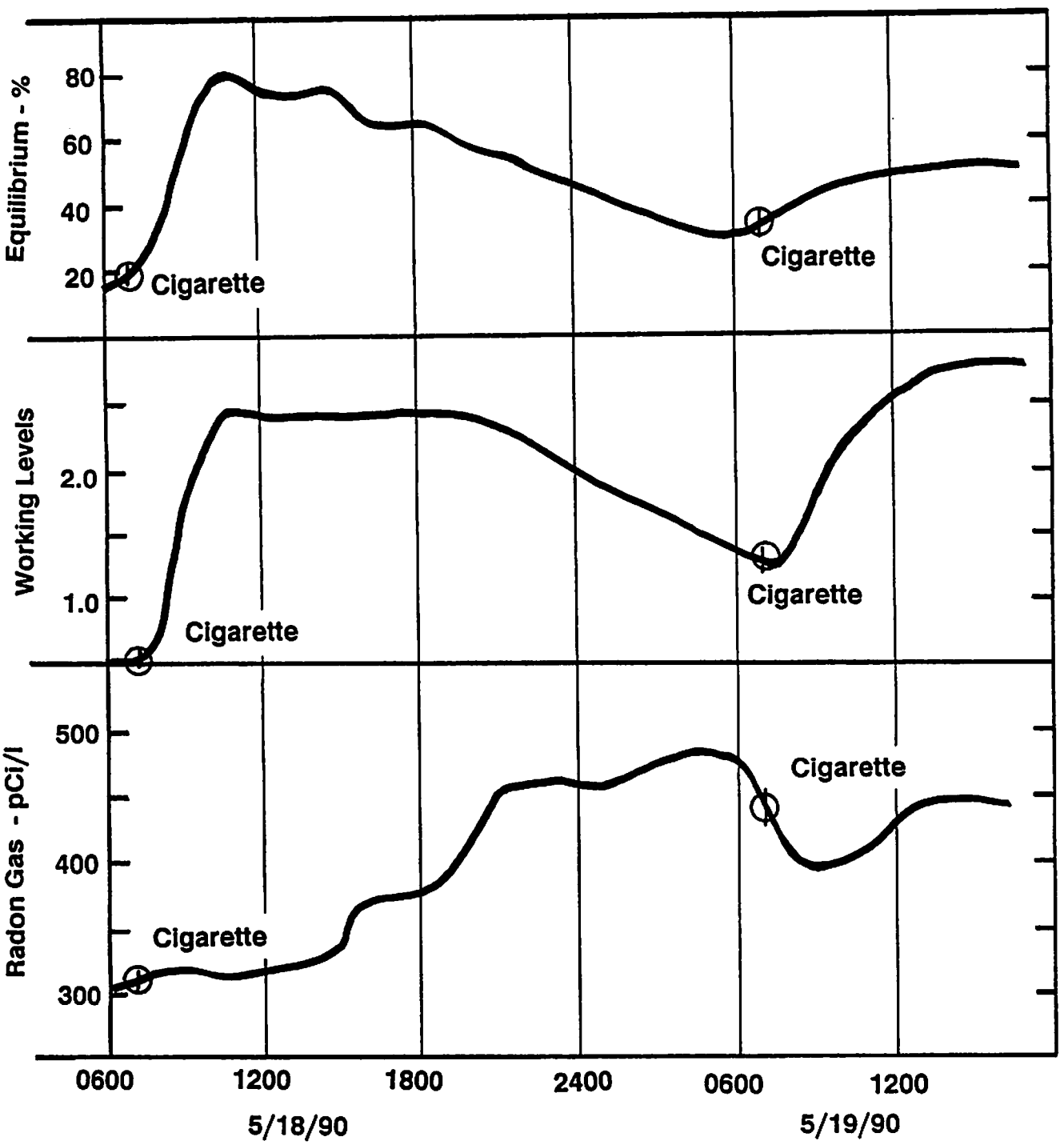

Figure 2

Effect of Passive Smoke on Working Levels

Nazareth House

