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NEW INSIGHTS FROM RADON RESEARCH IN INTERIOR ALASKA

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INTRODUCTION

Residents in the interior of Alaska spend a significant amount of time indoors during the colder winter months of the year. Achieving suitable indoor air quality in an economic manner, is important to maintain a healthy indoor environment. Indoor radon gas concentrations are a problem for some areas in the Fairbanks basin. Consequently a good radon public awareness program is necessary to help owners make informed choices about radon reduction and reduction strategies. Information about indoor radon concentrations was gathered from 57 Fairbanks area homes in this study. This paper is a review of highlights of a thesis by the first author, Mr. Jack Schmid and was presented to the University of Alaska Fairbanks in the partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering, in May 1999.

Tracer gas tests were used to estimate ventilation rates. The gases used included carbon dioxide. Differential pressures across the building envelope were correlated with indoor temperature differentials. It was demonstrated that there are homes in the hills surrounding Fairbanks with elevated levels of indoor radon and results show that subslab depressurization radon mitigation systems were effective. It is also clear that radon control is most economic when done during initial construction. Map 1 shows the Fairbanks area, a river bottom surrounded by an amphitheater of hills, known as the Tanana/Yukon uplands. Latitude is 64° 47' N, and Fairbanks is only 150 miles from the Arctic Circle. Winters are long and cold and are in the climate zone known as subarctic continental, typified by those long cold winters and short warm summers.

Several previous studies of the radon conditions and occurrence in Interior Alaska set the backdrop for this research study. A survey conducted by the Department of Transportation and Public Facilities of the State of Alaska, focused specifically on buildings in the hills surrounding Fairbanks. It was conducted in 1987 and 38 houses from the data sample were at or above the 229 meter contour interval (700 feet). Detection devices used in this particular survey were activated charcoal detectors (Air-Chek) and were exposed for durations between 24 and 96 hours. They were also deployed in the month of July (Hawkins et al., 1987). In 1989, an EPA ten state survey was conducted which included Alaska. The Alaska portion was performed jointly with the Alaska Department of Geology and Geophysical Surveys and is referred to as the ADGGS survey. There were 204 houses from the Fairbanks area included in this sample and all measurements were made with charcoal detectors, exposed for 48 hours. These detectors were placed in the winter in the lowest livable level of a home (Nye and Kline, 1990).

The ADGGS survey was a telephone random survey and the subjects of the survey were responsible for deployment of the detectors as directed. They also reported the type of terrain around their house. Terrain categories were: hill tops or ridge crests as the highest, steepest, shallow soil category; steep slopes; then gradual slopes, less than 10°; and then flat areas and riparian bottom lands. There were actually no specific criteria defining each category and the determination of the site was left up to the subjects. This survey showed that the highest incidence rate and the highest levels of radon in Interior Alaska, occurred in the Fairbanks uplands and that the steepness and location of the site was an important characterization for the likelihood of radon occurrence.

THIS STUDY AND SOME FURTHER BACKGROUND

The intent of the study was to learn in more rigorous detail, the driving forces operating on a building, which helped to induce radon flow into it. Of course the basic physics follows the law known as Darcy's Law, a law which describes flow through porous media, describing that flow as proportional to the permeability of the media and the magnitude of the pressure gradient. Because of the atmospheric effects, the pressure gradients and determination of the effects of the pressure differences across the shell of the buildings in Interior Alaska are an important investigatory element of this research. Radon transport is suspected to be directly related to ventilation rates and air leakage rates, so stack effect and its determination of soil gas transport is an important process to understand in our climate. Therefore, it was a focus of this research work.

For the Darcy flow of soil gas, the amount of flow can be described in terms of, flow of air, soil gas resistance to that flow, and the differential pressure across the building shell inducing that flow. Atmospheric pressure variations have also been demonstrated to be a factor in driving soil gas into a house under some conditions, and this flow generally follows the time rate of change of atmospheric pressure. Although some of that type of investigation was undertaken in this study, it was not the major focus. It is generally understood from calculations done by the researchers, that temperature driven flow is by far a dominant factor in the movement of soil gas and consequently radon, into a house from the subsoil beneath it.

