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Session VII: State Programs and Policies Relating to Radon

Session VIII: Radon Prevention in New Construction

April 2-5, 1991
Adam's Mark Hotel
Philadelphia, Pennsylvania

The 1991 International Symposium on Radon and Radon Reduction Technology

"A New Decade of Progress"

April 2-5, 1991
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Philadelphia, Pennsylvania

Sponsored by:

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The 1991 International Symposium on Radon and Radon Reduction Technology

Opening Session

Opening Remarks . . . . Symposium Co-Chairpersons

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Welcome. . . . . .Edwin B. Erickson,
EPA Region III Administrator

An Overview of the NAS Report on Radon Dosimetry . . . . .Jonathan Samet
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The 1991 International Symposium on Radon and Radon Reduction Technology

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Session VII:

State Programs and Policies Relating to Radon

WASHINGTON STATE'S INNOVATIVE GRANT: COMMUNITY SUPPORT RADON ACTION TEAM FOR SCHOOLS

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ABSTRACT

In February, 1990, the Environmental Protection Agency awarded the Washington State Department of Health $100,000 from the State Indoor Radon Grants Program to fund an innovative project titled, "Community Support Radon Action Team for Schools." The Department of Health contributed an additional $34,000 to the project and organized a team of public and private sector experts. The goal of the team was to write a manual of cooperative and cost-effective approaches school administrators could use to assess and mitigate radon exposure in schools.

The team of federal, state and local experts from the fields of health, education, energy, building science and codes, safety, administration, communication, and radon testing, diagnostics and mitigation, chose to write and evaluate the manual with the cooperation of a school district in northeastern Washington.

The manual includes chapters on administrator's overview, radon facts, radon awareness, radon and liability, strategic planning, public informational materials, school radon testing, building inspection and radon diagnostics, radon mitigation, long-term radon management, and case studies. These chapters and the experience gained in their application in the school district will be discussed.

INTRODUCTION

Despite the identification of elevated radon exposure levels (100 pCi/L) in some buildings in Washington State's five northeastern counties, very few residences, schools or public and commercial buildings have been tested or mitigated. Within the Core Radon Program, the Department of Health (DOH), the State's lead agency responsible for a radon program, has insufficient resources to help school districts that want to tackle their radon problems but lack the funds, organization, staff and technical expertise.

DOH with its State Radon Task Force encourages state agencies, local governing bodies and other organizations to work cooperatively to reduce the public health risk from radon. In discussions with personnel in the school community, government agencies and the private radon industry, DOH found a manual was needed to help schools resolve radon issues. Since a variety of relevant expertise was present in Washington State, a team approach to developing the manual had merit. EPA agreed and awarded funding for DOH's innovative project, "Community Support Radon Action Team."

THE RADON ACTION TEAM

The Community Support Radon Action Team, a group of public and private sector experts, met ten times from March, 1990 to February, 1991 and numerous times in small working groups to develop the **School Radon Action Manual**. The team was composed of health, radon and building science experts from DOH, Region 10 EPA, the Washington Energy Extension Service (WEES), the Spokane County Health District (SCHD) and the City of Spokane Building Services Department (SBSD). Also, Faytek, Inc., Quality Conservation and Thomas J. Gerard & Associates, Inc. from the private sector provided expertise on radon testing, diagnostics and mitigation, and HVAC (heating, ventilation and air conditioning) systems, respectively.

In addition, the school community was represented on the team by a manager of state school facilities from the Office of the State Superintendent of Public Instruction (OSPI); a writer and a safety coordinator from the Education Service District 101 (ESD 101, one of nine regional agencies in Washington providing administrative and instructional support to local school districts); an administrator experienced in school radon testing from Spokane School District 81 (SSD); and an administrator, a public information officer, a supervisor of school maintenance and an HVAC specialist from Central Valley School District 356 (CVSD). The Northwest Regional Foundation (NRF, a private, non-profit corporation committed to facilitating change in communities) provided a facilitator to help this group of people work as a team to write the manual and evaluate its application in the CVSD. Finally, as a legal consultant, a Washington State Assistant Attorney General (OAG) contributed his expertise about liability.

THE TEAM PROCESS

In initial meetings, team members discussed the project goal, participants' self-interests, the process of radon problem solving in a school community, manual contents, working group assignments and site selections for the case studies in CVSD. The major goal of the team was to compile educational, problem solving and organizational resources in the **School Radon Action Manual.** The manual was designed to help school personnel communicate with their school community about radon and use internal resources as well as the private sector to cost-effectively assess and remediate for radon in their schools.

Radon Action Team members represented a wide variety of expertise and self-interests. Health professionals focussed on the need to communicate the health effects of radon exposure accurately and effectively to the public. School administrators desired to test, diagnose and mitigate for radon in a cost-effective manner while informing and involving their communities. Radon testing professionals demanded a scientific approach that complied with EPA interim protocols. Building science professionals concentrated on each building as an integrated system that demanded careful, logical problem solving techniques as radon and other indoor air quality problems were tackled. Team members decided to cooperatively pool their knowledge and concerns in the manual development realizing they had differences in perspectives and opinions which would be debated during the writing process.

In fact, many vigorous discussions did take place over the course of the year. One often debated question was: How much testing, diagnostics and mitigation work can school personnel accurately and cost-effectively accomplish before they call in the private sector for help? A second question was: How can a school district communicate about radon to its community which often wants problems immediately solved, while the district trains its staff, hires consultants, requests bids, raises funding and plans to remediate radon problems as they are discovered over several years of testing and diagnostics? Team members decided they could provide accurate and concise guidance on such things as radon testing options, building inspection and radon diagnostics, and public informational materials. They concluded, however, that ultimately it would be school administrators with an intimate knowledge of their communities and resources who would answer these questions.

SCHOOL RADON ACTION MANUAL

The **School Radon Action Manual** contains sections designed for school district administrators, public information officers, building managers and maintenance personnel. The manual organization follows a school radon action process (illustrated in Figure 1) recommended by the team. A list of the sections with a summary of their contents follows:

The "Administrators' Overview" includes what radon is, where radon is found, what the health risks are and when radon was recognized as a health hazard. Other topics are how radon enters a building, how it is measured, how radon concentrations are reduced and who can perform the radon testing and mitigation. In this section, the team recommends that school district staff involved in radon testing, building diagnostics or mitigation attend an EPA endorsed training course. Also, it is recommended that school district consultants show that they have successfully participated in EPA's Radon Measurement Proficiency Program, or employ individuals who have passed EPA's National Radon Contractor Proficiency Program.