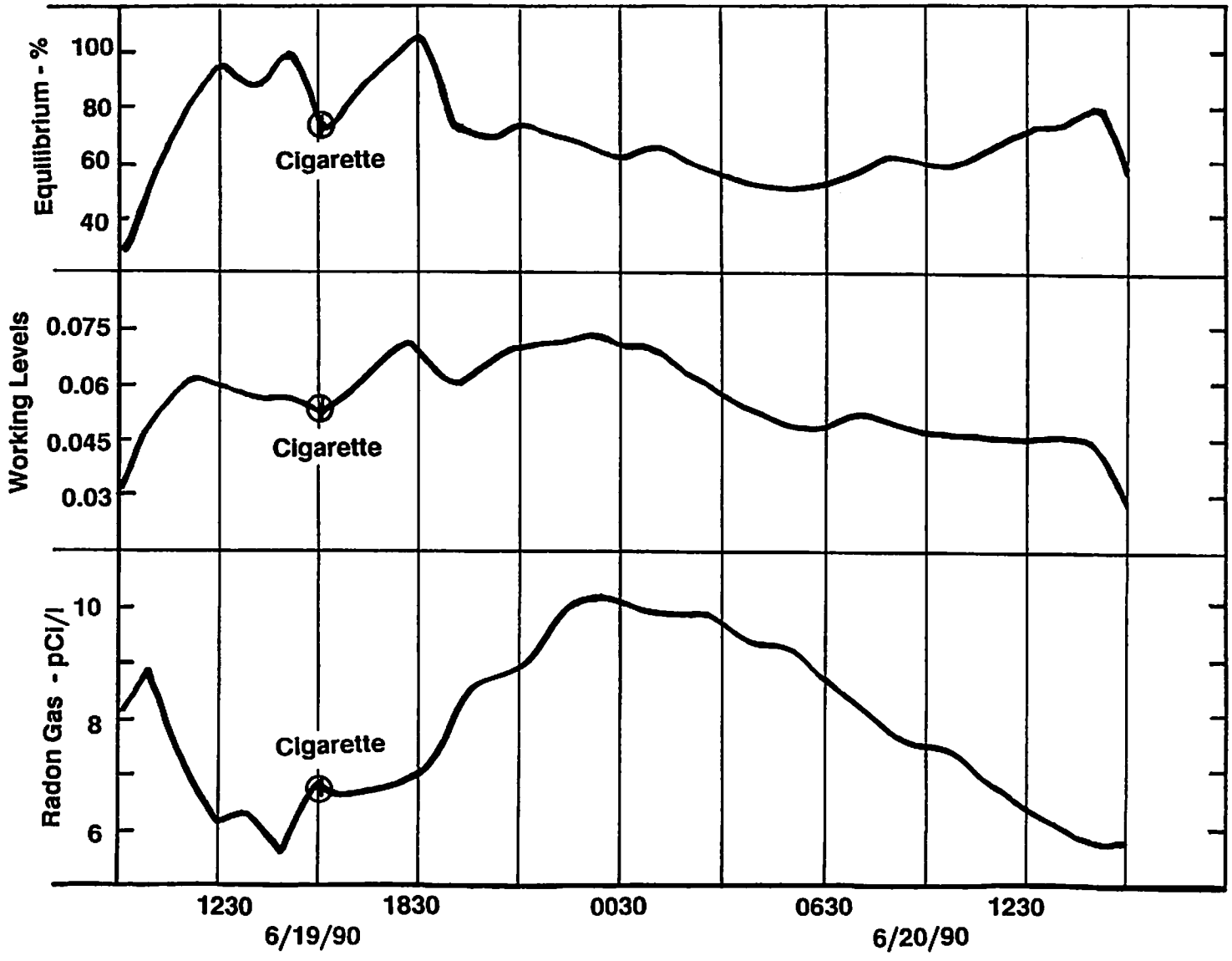

Figure 3

Effect of Passive Smoke on Working Levels

Bethlehem House