In order to determine the permeability and the air leakage of the house, a blower door was employed. This blower door uses a fan to induce a large and roughly uniform pressure difference across the building envelope. This enables the measurement of airflow required to maintain that pressure difference. Although there is no simple relationship between the ventilation rate of the building and its air leakage, the Lawrence Berkeley Laboratory infiltration model provides a means of generating specific infiltration and flow rate (Sherman, 1998). Using this model requires the use of the leakage distribution, house height for determining stack factors, wind shielding parameters, and both indoor and outdoor temperatures. Blower door data for this work, were analyzed with software provided by the blower door equipment manufacturer. The software uses the Lawrence Berkeley Laboratory (LBL) model, developed by Max Sherman (Energy Conservatory, 1992). This model estimates an average natural infiltration on an annual basis. House parameters put into the model are the number of stories, the volume of the house, the above grade exposed surface area, and a wind shield factor. Parameters for climatic factors and leakage distribution are entered into the initial program setup and are not among the operator entered parameters at the test site. All of this data acquisition was aimed at finding effective air quality management strategies and mitigation factors that worked in the Fairbanks area.

A QUICK REVIEW OF METHODOLOGIES

Initial background data were collected using two methods. The first was phone contact of home owners who had previously tested their homes with alpha track detectors obtained through the Alaska Cooperative Extension. Records available comprised information of a fraction of purchases of radon test kits from Alaska Cooperative Extension and some information was no longer current. The second method was to solicit home owners in radon prone areas who would allow their homes to be tested for elevated indoor radon levels. Criteria used for house selection was a location in the hills surrounding Fairbanks that had direct communication with underlying soil via a basement, crawlspace, or a concrete slab on grade construction. Other types of houses were excluded from the study.

Two alpha track detectors were provided to each home owner to place in their homes and they were placed during the 1995/96 and 1996/97 heating seasons. Generally the EPA suggested protocol for where to place the tests were utilized. The detectors were typically deployed for ten to twelve weeks during the heating season from October through March. During some of these periods, additional data was available by strategic timing of air leakage tests, blower door tests, and tests of infiltration utilizing tracer gases. In order to fully understand the relationship of temperature and temperature differential induced leakage, outdoor and indoor temperatures were measured simultaneous with the radon and other indoor air quality measurements as well.

In three cases the differential pressure across the foundation slab was measured. This required a very cooperative home owner since penetrations were required in the foundation slab, i.e., drilling through the slab. One particular house which was very intensively monitored, referred to as house R-P, was also unoccupied for about eight weeks during the heating season. This offered the opportunity to take measurements and operate the radon subslab depressurization system which this house had, for investigative purposes without disturbing resident householders. This house provided a very interesting case study and served all the reasonable functions that a research test house would.

RESULTS

Information collected during the winter seasons of 1996 through 1998 from alpha track detectors recording indoor radon concentrations are reported on Table 1. The reporting is done in ranges from less than 4 picocuries per liter, 4 to 20, 20 to 80, and greater than 80 picocuries per liter. Three of the 19 homes which had less than 4 picocuries per liter, incorporated vapor barriers (polyethylene) under the slab, which minimize infiltration routes from the subslab during construction to reduce the radon influx. Three homes with concentrations of 4 picocuries were mitigated for concentrations greater than 30 picocuries per liter.

One result is an indication of how effective the subslab depressurization system is for lowering the radon concentration in a house. Figure 1 from Schmid's thesis shows house R-F with the subslab depressurization system off and on. The large vertical bars indicate the duration during which the fan was off. It's extremely clear that the radon level in the house ascends over about a day, from around 3-5 picocuries per liter to nearly 80 and then levels off. Late in the evening of the second day during which the subslab depressurization was off, the heat recovery ventilator was turned on and it slowly, with some strange cycling, lowered the rate from the approximate starting point of 40 picocuries to about 25-30, after which, on the 12th February, the subslab depressurization system was turned on again and radon levels in the house rapidly fell back down to their previous mitigation levels.

A similar pattern was noticed in other houses that were tested with the fans off and on. In no case when the fan was off, did the concentration of radon not exceed the mitigation level in the house by a factor of more than 10. A subslab depressurization system is clearly an effective mitigation strategy.

