1995_06

OCCUPANT RADON EXPOSURE IN HOUSES WITH BASEMENTS

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ABSTRACT

This study compares basement and main-level radon exposure based on bi-level week-long radon measurements, occupancy and activity data collected in normal use during heating and non-heating seasons in a geographically-stratified random sample of about 600 Minnesota homes, in response to critiques of radon measurement protocol.[3] Basement radon (Rn1) (M=4.5, SD=4.5) and main level (Rn2)(M=2.9, SD=3.4) correlation was 0.8 (p=.00), including seasonal variation. In a 101-house subsample where Rn1 >=4.0 pCi/L and Rn2 <=3.9 pCi/L, maximum household exposure in basements was 1162 pCiHrs (M=120, SD=207), main-level 2486 pCiHrs (M=434, SD=421). In same households, persons with most basement-time maxed 100 *hrs* (M=13, SD=23), persons with most main-level time maxed 160 hrs (M=79, SD=39). Basement activities show two patterns, 1) member used it for personal domain, e.g. sleeping, and 2) household used it for general activities, e.g. TV or children's play. Basement occupancy justifies measurement of radon in the lowest livable housing level.

INTRODUCTION

The US Environmental Protection Agency (EPA) has recommended that homeowners measure radon in their houses on the lowest livable level to determine the possible need for action aimed at reduction of radon concentrations. Because that level may be a basement, some scientists believe that protocol exaggerates radon risk. They cite studies showing that radon is found in greater concentrations in basements, and that people spend little time there (For documentation, see footnote 3). Health professionals in Minnesota have raised questions about the regional applicability of those studies. Factors of climate and cultural background have long been considered the causes of regional differences in structure types and occupancy practices in homes throughout the United States (Beyer, 1965). These differences may influence exposure of occupants to indoor pollutants, including radon. This paper reports an investigation of housing and household characteristics, and week-long concurrent dual-level activity diaries and normal-use radon measurements in a geographically-stratified random sample of Minnesota homes, designed to inform policy decisions.

STUDY METHODS AND MATERIALS

To capture both workday and non-workday variations, the investigation examined household occupancy during seven consecutive days, and concurrent radon measurements during normal operation of the house in distinct seasons. Validity of seven-day measurements, ease of placement, and ease and cost of mailing were factors

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2 The authors wish to acknowledge the financial support and guidance of EPA Region V, the Minnesota Department of Health, and the Department of Design, Housing, and Apparel of the University of Minnesota, and the 31 Minnesota Extension Service County Educators who co-operated in the study.

3 Nero, A. V., Letter (and attachments) to the Radon Program Review Panel, Environmental Protection Agency, 401 M Street, SW. Washington, DC 20460: December 10, 1991.

considered in selecting Air-Chek "tea-bag" radon measuring devices.[4] The final plan of study began in November, 1993 and included two waves of testing, one in the heating season , which extends from September 15 to April 15, and the other during the non-heating season, with analysis of data to end March 31, 1995. A random sample of 20 potential participants was drawn from telephone listings in each of the 87 Minnesota counties, half used in each wave. Each potential participant was sent an initial letter explaining the survey and inviting them to respond by pre-paid card, to mark whether they were Minnesota residents occupying a primary dwelling with a basement suitable for use (not a mobile home, apartment, or cabin) and whether or not they agreed to complete the study. When only 170 agreed to participate by letter (47 negative responses, 31 undeliverable letters returned), telephone follow-up was added.

Co-operation was enlisted from Minnesota Extension Service (MES) County Educators who co-signed the letters of invitation sent in the first wave in 73 of the 87 counties and issued local publicity during the entire study. The survey interviewer's call elicited the respondent's immediate attention, and created an opportunity to ask questions about radon and the study. Follow-up telephone contact was attempted until eight participants in each county agreed to participate. If, during the entire survey, fewer than eight in a county were eligible and agreed to participate, that many additional participants were sought from the sample in an adjacent county. About a week after mailing the packets, interviewers contacted the participant to verify arrival and condition of the packet, and if possible, a week later when detectors should have been near completion. At each call to the participant, interviewers volunteered to answer questions and encouraged placement and prompt mailing of detectors, and regular diary entries. Answering machine messages could be left on second and subsequent contacts.