"Radon Facts" gives greater detail on radon discovery, radon and radon progeny, the health effects of radon, the health risk to children and comparisons of school to home exposures.

"Risk Awareness" deals with assessing risk, the nature of radon risk, 4 pCi/L as an action level, the Indoor Radon Abatement Act, the health risk to children and smokers, challenges to EPA's risk estimates, getting to ALARA (As-Low-As-Reasonably-Achievable), managing and communicating radon risk and the risk awareness process.

"Radon and Liability" concludes that health hazards presented by radon and indoor pollution in schools and public buildings may be substantially reduced by technical analysis of the problem and a careful administrative response from management. Failure to initiate the analysis and respond to the problem presents the risk of liability for any school or public institution. Suggestions for a program that schools can develop to deal with radon and other indoor air quality problems are given.

"Strategic Planning" deals with how a school district may develop a plan for dealing with radon in its buildings. Topics covered include prerequisites for planning, action steps, timelines and financing. Formulation of a radon action team is recommended.

"Public Informational Materials" includes internal and external communications strategies utilized by the Central Valley School District as it dealt with radon in its schools. It includes

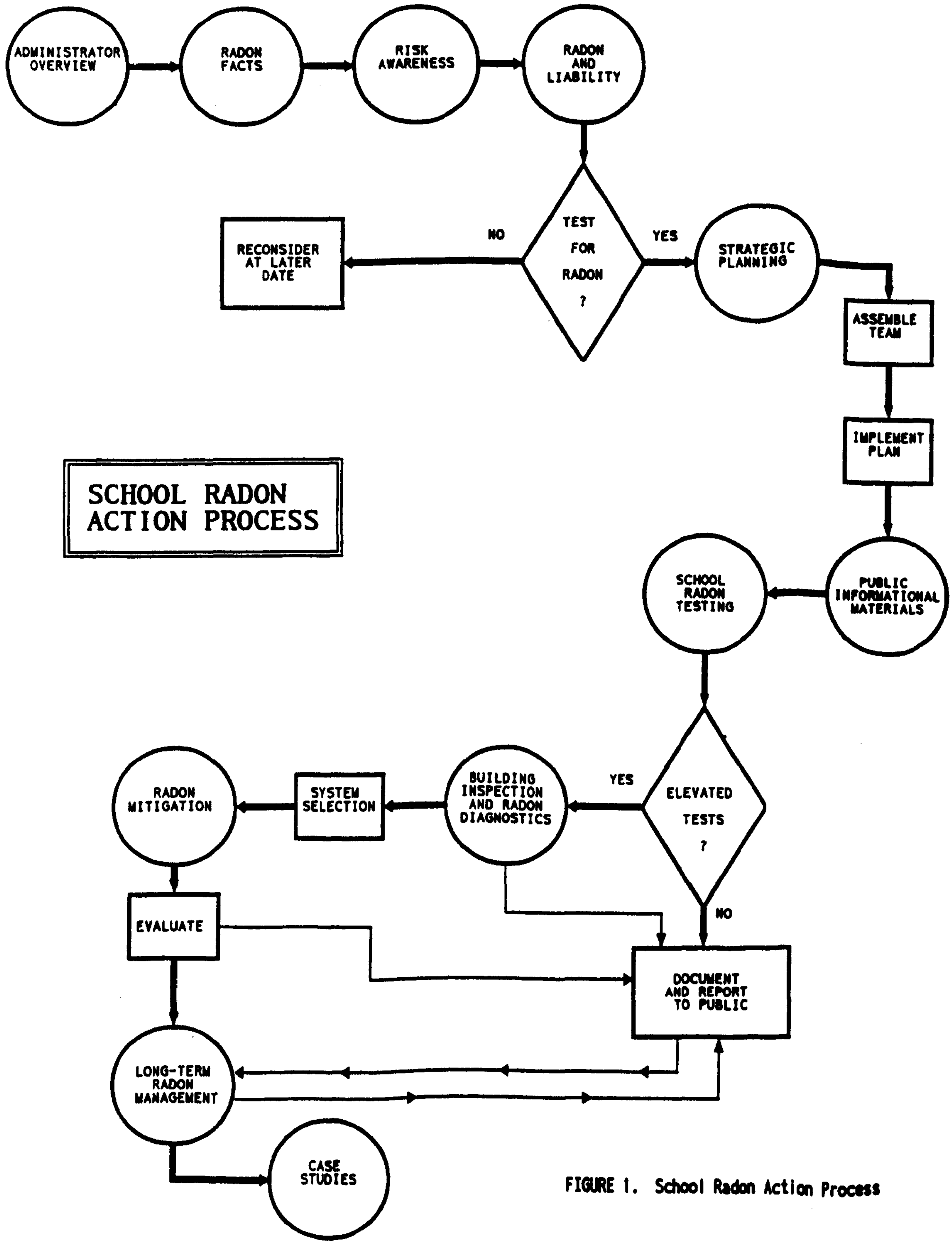

FIGURE 1. School Radon Action Process

strategies for communicating with staff, administrators, students, parents and the news media. Sample press releases and letters are included in this section.

"School Radon Testing" deals with testing school buildings for radon. It provides information on qualifications necessary to perform testing, school district requirements, testing procedures and forms, testing methods with advantages and disadvantages, and evaluation of testing results.

"Building Inspection and Radon Diagnostics" describes how to inspect buildings and perform or oversee diagnostic testing for radon entry locations. It includes checklists for review of testing data and for mechanical and structural inspections.

"Radon Mitigation" provides strategies for mitigation if elevated levels of radon are found in a building. Topics include radon entry, causes of pressure differentials, variations in radon concentrations between rooms, mitigation techniques and dealing with contractors.

"Long-term Radon Management" provides the basics for continual monitoring of indoor air quality, including radon, for the district. Topics include team design, program design, public policy guidelines and documentation.

"Case Studies" documents the application of the manual in six schools in the Central Valley School District (CVSD). This section describes the radon action process that CVSD employed with the manual and team members' expertise. Based on this limited application of the manual in one school district, the team offers suggestions to other school districts about what worked and what didn't work.

The "Glossary" defines key terms school district personnel must understand to communicate meaningfully about radon as a public health issue. The "Bibliography," a "Team Members' List" and "Federal and State Contacts" complete the manual.