Earlier mention was made of the importance of the subarctic continental climate as the driving force of the temperature difference between the indoors and outdoors, and as a factor in increasing radon concentration and radon induction indoors. Figure 2 from house R-P, is a plot of several days when radon concentrations were measured, plotted versus the indoor/outdoor temperature differential. During the period indicated, the indoor/outdoor temperature differential varied from about 34°C to about 43°C and the radon concentration varied in a tightly linear manner with an R^2 variance of 0.54 between 400 and about 700 picocuries per liter.

Radon concentrations were also measured during the summer to indicate how the magnitude of radon induction changes from winter to summer. Table 2 shows three different instances during the summer (or at least the warm period of the year) for two different houses. House R-P for the period 17th May through 14th September 1998 and the house R-L between 14th May and 13th June and again from 19th September through 12th October. Indications are that the average is well below the EPA remedial action level, a maximum of 1.3 picocuries per liter in house R-L during the early summer and the minimum of 0.2 picocuries per liter in house R-L during the autumn test period. Even house R-P which is one of the houses with the highest winter radon concentrations measured, had an average of only 1.2 during the summer months of 1998.

Perhaps one of the most interesting results of this study, occurred in the intensive evaluation of house R-P and is demonstrated in Figure 3, a complex plot of the indoor/outdoor temperature differential. This figure shows that when the temperature differential exceeds 33°C, the basement actually goes negative in pressure with respect to the subslab area. This means that the subslab depressurization system is being overpowered by the outdoor/indoor temperature differential and the mitigation system is virtually ineffective. There are several reasons for this, which will be discussed in the results, but primarily it's due to the fact that the house is extremely leaky above grade, and the pressure differential gets to be so enormous that even the subslab depressurization can't keep the difference greater than a negative pressure. So this house, because of the climate it is in, has double jeopardy and sometimes even the subslab depressurization isn't enough to keep radon out.

Table 1 cited earlier, clearly illustrates that of the homes sampled in the hills around Fairbanks, a substantial fraction have radon concentrations above the EPA remedial action level of 4 picocuries per liter. The proportion of the homes in this category in this most recent study was 52 percent. (Three homes were mitigated in this study to below 4 pCi/L). Nationwide only 6.1 percent of the homes exceed 4 picocuries per liter (BEIR VI, 1999). About 30 percent of the risk attributed to radon exposure, is associated with homes having a concentration greater than 4 picocuries per liter. Many homes in the Fairbanks area have concentrations above 20 picocuries per liter. This recent survey adds confirmation that homes in the hills around Fairbanks have a much higher probability of having elevated indoor radon concentrations than homes in the lower alluvial areas down near the flood plain of the Tanana and Chena rivers.

A result crucial to considerations regarding expenditures for public education, has been included in Schmid's thesis (1999). He makes the statement that "when considering the public education effort to help residents become more aware about radon, it is necessary to look at the investment required. The funds spent on public education are modest compared to the impact it has on the public. Investment in the State of Alaska for radon education is approximately $30,000 per year". In Appendix I of the Benefits and Costs of the Clean Air Act of 1970 to 1990, estimates of the public's value of a statistical premature death avoided ranged from $0.6 to $13.5 million in 1990 US dollars (US EPA, 1997). Efforts to educate the public might avoid about nine cases of cancer over ten years. The cost per life saved for this group educated over a ten year period, is 10 years times $30,000 per year expense, times one-ninth (for one out of the nine lives saved), yielding $33,333 per life saved. This is clearly much less than the public's perceived value of saving a life. These risk calculations are further elaborated in the Schmid thesis. They were based on the radon concentration distribution in the Fairbanks homes, the number of people mitigating, and a linear dose response for the effects of radon. The estimate considers only those homes with greater than 40 picocuries per liter to be very conservative in this assessment. This estimate therefore ignores the fraction of houses that have concentrations between 4 and 40 picocuries per liter and those houses which have been built using passive reduction methods, such as the radon resistant new construction system advocated by EPA.

Equally interesting as a summary, are the conclusions that can be drawn (at least strong inferences which can be drawn) by looking at the substantial variations in soil gas radon concentrations that were observed between summer and winter. Particularly of interest is a period, 3rd through 9th May 1998. During one measurement period, concentrations went from 7,946 picocuries to 6 picocuries per liter in only six days. These concentrations were determined using grab sample technique with a scintillation counter. Although more information needs to be gathered on what actually happens to radon concentrations and radon soil gas concentrations in the summer time, clearly a large change seems to be occurring between winter and summer in inducted radon, in differential pressures driving the radon into residences, and the resulting radon concentration in homes in summer.