Each respondent who agreed to participate was mailed a packet containing two free radon measurement devices to place in their home for seven consecutive days, a household and housing characteristics questionnaire to complete, a diary in which to record types and duration of activities performed by household members on the two lowest levels of their house during the test week, and a first-class post-paid pre-addressed padded return mailer. The researchers logged in completed materials, sent the detectors to the laboratory for analysis, and sent the participants the confidential radon results.

In late June increasing humidity during week-long exposure began to cause failures in analysis. In those cases, when diaries had been completed, participants were offered replacement diaries and detectors for fall use, and the replacement data were used. Respondents who had detector packages damaged or lost in the mail were also offered replacements. The protocol for this study, intended to capture radon exposure in the household during normal week-long activity, differed from EPA short-term test protocol. To reduce confusion, recommended procedures for this study were fixed to the outside of the detector envelopes, printed in the diaries, and discussed by interviewers. Concise, well-placed, easily-read directions to participants are important in any study. In this study, additional verbal instructions, repeated at each opportunity, produced the greater response rate with the least error. EPA-approved protocol for quality control in this investigation included duplicate detector placement, blanks and spikes. Placement and results of detectors were logged by county only, in accordance with University of Minnesota Human Subjects in Research guidelines.

RESULTS

<u>Radon Measurements</u>

Valid radon measurements in the basements (Rn1) of the 631 Minnesota homes where basement measurements were obtained ranged from below the level of detection (0.3 pCi/L) to 44.4 pCi/L ($\underline{M}$ = 4.5, $\underline{SD}$ = 4.5). The lowest level of detection of Air Chek "tea-bag" detectors is 0.3 pCi/L. When measurements were below the level of detection, 0.2 was entered in the data, as an estimate of background concentration. See Fig. 1. In the 634 Minnesota homes where measurements were obtained on the next higher housing level (Rn2) valid radon measurements ranged from below the level of detection to 34.3 ($\underline{M}$ = 2.9, $\underline{SD}$ = 3.4). See Fig. 2. A scatterplot of

[4] From Air-Chek, Inc., Box 200, Arden, NC 28704-9901

measurements on both levels of the same houses indicates a linear relationship, with the best-fit line passing through the intercept and the x=30:y=18 intersection. Correlation between pairs was 0.785 (p=.000). See Fig. 5.

Radon was measured in lesser amounts in spring and summer, especially on the main level. That trend might be attributed to measurement protocol calling for normal operating conditions, which could include open windows on the main level of the house, although in nearly 70% of the houses tested, respondents reported the presence of air conditioning equipment. In five of the nine months, the mean of the basement measurements exceeded the EPA action level of 4.0 pCi/L, with three other months where the mean was at or above 3.5 pCi/L. The mean of level 2 measurements exceeded 4.0 pCi/L in only one month. Radon concentrations were not uniformly greater in the basement than on the main level. The percentage difference (100*[(Rn1-Rn2)/Rn2)]) between pairs of detectors in the same house varied from -7.2 % to 21.2% (M = 1.5%, SD = 2.8%, n = 618). In 15.4% of the cases Rn1 measured less than Rn2, in 4.2% of the cases they were equal, and in about 40% of the cases Rn1 concentration was more than double that of Rn2. Correlation between the pairs of detectors was 0.785 (two-tailed significance .000).

Housing Characteristics

Housing and household characteristics of the survey participants were gathered in two segments, 1) a questionnaire of general descriptions of the household, and 2) a diary of time each person in the household spent in each room of the two lowest housing levels, engaged in active, moderate to quiet activities, or sleeping. All housing and household characteristics discussed in this paper are limited to the 589 cases where both diary and radon measurements were adequate, or to a 101-case subset. Means were substituted in a few cases for non-critical missing data, such as age or income of occupants.

Houses in the study varied in age from less than one to over 100 years. About one-third were built before 1940, another one-third built between 1950 and 1969, with one-third built since 1970. About 40% of the houses were single story structures, and about 36% were two or three story houses, all with closed basements. Walk-out basements were listed in 14% of the houses. Other types, such as split level, split entry, etc., comprised 16% of the houses in the study. Occupants were asked to assess the condition of their house and mechanical systems, where 1 stood for poor, 2 for fair, and 3 for good condition. In a scale computed of occupants' assessment of the condition of the structural characteristics of sample, houses were rated "good " in 515 (87%) of the cases, "fair" in 67 (12%) of the cases, and "poor" in 7 (1%) of the cases.