CASE STUDIES

During this project, part of the manual's school radon action process (see Figure 1) was evaluated using six buildings in the Central Valley School District of Spokane County, Washington. The school community (including school board, faculty and staff, parents and students) was informed of the project and the radon action process by Radon Action Team members through the use of the sections: "Radon Facts," "Risk Awareness," and "Public Informational Materials." School personnel were trained by team professionals using parts of the sections: "School Radon Testing" and "Building Inspection and Radon Diagnostics." The manual sections, "Administrator's Overview," "Radon and Liability," "Strategic Planning," "Radon Mitigation," and "Long-Term Radon Management" were still being developed during this time so they were not evaluated in this school district.

Selected for evaluation of the educational, communications, testing and diagnostics processes were three elementary schools, a junior high school, a high school and an administration building. Team members made presentations about the project and the school radon action process at meetings of the school board, administrators, faculty, staff, Parent Teacher Association (PTA) and press. Four junior high science instructors wrote model radon awareness curriculum which they taught and are refining for distribution next summer. Literature on radon was displayed and made available to staff and the public in the building reception areas. Letters were sent home to parents, and articles published in the newspapers. A spirit of openness and cooperation was nurtured by the radon action team and the school administrators.

The team decided to employ charcoal canisters to test the administration building and the high school and electrets to test the other four schools. In both cases, school maintenance personnel were given training from the manual in placing the detectors, retrieving them, and keeping records. Charcoal devices were sent to the manufacturer's lab for analysis while electrets were read by school personnel. Faytek, a private EPA proficient testing company, provided training and oversight throughout the whole testing process.

Elevated radon levels were found in the administration building, high school, and three elementary schools. At the writing of this paper, building inspection and radon diagnostics are in progress by both team members and school personnel. School personnel have provided information about building histories and basic building operation. They have completed some initial mitigation involving sealing cracks and adjusting HVAC systems. Most of the detailed diagnostics is being performed by radon professionals from Quality Conservation, EPA proficient contractors, and a mechanical engineer from Gerard and Associates, all team members. Quality Conservation is in the process of developing remediation plans for two elementary schools and the high school. At the end of the project, a cost analysis of testing with charcoal versus electrets and testing and diagnostics using school personnel with private sector oversight versus private sector only will be made. Due to time and funding limitations, the team's efforts will end after the three remediation plans are given to the Central Valley School District.

SUGGESTIONS FOR SCHOOL PERSONNEL

Although the work on the case studies is still in progress, some preliminary and general suggestions have emerged from the Radon Action Team's work in the Central Valley School District. This school district is to be applauded for its progressive approach to radon problem solving and its offer to share lessons learned from this project with other school districts.

Suggestions are as follows:

As a part of strategic planning, the team recommends that schools assemble a Radon Action Team which incorporates relevant expertise from both the public and private sectors. The team organized for this project provides a model for team member selection (although smaller teams are appropriate for individual school districts). It is important that regular meetings of this team be held and that progress reports be shared with and decisions supported by upper level administrators (school board members, superintendents, district level administrators, and principals) in the school district. As part of the school district's operations strategy, it is recommended that EPA testing protocols should be followed. Decision points and procedures for immediate risk interventions should be developed. Thought should be given to scheduling, and minimizing class disruptions and loss of detectors.

During the public informational process, we suggest that a public information officer or a superintendent be the primary contact for all information requests. This contact person should be a team member, well-informed about radon issues, activities in the schools and the district's strategic plan. Requests for information should be answered accurately, openly and quickly, with a timeline given for the radon action process (eg. when test results will be reported, when buildings will be fixed). A good relationship should be established with the press at the outset of the process. The contact person needs to be flexible, calm and ready to handle "incidents" with concerned individuals and groups. Staff in buildings with preexisting indoor air quality problems may show a heightened interest or sensitivity to radon testing. More communication may be needed. PTA meetings work well to inform parents and faculty. The public information officer should be accompanied by other team members who have expertise in radon health effects, testing, diagnostics and mitigation, to gain public credibility through answering a broad range of questions.

Before a school district begins the radon testing process, school personnel should evaluate the various options for testing, considering cost-effectiveness, available internal and external resources, liability issues and time constraints. These options include use of private testing firms, use of school personnel or a combination of the two. If school personnel will be involved in performing school radon testing, the team suggests that school personnel (perhaps one or two maintenance personnel) receive EPA approved training. Also, a private, EPA proficient testing company should be employed as a consultant to oversee placement, retrieval, and recording of test results. Quality control procedures must be performed for both charcoal canisters and electrets. If school personnel read electrets, they must have training in appropriate analytical techniques. Forms and computer spreadsheets should be used from the outset to ensure accurate and complete record keeping of data. Building maps should show radon levels for each room and be color coded to make radon hotspots evident. Originals of all data should be kept in one file.

During testing, building inspection and radon diagnostics, plans and maps are required. Team members found that both architectural drawings and AHERA (asbestos) plans were sometimes inaccurate, inadequate or missing altogether. Also, the district public information officer needs to be prepared to control panic from school community members who want immediate action to lower radon levels. Radon diagnostics and mitigation take time and money to perform. Scheduling testing before a holiday such as winter break may give the district more time to perform this process.

SECOND YEAR PLANS FOR THE SCHOOL RADON ACTION MANUAL

The Washington State Department of Health (DOH) has asked EPA for second year funding to design training curriculum and materials for state and national presentations on the **School Radon Action Manual**. In addition, DOH will train instructors from the Community Support Radon Action Team who will be available for presentations to regional and national conferences of school administrators, teachers, facilities maintenance personnel, public relations staff, public health officials, and radon program and industry representatives. Finally, DOH will evaluate and revise the manual by observation of its application in two Demonstration School Districts, a small rural school district and a medium-sized suburban school district.

ACKNOWLEDGEMENTS

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Conservation); and Tom Gerard (Gerard and Associates). Other important contributions were made by T.R. Strong, Robert R. Mooney, Kate Coleman and Ed Scherieble (DOH); Dick Sovde (CVSD); and Larry Watters (OAG).

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KENTUCKY INNOVATIVE GRANT
RADON IN SCHOOLS' TELECOMMUNICATION PROJECT

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ABSTRACT

One of the many challenges facing the U.S. Environmental Protection Agency and individual state radiation control programs is to provide decision-making information and technical support to school administrators about radon testing and mitigation in school buildings.

This paper provides information on the development, delivery and overall implementation of a model radon telecommunication outreach program to school administrators in Kentucky and to the following states: Alabama, Arkansas, Georgia, Louisiana, Michigan, Missouri, Mississippi, North Dakota, Nebraska, New Jersey, Ohio, Pennsylvania, Texas, South Carolina, Wisconsin, and West Virginia, Virginia, and Florida.(Figure 1)

The two hour interactive broadcast will be delivered by satellite to all locations through the Kentucky Educational Television Network (KET).