Some Important Conclusions

These surveys confirm the previous work indicating that homes in the hills around Fairbanks have a much higher probability of having elevated indoor radon concentration than homes in the lower alluvial areas. The fraction of houses in the hills exceeding the 4 picocuries per liter action level in the three Alaska surveys cited, was much greater than the national average. Thirty percent of the homes in this latest UAF survey had indoor radon concentrations greater than 20 picocuries per liter. The probability of having many homes in the area where the risk of exposure to radon is high, make the public education function of the State of Alaska and the US EPA important. In terms of public health, the goal of the public education program is to decrease radon risk. Those affected by radon in their homes deserve a response to their questions tailored to the specific conditions. The radon education program has credibility in the community. Maintaining this credibility and effectiveness requires accurate and helpful information.

Subslab depressurization systems were effective in significantly reducing indoor radon concentrations in this study. Reductions of indoor concentrations were from one to two orders of magnitude. Annual concentrations in mitigated circumstances were well below the 4 picocuries per liter action level.

Regarding seasonal variations in radon concentration, initial results from this work indicate that the summer season may not reflect the annual average indoor radon concentration in any credible way. In the two houses monitored during the summer, indoor radon concentrations were below two picocuries per liter, and were one to two orders of magnitude lower than during the cold months. A person wishing to assess his risk from exposure to radon wants to know his average exposure. All testing infers an average exposure, but a longer test is more likely to approach the actual exposure. The best way to know the average annual exposure, is to test for a year.

Leaky houses were found to be problematic in this study and altering the leakage distribution to lower the neutral pressure level, could reduce the differential pressure across the foundation. Drawing from experience with building science and energy conservation strategies, this simply means that it is extremely useful for both energy efficiency and for radon mitigation, to seal the top of the house against air leakage. This is the area of the house where leakage is maximum if there is a large stack effect, and where a large differential temperature in the house drives vertical convection of air.

Strategies on where to place intentional openings and how to minimize the pressure difference across the envelope, particularly leakage area at the top of the house, are worthy of further study, but indications are that this strategic element of design ought to be given more attention because all of its effects are positive in a building science context. The phrase "seal the lid", from weatherization experience, is effective in radon mitigation as well.