Crawl spaces were present in 151 (27%) of the cases. The crawl space opened to the basement in 129 cases (22% of the total houses, or 85% of the crawl spaces). Crawl space walls were constructed of concrete block in 83 (14%) of the cases, poured concrete in 30 (5%) of the cases, stone in 24 (4%) of the cases, and wood in 13 (2%) of the cases. The floors of the crawl spaces were covered with concrete in only 31 (5%) of the cases, with 117 (20%) of them remaining open earth. Respondents reported basement sumps and cracks in the basement floors in 290 (49%) cases.

Forced air heating systems were used in 63 (77%) of the houses, with 111 (19%) using resistance or hot water heat. Space heaters or gravity furnaces were present in 8 (3%) of the houses. Gas was the main space heating fuel in these houses, 270 (46%) used utility or natural gas and 98 (17%) used propane. Fuel oil in 111 (19%) of the cases, electricity in 65 (11%), and wood in 44 (8%) comprised the other most often used heating fuels. Air conditioners were reported in nearly 70% of the houses, with central units in 267 (45%) of the cases and window units in 144 (24%) of the cases.

One hundred ninety-one houses (32%) contained fireplaces. Gas fuel was used in water heaters in 279 (47%) cases, clothes dryers in 118 (20%) of the cases, and kitchen ranges in 158 (27%) of the cases. In eight cases, gas clothes dryers were not vented to the outside. Thirty houses (5%) had heat recovery ventilators, mostly in middle to older homes. Exhaust appliances, such as bath and kitchen fans, and clothes dryers exhausted to the outside, were listed in 549 (93%) of the homes. One hundred ninety-one, about one-third, reported three of these appliances, and slightly more than one-third had two. The one-third of the houses built since 1970 contained 57.4% of the three-exhaust group; correlation of house age and number of exhaust appliances was 0.39 (p=.000).

One group of basements were fitted for family use, with television rooms, etc. , while another group provided bedrooms and other spaces for individual use. The main kitchens were located above ground level in almost all cases, but facilities for preparation of meals and snacks were present in many basements. Recreation or playrooms were located in the basement in 147 (25%) cases, and on level 2 or higher in 12 (2%) cases. Rooms were designated as laundry rooms in basements in 244 (41%) cases (although 356 households performed laundry or clothing care in the basement during the test week), and in upper levels in 69 (12%) of the cases.

Bedroom numbers varied from one to six, with three (39%) and four (26%) the most common. One bedroom was reported in the basement in 142 (24%) of the cases, and two in 54 (9%) of the cases. Two houses had three bedrooms, and one had four. No rooms named as bedrooms were found in the basement of 390 (66%) of the cases. Bathrooms in the houses varied from one to four. Three hundred seventeen (54%) listed only one bathroom, 222 (38%) listed two, 49 (8%) listed three and 1 (<1%) listed four bathrooms. Over one-third of the houses, 213 (37%), listed one or more basement bathrooms, with 129 households using them for showers or baths during test week. Twelve houses (2%) without basement bathrooms reported basement showering during the week.

Household Characteristics

The households in the study varied from one to ten members in size (M=3.0, SD=1.4). Occupancy data were collected for up to seven people per household, with fewer than ten households having additional members. Children in day care facilities, service personnel, and occasional visitors were not recorded. Almost half (170 or 46%) of household members in this sample reported having incomes over $50,000 and 165 (28%) have 16 or more years education. Correlation between income and education was 0.43 (p=.000). Female headed households, where no male head was present, represented 11% of the cases. Of those 67 cases, 36 women (6% of the total sample) were 65 years or older, with a mean age of 57 years. Seventeen percent of the male household heads in the sample were 65 years or older with a mean age of 49.6 years. Telephone interviewers did not actively solicit those 80 years or older, although many elderly did return invitation cards, and many filled out excellent, detailed descriptions of their week's activities. The respondents were not asked if they owned their own homes.

Activity types

Each activity any family member was reported performing in the basement during the test week was recorded, and assigned a category, active, quiet to moderately active, or sleeping. Thus, time in the basement spent building a wood fire would be recorded both as active time, and as a descriptive variable assigned to fire building and fuel collection. Both are important data, but colinearity between the variables could be expected in multiple regression analysis.