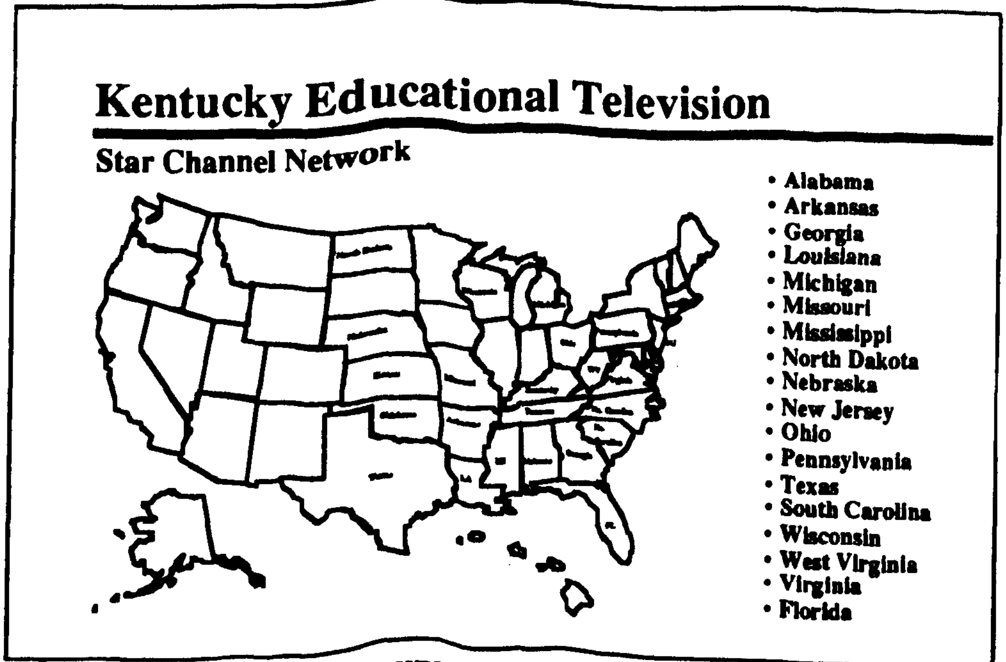

Figure 1: KET Star Channel Network State Contacts

In schools around the world, students are "talking" to other students they may never see; teachers are instructing students who are not in the room; professionals are meeting with far away colleagues without leaving their desks. Distance learning concepts and technologies make these interactions possible.

Distance learning is defined as the application of telecommunications and electronic devices which enable students to receive instruction that originates from some distant location. It involves four major concepts:

1. students are seperated from one another and from the teacher;
2. interactive two-way technologies are used to unite them;
3. the learning is planned, delivered, and evaluated by an institution;
4. students organize themselves and collaborate around a goal which may be theirs or the teacher's (1,2).

<u>SEPARATED</u>

Virtually any subject can be taught via distance learning. During 1989-1990, the National University Teleconference Network (NUTU) offered 94 programs, both fee-based and free. The greatest percentage (41%) of these programs were directed to Engineers with the remaining being delivered to: Education (38.6%), Medical and Allied Health (27.3%), and general interest (34.1%) (3). Distance learning provides a connecting network to learners who may be in the next building, another city or in a different country. Distance learning also allows the learners to "tune-in" at a time and location convenient to their schedule.

<u>UNITED</u>

The key to distance learning is two-way interactive technology. In the past, print technology and the U.S. Postal Service delivered correspondence courses to students in dispersed locations. Radio and telephone added an audio component and the possibility for two-way interaction. Later, education television broadcasts, cable programs, and video cassettes offered other ways of distributing course materials. Interactivity was added via telephone and then computer.

Today, computers, satellites and telecommunications technologies such as fiber optics expand the power of older distance learning technologies. Computers make it possible to access electronic mail, bulletin boards, interactive computer conferences, data bases of information and computer assisted instructional lessons and courses. Microwave dishes and satellite links enable the computer to reach across the street and around the world. Telephones, fiber optics and satellites permit one-way and two-way interactive video conferencing.

Distance learning technologies fall into the categories of video, voice and data communications. Video is the primary means of delivery. It is the most attractive, complex and expensive. Audio telephone delivery provides one-on-one interaction or handles groups of three or more in different locations via an audio bridge. Audiographic teleconferencing permits the transmission of still images and audio signals over telephone lines. Electronic blackboards and tablets, FAX, slow scan, and compressed video also use telecommunications technologies.

Video, voice, and data communications can reach learners at any time and in any place. But the real power of distance learning lies in two-way interactive technologies (2). The reason for this is the capability for interpersonal communication. One-way systems leave the learners passive, uninvolved and isolated. Two-way systems let them actively exchange ideas, information and feelings. It puts high touch into high technology. They can reach out and touch a real someone.(2)

KENTUCKY EDUCATIONAL NETWORK (KET)

Kentucky is the first state in the nation to fund and construct a statewide telecommunications delivery system. KET was established by the Legislature in 1968 to provide instructional services to teachers. The Satellite uplink costs $500,000 and $2,000 for each school downlink. It is the largest system in the nation. The KET Star channel system consists of a transmitting and receiving site at the KET Network Center in Lexington, Kentucky and has more than 1,300 receiving sites (down links) located throughout Kentucky at public schools. The KET satellite can uplink programs not only to Kentucky schools but also to schools throughout the nation (Figure 1 and Figure 2).