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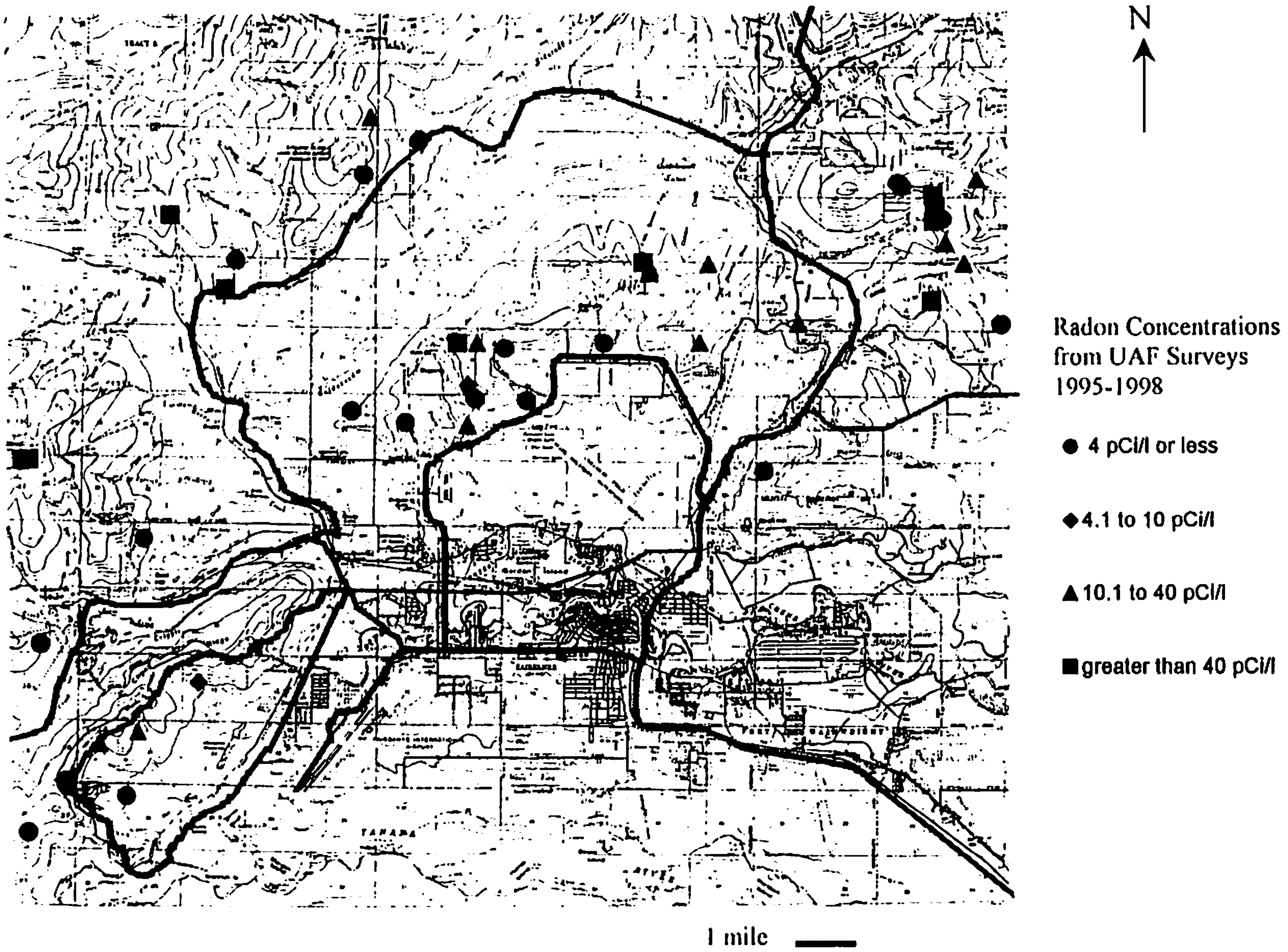
Fairbanks, Alaska and surrounding vicinity



Map 1 Radon Concentrations in Hills Surrounding Fairbanks

Table 1
Summary of ATD Survey Results 1996-1998

Number of homes	<4 pCi/L	4-20 pCi/L	20-80 pCi/L	>80 pCi/L
34	19	9	4	2

Table 2
Warm Weather Indoor Radon Concentrations

House	Date	Average	Standard deviation
R-P	5/17/98-9/14/98	1.2 pCi/L	1.0 pCi/L
R-L	5/14/98-6/13/98	1.3 pCi/L	1.1 pCi/L
R-L	9/19/98-10/12/98	0.7 pCi/L	0.2 pCi/L