In the 589 households where complete data are available, the types of activities practiced are extremely broad. Those practiced most often included laundry and clothing care (356 cases or 61%), utility (239 cases or 41%), and cleaning (204 cases or 35%). Families used the space for TV, quiet games or talking in 184 (32%) cases, children's play in 105 (27%) cases, sleeping in 87 (15%) cases, and office or school work in 86 (15%) cases. Household repairs were conducted in 91 (16%) cases, and occupants exercised in 78 (14%) cases. Other activities included crafts, such as painting, quilting, machine sewing and woodworking in 65 (11%) cases, meal preparation or eating meals in 40 (7%) cases, pet care in 36 (7%) cases, and computer activity in 31 (6%) cases. Wood fire support, such as stacking fuel, building or tending the fire, was practiced in 28 (5%) cases.

Basement use follows two general categories, 1) when the space is used for a specific activity by most or all of the family, or 2) when the space is the domain of one or more individual members of the family. Rooms in the basement are named as family or recreation rooms more often when they are used by greater numbers of family members (114 in family use, 22 in individual use), family rooms (128 to 43), and activities such as crafts are listed for family uses (49 for family, 8 for individuals), children's play (70 for family, 25 for individuals). More solitary activities are listed in individual spaces, such as bedrooms or workshops. Computers were located in only 18 of the family-use spaces, and in 33 of the individual-domain spaces. The activity types and occupancy times may have implications for health and safety policy decisions, in that specific activities suggest the presence of particular pollutants and pollutant interactions, and where duration of exposure may be significant. These data may inform decisions about ventilation standards now being proposed in Minnesota, and commercial ventures of many kinds throughout the cold-climate regions of the northern plains.

Duration of occupancy

The number of minutes the household diary reported each person spending on each of the two housing levels, engaged in each of the three exertion categories, was calculated and recorded, making a subtotal of six occupancy categories per person. When duration or level of exertion was questionable in a diary, the data that reflected the lesser risk was recorded. Only seven household members could be recorded in the diary but fewer than ten (<0.2%) households had eight or more members. Eleven households reported commercial daycare facilities operated in the home, serving from 8 to 12 additional children, whose time in this house is not recorded in these data. The hours all household members were reported occupying the basement (M =27.1, SD=45.2, Maximum = 468.3), the main level (level 2) (M =173.0, SD = 107.6, Maximum = 753.4), and total house occupancy (M=199.9, SD=124.2, Maximum=771.4) were computed. The average number of hours spent per person in each household in the basement (M=8.5, SD=13.3, Maximum=117.1) and on the main level (level 2) (M=63.8, SD=35.1, Maximum=166.65) was calculated. In each house, the person who spent the most time in the basement (M=17.1,SD=25.7, Maximum=144.0) and the person who spent the most time on the main level (level 2)(M=76.5,SD=38.1, Maximum=167.5) were calculated.

Exposure

The concentration of radon measured in the basement multiplied times the total hours in the basement yields the total picoCurie hours (pCiHr) of basement exposure (M=122.8, SD=306.2, Maximum=3409.2). The radon measured on the main level (Level 2) multiplied times the total hours spent on that level yields the pCiHr exposure on that level (M=550.8, SD=883.9, Maximum=11651.7). The sum of those numbers is the self-reported radon exposure of the household (M=6731.6, SD=1096.6, Maximum=15033.5). Each person's radon exposure was also calculated, and the greatest exposure in basements (M=82.2, SD=218.7, Maximum=2874.9) and main level (level 2) noted (M=238.8, SD=334.7, Maximum=3032.7).

The portion of the total exposure due to basement exposure (M=.18, SD=0.21, Maximum=0.99) is determined, and in those houses where 50% of the radon exposure to the family can be attributed to basement exposure, there are some interesting conditions. Nearly 60% of these houses had sumps or wells in the basement, as compared to about 50% of the total group. These houses were, in general, about the same age as those in the total sample, but there were fewer one-, two-, and three-story houses with closed basements, and more open structures, such as split-level or split-entry types. Although 70% of these houses had basement bedrooms, only 52% were used for sleeping during the test week. In 70% of the basements there were bathrooms finished, and 54% of the individuals reported bathing or showering during test week. Television, reading and conversation in their basement occupied 67% of the families during test week, the family's children played there in 22% of the cases, and 19% exercised vigorously. Over half spent time cleaning those spaces, and 36% were involved in storage activities (several took out or put away holiday decorations). Three commercial childcare facilities, serving 6 to 13 children, are located in these basements, but listing only family members, not these children, was expected in this study.