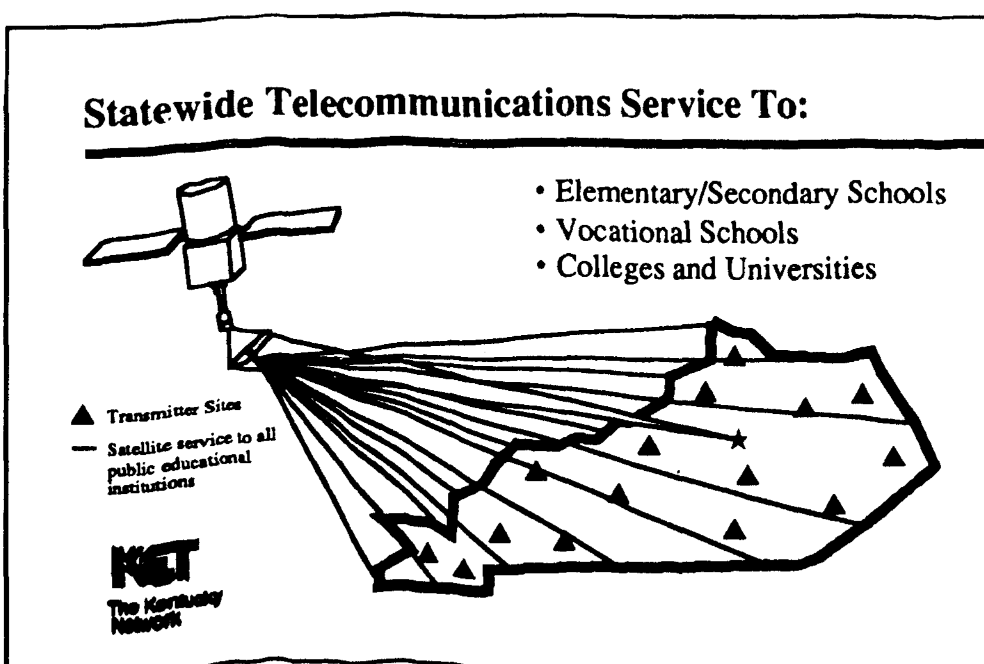

Figure 2: KET Reaches all Public Schools in the State

This potential nationwide KET linkage will allow the Kentucky radon program to offer the "Radon in Schools" broadcasts to radiation control offices and education departments in the following states.

Alabama	Arkansas
Georgia	Louisiana
Michigan	Missouri
Mississippi	North Dakota
Nebraska	New Jersey
Ohio	Pennsylvania
Texas	South Carolina
Wisconsin	West Virginia
Virginia	Florida

Kansas, Oklahoma, Tennessee, and North Carolina are not currently KET STAR Channel participants, but linkage to these states can be arranged.

TARGET AUDIENCE

The radon program, funded through the U.S. Environmental Protection Agency, State Indoor Radon Innovative Grant, will apply KET's high technology approach to providing radon information to school administrators, school building managers, daycare operators, and others engaged in managing buildings where citizens learn and work.(Figure 3)

Once the broadcast dates have been scheduled and pre-broadcast materials developed, all state radiation control offices, radon programs, state departments' of education and other target participants will be invited to link up and take part in this project.

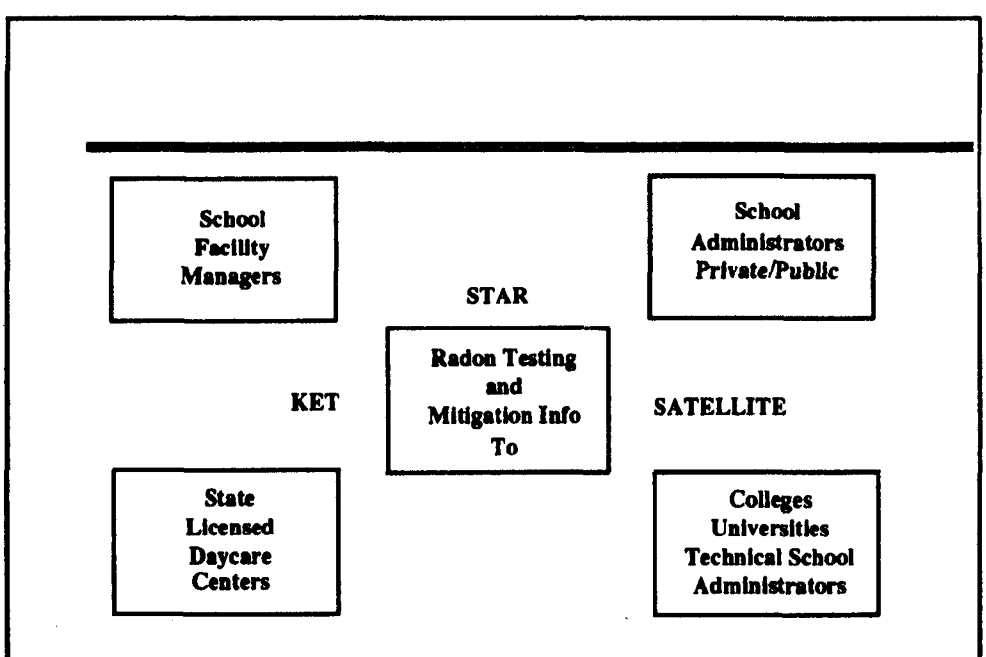

Figure 3: KET/Radon Target Audience

For Kentucky public school officials, the radon in schools broadcast will arrive soon after they receive confirmatory radon measurements for their building(s). For others such as daycare and nursing home operators, the information will arrive as they begin to consider how to go about testing and mitigating their buildings.

By using the Star Channel satellite and distance learning concepts, the radon program staff can reduce the need to travel statewide to disseminate radon information to these groups. An additional benefit of this communication media is that the audience is exposed to a consistent message with minimal presenter bias.

KET-RADON PROJECT GOALS

The second KET/Radon Innovative grant goal will go beyond the initial broadcasts to research the potential for using telecommunications to deliver information about radon. To do this, the KET project staff will investigate existing telecommunication networks and apply this knowledge to the delivery of radon information and technical training. Another aspect to be investigated will be the possibility of linking the USEPA Regional Radon Training Centers, through a central training delivery system with on-site training center faculty in designated locations (Table 1).

TABLE 1: KET/RADON INNOVATIVE GRANT GOALS

KET - Radon Project Goals

- **Design and Deliver two Radon Programs utilizing the Star Satellite and telecommunications.**
- **Investigate the potential for using KET Network to deliver Radon information, Training, and Continuing Education.**

SCHEDULED BROADCASTS

The Spring broadcast date is expected to be scheduled prior to the time school officials finalize their 1991-1992 budget requests. Hopefully, the timing of the broadcast and the technical information provided, will be sufficient to allow school officials to request funding for radon testing and mitigation projects (Table 2).

TABLE 2: BROADCAST SCHEDULE

Radon Broadcasts

- **Spring 1991 - Testing**
- **Fall 1991 - Mitigating**

The Spring broadcast will emphasize radon testing protocols for schools and illustrate ways to communicate radon risk information to parents, staff, children and the public (Table 3).

TABLE 3: SPRING BROADCAST DESIGN

Spring 1991

Broadcast Design

- **Testing for Radon in Schools**
- **Decision steps based on**
  - **Initial Screening Measurements**
  - **Confirmatory Measurements**
- **Risk Communication Suggestions**
- **Resources Available**
- **Live Panel of Radon Experts for Teleconference**

Kentucky school representatives, experienced in radon testing and mitigation in their own school building(s), will share insights and lessons learned. These segments will be pre-taped in the actual school setting. Also, the radon school based outreach program being implemented by the Jefferson County Public School District and Jefferson County Parent-Teacher's Association will be highlighted (Table 4).