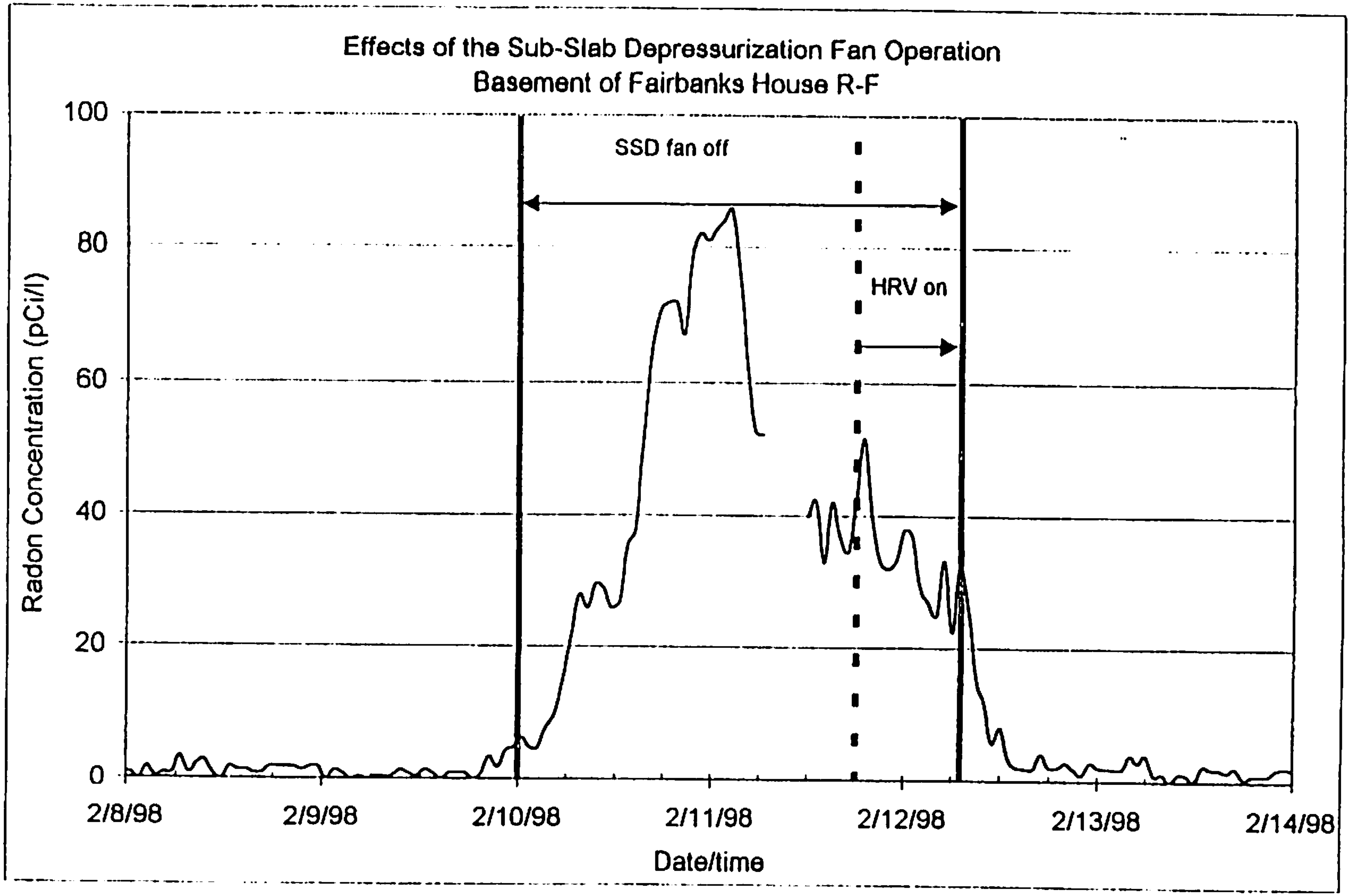


Figure 1. House R-F, SSD system off and on

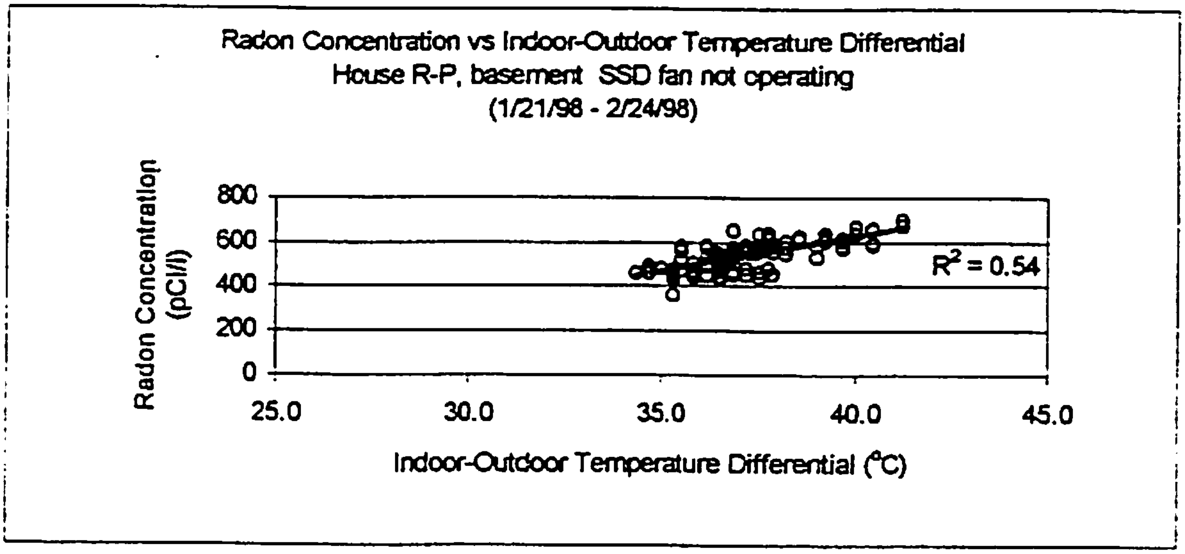