101 Borderline Houses

In the 131 houses where radon measures 4 pCi/L or greater on both housing levels, or the 370 houses where radon measures 3.9 pCi/L or less on both housing levels, there is no difference between mitigation recommendations resulting from changes in protocol. Mitigation becomes an issue in approximately 15% of these homes where radon measures 4.0 pCi/L in the basement and measures 3.9 pCi/L or less on the next higher level. In this group of houses, a subsample of 101 homes where diary data is complete, the radon in the basement varies from 4.0 to 24.5 pCi/L (M=6.89, SD=3.71), and radon on level 2 varies from below the level of detection to 3.9 pCi/L (M=2.26, SD=1.19). In those households, the greatest exposure of the family in the basement is 1161.6 pCiHr (M=119.9, SD=206.7), and greatest family main level (level 2) exposure is 2486.3 pCiHr (M=433.9 SD=421.2).

Because one person often spends a great deal more time in the basement than the rest of the family, Fig. 6 gives a graphic comparison of the average of family member's basement radon exposure (M=38.9, SD=66.0, Maximum=387.2) to the basement radon exposure of the individual member of the family who spends the most time in these borderline basements (M=80.2, SD=139.2, Maximum=708.8). Reference markings have been included to show the comparison of 4 pCi/L for 40 hours, comparable to the standard work week. Because the amount of time spent in the basement is critical to deciding whether these borderline houses should or should not be mitigated, these data are significant.

DISCUSSION AND CONCLUSIONS

When considering policy implications of these data, it is crucial to remember three facts, 1) these are self-reported occupancy data, that may not reflect complete occupancy time, 2) radon measurements were not performed according to EPA worst-case protocol, and 3) 4.0 pCi/L is not a health-based standard. Therefore, no actual assessment of health risk can be derived from these numbers.

Many other categories of analysis of these data excite interest. Houses where basements are heated for human comfort during occupant activities may have different radon distribution than houses where preventing freezing of utilities is the main concern, so if the sub-sample measured in the heating season were split, with those who occupy the basement only for activities such as building a fire or retrieving stored products in one portion, and households performing more diverse activities, the radon concentrations on the two levels might produce an interesting contrast. Other occupancy analyses that could prove interesting might include: 1) descriptives of age and occupancy time of the person who uses the basement most in each family, 2) relationships between family size and age and basement use, 3) seasonal differences in activities, 4) the relationships between house age and various other structural and equipment characteristics, 5) rural/urban differences in housing characteristics and 6) the use of basement bathrooms related to presence of other bathrooms, and age and sex of users. Each of these manipulations could produce information for policy decisions.

This study of a random sample of homes shows that people in Minnesota do live in their basements for a significant amount of time. When the basement is suitable for occupancy -- even when some of its characteristics are less than desirable -- families in Minnesota find activities they prefer to perform there. Therefore, when the basement could be lived in, that is the housing level that should be measured for radon.

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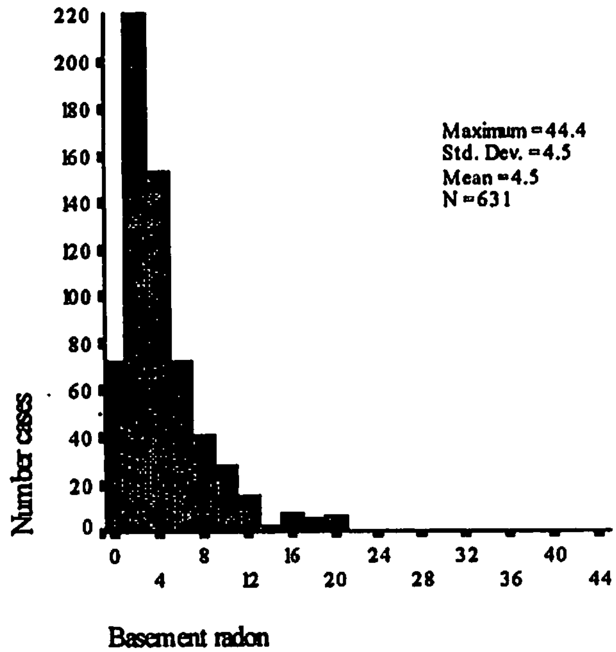