TABLE 4: FALL BROADCAST DESIGN

Fall 1991

Broadcast Design

- **Mitigating for Radon in Schools**
- **Decision Steps**
- **Risk communication suggestions**
- **Resources Available**
- **Live Panel of Radon Experts for Teleconference panel**

The Fall Radon in Schools broadcast will provide school mitigation information. Again, Kentucky school representatives will share their experiences in an attempt to communicate the message that radon issues are manageable within a school setting and that there are others who have survived the process (Table 4).

Each two hour broadcast will feature a "live" interactive question and answer period for the last 30-40 minutes of the program. A panel consisting of radon experts from U.S. EPA and other agencies will respond "on air" to participants' questions. The audience will be provided with an 800 telephone number to the KET studio and encouraged to call in with their questions. The 800 call-in number will remain active for one hour after the broadcast. Trained radon staff will answer the incoming calls, write out the questions and route them to a panel member.

A panel member will read the question aloud and provide an answer or refer the caller to additional resources. Any caller who does not have their question addressed on live broadcast will receive a written answer by mail following the program. Callers will not be identified by name or school and their voices will not be aired.

The entire broadcast plus the live panel call-in segment will be taped for future broadcast schedules. Individual tapes will be made available through a loan program (Figure 4).

BROADCAST PRODUCTION

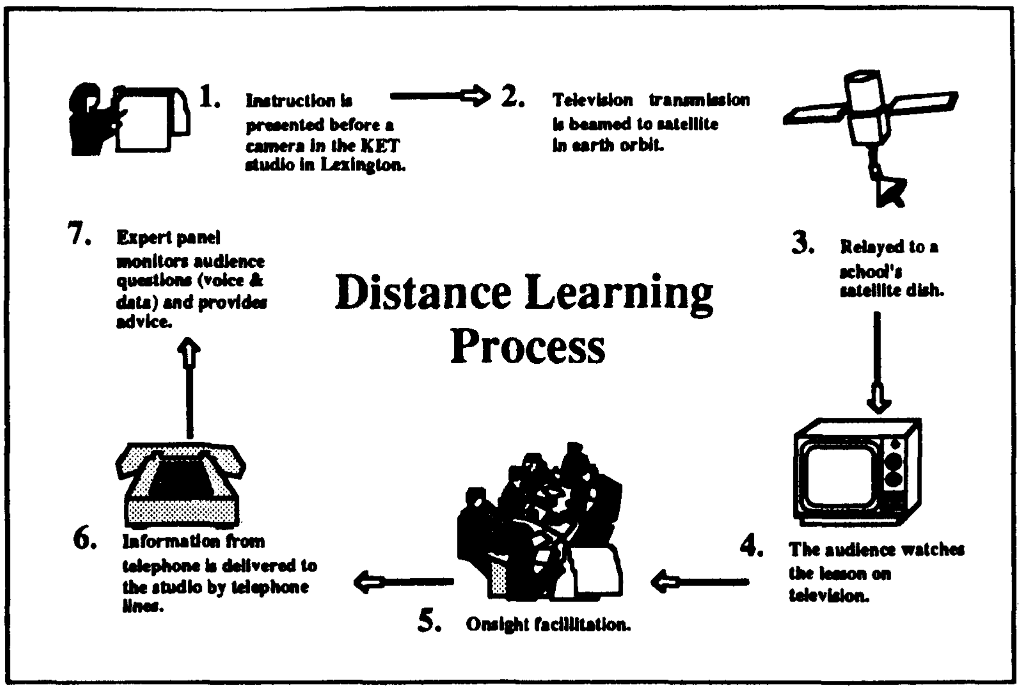

Figure 4: Distance Learning Process

Pre-broadcast activities can be divided into two major steps; audience preparation and broadcast production processes. In regard to the participants, the State Department of Education, Human Resources Licensing and Regulation Department, and KET will assist by providing mailing labels for the target audiences. The project staff person, in coordination, with the USEPA and KET and others, will prepare the broadcast design. KET staff will take the lead in taping and editing broadcast visuals. Field taping of actual school settings is planned as part of a pre-production activity. Existing video productions may also be integrated.

Other pre-broadcast activities include sending a radon resource literature package along with each invitation. In each school district, a KET receiving school will be identified as a radon resource broadcast center. These resource centers will provide on-site facilitation during and after the broadcast by a "radon trained" resource person. County Extension Agents, school representatives, local health officials, and others with demonstrated knowledge of radon testing and mitigation will be designated to serve as on-site facilitators. The facilitators will receive a pre-broadcast orientation to ensure statewide consistency of information. For security reasons, all non-school related participants (daycare operators, etc.) will be assigned to a resource center. Closest to their home/work.

EVALUATION

The nature of this project requires an extensive system of checks and balances at each phase of development. This will be provided by the KET staff assigned to the project, as well as the project designated radon staff person. USEPA Region IV staff, and Regional Radon Training Center staff will provide ongoing assistance and review. An in-state work group will also be assigned to on-going evaluation. Members of this group will include, staff from the radon program, State Department of Education; Jefferson, Fayette, and Warren County School Districts; University of Kentucky Cooperative Extension Service, Kentucky Parent-Teachers Association, and others.

An immediate post-broadcast evaluation questionnaire and a six week follow-up will be administered to all participants. The results from the immediate and delayed evaluation will serve to measure the degree of change in participant attitude regarding radon.

ACKNOWLEDGEMENTS

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JEFFERSON COUNTY SCHOOL DISTRICT
AND
RADON PROGRAM

1. Work cooperatively to establish a radon comunication outreach program through the school to parents, staff, and students.

2. Promote the Jefferson County School District radon testing project and the communication outreach program as a model for other school districts in the state and the nation.

MODEL COMMUNICATION OUTREACH

Audience

School Administrators	Building Maintenance Personnel
Teachers	Ancillary School Staff
Parents	Parent-Teachers Association
Students	

Message

Long-term exposure to elevated levels of rdon gas is associated with increased risk of developing lung cancer.

Testing for radon gas is easy and mitigation methods are effective.

All homeowners should test their homes. Schools, daycares, public and commerical buildings should also be tested.

If elevated levels are discovered, action should be taken to reduce the levels.