Figure 2. House R-P, basement, Radon vs. indoor-outdoor temperature differential

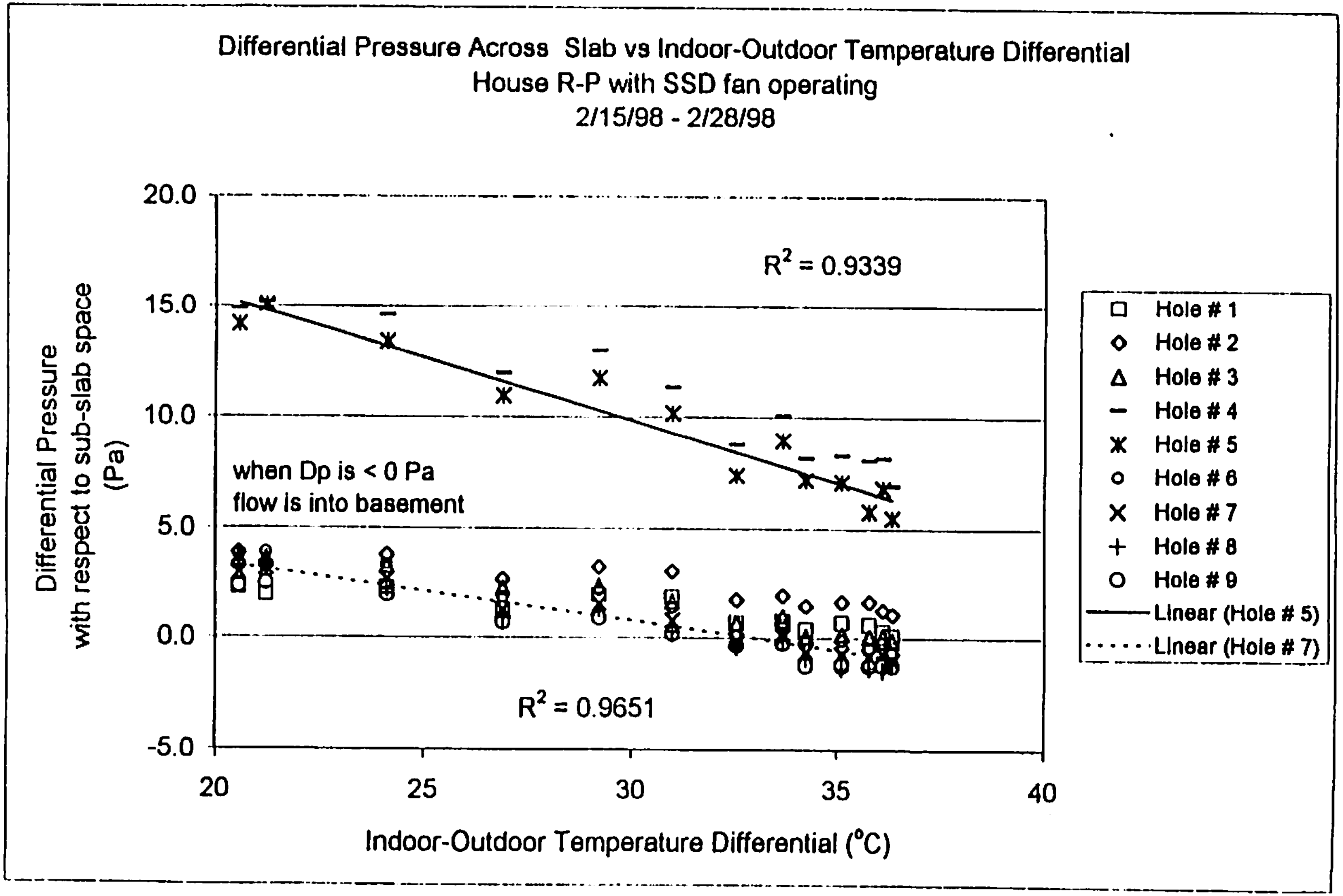


Figure 3. Dp across slab with fan on