Fig. 1 Radon Measured in Basements of Minnesota Houses

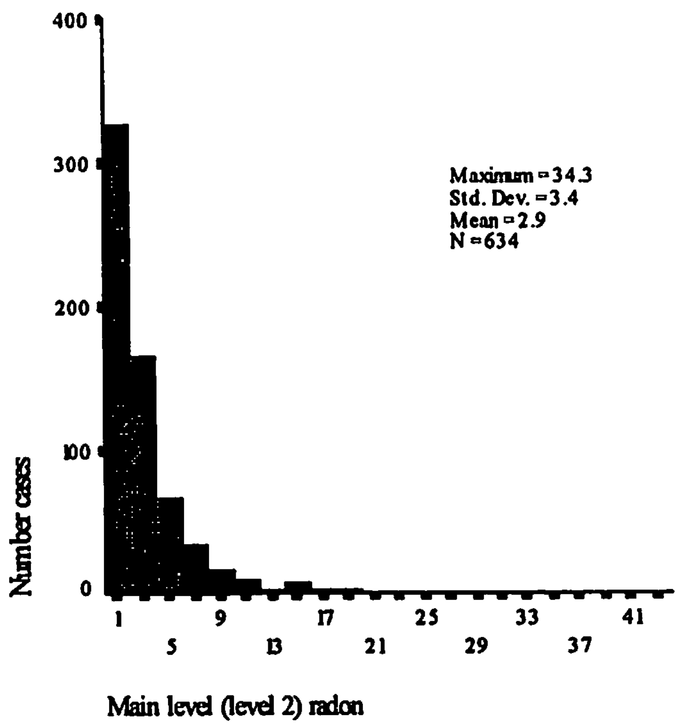

Fig. 2 Radon Measured on Main Level (Level 2) in Minnesota Homes

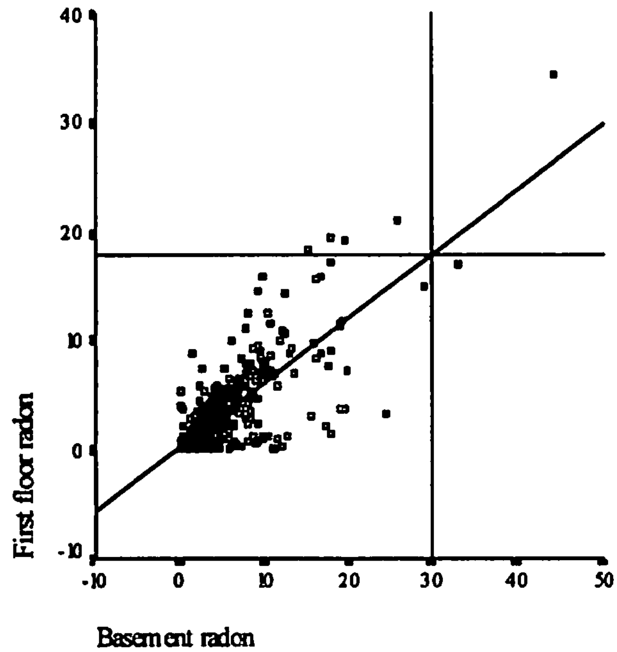

Fig. 3 Scatterplot Comparison of Same-House Basement & Level 2 Radon Measurements With Reference & Best-Fit Markings. Correlation Between Pairs = 0.785 (p=.000). N= 622.

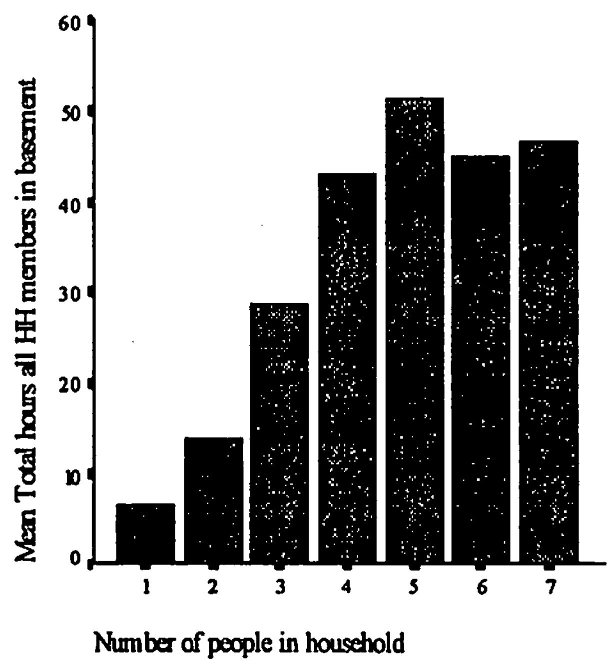

Fig. 4 Relationship of number of people in household to hours spent in basement by entire household. N= 589