RADON COMMUNICATION OUTREACH PROGRAM THROUGH SCHOOLS

Audience	Type of Communication	Message	Method
School Administrators Building Maintenance Personnel	Technical/Support and Motivational	- Testing Protocols - Decision process after testing - Mitigation strategies - Technical assistance - Public disclosure - Encourage them to test their homes	Kentucky Educational Television-Radon in Schools Broadcast Spring/Fall 1991
Teachers Ancillary School Staff	Informational and Motivational	-Levels of radon in school, by room - Mitigation strategy - Encourage them to test their homes	- Dissemination of informational literature -Presentations through the Kentucky Education Association
Parent-Teacher's Association	Informational and Motivational	- Levels of radon in school, by room - Mitigation strategy - PTA can help school administrators to reach parents with radon information - Encourage them to test their homes	- Presentation at State and District Meetings and Workshops - Assistance to individual schools/districts - PTA host Radon Awareness Program -PTA distribute radon info to parents - Host testing campaigns
Parents	Informational and Motivational	-Levels of radon in school, by room -Mitigation strategy - Encourage them to test their homes	- District/School/PTA sponsored radon awareness programs - Distribution of radon literature through PTA/ District office
Students	Informational and Motivational	- Facts about radon and indoor air quality - How to improve air quality	- American Lung Association lesson on radon in "Growing Healthy" curriculum -*Weekly Reader Poster Contest*

***Risk Communication Information Provided for Each Group**

REGULATION OF RADON PROFESSIONALS BY STATES: THE CONNECTICUT EXPERIENCE AND POLICY ISSUES

Submitted by:

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(1) State of Connecticut Department of Health Services
(2) State of Connecticut Department of Consumer Protection
(3) State Representative, Connecticut General Assembly

ABSTRACT

The desire of state governments to provide information on proficient radon professionals to their citizens has resulted in a variety of informational and regulatory programs. The State of Connecticut has developed a new registration program for radon professionals, pursuant to Connecticut Public Act 90-321, that combines requirements for successful completion of both state registration and federal proficiency programs in order to be listed. Under this program, radon testers and testing companies are required to successfully participate in the current round of the EPA Radon Measurement Proficiency (RMP) Program. Radon mitigation contractors must successfully participate in the Radon Contractor Proficiency (RCP) Program and register with the Department of Consumer Protection. Radon Diagnosticians are required to successfully participate in both the RMP and RCP Programs. The process by which Connecticut developed this program and recommendations for EPA policy changes are discussed.

INTRODUCTION

The State of Connecticut Department of Health Services (DHS) began receiving inquiries on radon and requests for information on radon professionals soon after high levels of radon were discovered in a home in Pennsylvania. Many of the callers requested our recommendations for radon testing companies and mitigation contractors. Most callers wanted information on what types of testing services were available, what prices were reasonable, which companies had the most experience and whether they could conduct the test themselves. Callers who had already tested asked for information on mitigation systems and lists of "approved" mitigation contractors. Some of the better informed callers also asked about whether it is appropriate for the same company that conducted the radon test to also conduct the mitigation operation. In time, other consumers also reported problems with the radon testing and mitigation companies.

The DHS response to these requests has evolved through a number of changes. These changes have included both the information provided on radon assessment and control and the means by which we regulate radon professionals. Our ultimate goal is to provide sufficient information to Connecticut consumers to enable them to make informed choices on testing and mitigation services.

This paper will outline the evolution of radon professional regulation in Connecticut, provide recommendations for other state programs, and propose changes for the EPA proficiency programs.

EARLY GUIDANCE ON RADON PROFESSIONALS

The DHS first attempt at providing guidance to Connecticut consumers on radon professionals was the development, in 1985, of a list of radon testing companies. The information was obtained from results of an early round of the EPA's Radon Measurement Proficiency (RMP) Program. The DHS determined that additional information on both the types of testing services offered by each company and the price of each testing service would also be beneficial. Information on DHS recommendations regarding screening devices and procedures was also included.

During 1986 the DHS provided the public with a list of mitigation contractors used by the EPA in the northeast since little information was available on Connecticut mitigation companies. As mitigation companies became established in Connecticut, the DHS expanded the list to include information on mitigation company services. Since this list of contractors was not derived from a state or federal proficiency program, disclaimers were added to warn the public that the DHS could not be responsible for a company's performance.

During 1986-88 the DHS prepared additional informational material on radon exposure in Connecticut that was mailed in response to telephone inquiries on radon testing. This material included fact sheets summarizing the results of the various statewide radon surveys, and the two EPA radon pamphlets (1,2).

In August 1987, the DHS held a news conference to announce the results of our second statewide survey. At this conference the Department recommended that all Connecticut citizens test their homes for radon regardless of the geographic area of their residence, since our surveys to date had revealed the potential for high levels of radon in all areas of the state. The DHS formally organized a Radon Program in December 1987 to publicize these recommendations and conduct additional surveys. A third survey revealed consistent results in the percentage of homes (20%) with radon levels in excess of the U.S. EPA guideline of 4 picocuries (pCi/L) per liter (3,4,5). These results further emphasized our recommendation that all Connecticut residents test their homes for radon (3,4,5).

During 1989, a second state agency became increasingly involved in assisting Connecticut consumers in evaluating radon professionals. This agency, the Department of Consumer Protection (DCP), recommended that individuals offering mitigation services register as "home improvement contractors." This existing DCP registration program provided consumers with additional protection in the form of the "Home Improvement Guaranty Fund" with monies that can be used to correct poorly installed or unfinished mitigation systems.

During this time, the Radon Program greatly revised the format of how information on radon is provided to Connecticut residents. This new approach included the development of two information packets. Information packet "A" included a list of testing companies, a fact sheet and the EPA pamphlet "A Citizen's Guide to Radon" (1). Information packet "B" included the EPA pamphlet "Radon Reduction Methods A Homeowners Guide" (2), and the list of diagnostic services and mitigation contractors. Although the DCP registration procedures for mitigation contractors was not mandatory at this time, the DHS added a notice to the contractor list advising consumers of the benefits of this program. Table 1 summarizes the other registration requirements and recommendations. It should be noted that while the DHS Bureau of Laboratory Services had existing regulatory authority to require registration of testing laboratories, the DHS could not require mitigation contractor registration. During early 1990 the Radon Program also recommended that consumers select mitigation contractors that had successfully participated in the EPA Radon Contractor Proficiency (RCP) examination.

REGISTRATION REQUIREMENTS AFTER OCTOBER 1990

Many consumers were not satisfied with the status of our radon professional lists since these lists did not require contractors to demonstrate competency by completing a proficiency examination or program.