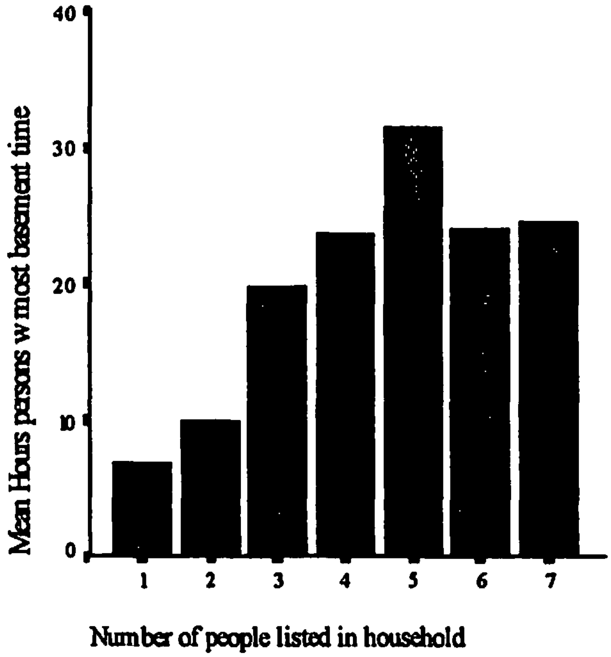

Fig. 5 Relationship of number of people in household to basement occupancy time of the individual spending the most time in the basement. N= 589.

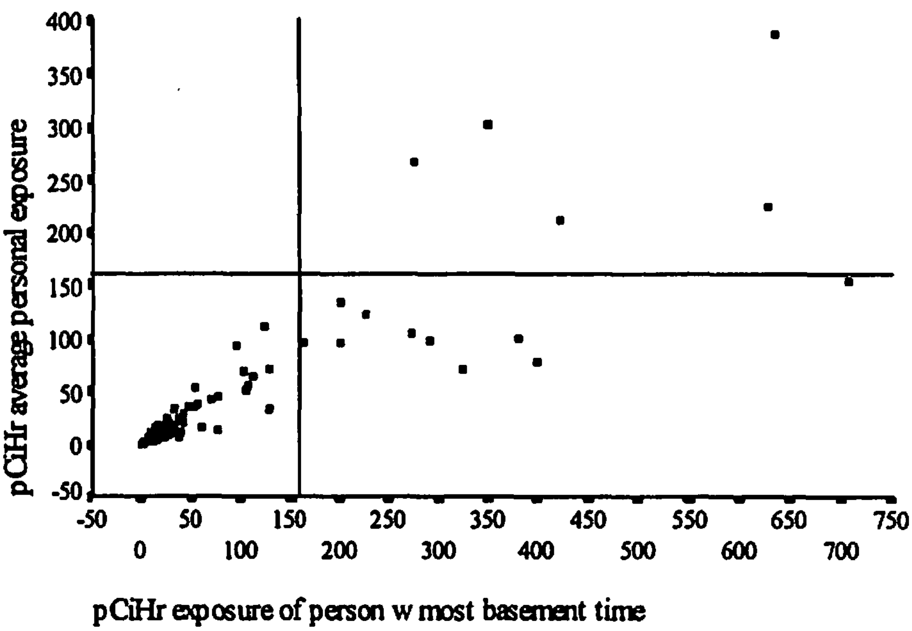

Fig. 6 Relationship of average personal basement radon exposure to that of the basement exposure of the person spending the most time in the basement, in pCiHrs. of houses where main level (level 2) radon measures <= 3.9 pCi/L, and basement radon measures >= 4.0 pCi/L. Reference lines mark 160 pCiHrs (4 pCi/L for 40 Hours).