A number of Connecticut State Representatives and agency staff began to independently suggest alternative approaches toward a more formal regulation of radon professionals. Many of these alternative approaches called for mandatory certification or registration programs. A proposed bill was submitted by the Conecticut General Assembly's General Law Committee that asked for a mandatory licensure program for all radon professionals. This proposed program would have required individuals offering radon testing, diagnostic or mitigation services to obtain a license from the DHS, that would be renewable on an annual basis. While the bill would have offered consumers better protection against fraudulant radon professionals than a registration program, it would have required additional agency staff to implement. The DHS testified against the bill, pointing out that due to fiscal constraints and a lack of staff it would not be possible to implement the legislation if it was enacted.

TABLE 1. REQUIREMENTS FOR LISTING OF RADON PROFESSIONALS IN CONNECTICUT PRIOR TO OCTOBER 1990

Requirement	Professional Class Testing primary and secondary	Diagnostics	Mitigation
Department of Health Services (DHS) Registration	Yes	Yes	Yes
EPA Radon Measurement Proficiency (RMP) Program	Yes	No	No
EPA Radon Contractor Proficiency (RCP) Program	No	Rec.*	Rec.
Education	Rec.	Rec.	Rec.
Department of Consumer Protection (DCP) Registration	No	No	Rec.

*recommended

One of the authors (Representative Jessie Stratton) began work on an alternative proposal that would increase the Department's ability to regulate radon professionals at little cost to the agency. After meeting with the representatives of appropriate state agencies (including the other authors) a bill was proposed to accomplish these goals using a more formal registration program. This proposed bill survived various committee meetings and hearings and was signed into

law by Governor William A. O'Neill on May 3, 1990. The requirements of Public Act 90-321 "AN ACT CONCERNING PERSONS WHO TEST FOR OR MAKE HOME REPAIRS TO ELIMINATE THE PRESENCE OF RADON GAS AND DIRECTING THE DEPARTMENT OF HEALTH SERVICES TO ADOPT REGULATIONS ESTABLISHING SAFE LEVELS OF RADON IN POTABLE WATER AND PAYMENTS FROM THE HOME IMPROVEMENT GUARANTY FUND" became law on October 1, 1990. This bill stated that "the Department of Health Services shall publish a list from time to time of: companies that perform radon mitigation or diagnosis; primary testing companies and secondary testing companies."
Table 2 summarizes these new requirements.

TABLE 2. REQUIREMENTS* FOR LISTING OF RADON PROFESSIONALS IN CONNECTICUT AFTER OCTOBER 1990

	Professional Class		
Requirement	Testing primary and secondary	Diagnostics	Mitigation
Department of Health Services (DHS) Registration	Yes	Yes	Yes
EPA Radon Measurement Proficiency (RMP) Program	Yes	Yes	No
EPA Radon Contractor Proficiency (RCP) Program	No	Yes	Yes
Education	EPA Measurement**	"EPA Approved"	"EPA Approved"
Department of Consumer Protection (DCP) Registration	No	No	Yes

* Under Connecticut Public Act 90-321
** Required by the DHS Bureau of Laboratory Services only

One should note the most significant changes relate to the registration process for radon professionals. Diagnosticians and mitigation contractors are now <u>required</u> to fulfill federal proficiency requirements by successfully participating in the RCP Program in order to be listed by DHS. This requirement of successful participation in the RCP Program established a minimum level of proficiency for radon contractors.

Individuals offering both radon testing and diagnostic services are specifically required to successfully participate in the federal RMP Program to be listed by the DHS under PA 90-321.

Both diagnosticians and mitigation contractors are required to fulfill an educational requirement specified in the bill. This requirement states that diagnostic specialists and the on-site supervisor must have "attended a program approved by the United States Environmental Protection Agency."

Finally, mitigation contractors are required to register with the DCP as "home improvement contractors." This requirement was added to the legislation to ensure that Connecticut residents retaining the services of radon mitigation contractors will be afforded the same protection available to consumers using the services of any other home improvement contractor. This protection can include receiving funding to complete unfinished installations or correct problem systems.

PROBLEMS ENCOUNTERED WITH THE IMPLEMENTATION OF PUBLIC ACT 99-321

The authors have documented the following problems in the implementation of PA 90-321. The first problem relates to the bill's reference to "EPA-approved" courses in outlining the educational requirements for the three radon professional groups. This term, suggested by EPA staff and others, referred to courses offered by EPA contractors including the newly organized Regional Radon Training Centers. It was chosen to avoid the resource intensive problem of state agency approval of source providers.

A number of radon professionals who wished to be listed by the state asked if courses they had taken from private vendors were considered "EPA- approved". Inquiries to the EPA revealed that they did not "approve" any radon courses at that time, although they did endorse the courses offered by the Regional Radon Training Centers.

A second problem relates to the infrequent review periods or "rounds" offered by the EPA Radon Measurement Proficiency (RMP) Program. Public Act 90-321 now requires both primary and secondary testing companies and diagnosticians to have "successfully completed" the RMP program in order to be listed. Therefore, newly organized companies must wait up to a year or more for the next test round prior to being listed.

A third problem relates to the requirement of individuals who wish to be listed as offering services as a radon diagnostician participate in both the EPA RMP Program and the Radon Contractor Proficiency (RCP) Program. The final language of the bill allowed any RMP participant including secondary companies to be listed as a diagnostician. The authors have found that only those companies with instruments capable of performing real-time radon measurements and successfully participating in the RMP Program with these instruments can conduct accurate diagnostic evaluations.

A forth major problem relates to the program's design as a listing rather than a registration program. While the program places little demand on the Department, it allows radon professionals to conduct business without requiring proof of proficiency and training.

SUGGESTED CHANGES IN EPA POLICY TO ASSIST STATES IN THE REGULATION OF RADON PROFESSIONALS

The Department's preliminary experience with PA 90-321 has already modified the author's thoughts on the definition of the model radon professional registration program. The following changes are suggested to aid states in the development of their radon programs. These suggestions include both changes in EPA policy and recommendations for states in their interpretation of EPA policy.

Most changes are related to the educational requirements. Table 3 lists recommended educational requirements which call for "EPA-equivalent" radon training courses specifically designed for radon testers and mitigators. EPA-equivalent being defined as having a course content based on courses offered by the EPA or by the EPA Regional Radon Training Centers.

The change in language from "EPA-approved" to EPA-equivalent will more accurately reflect the current EPA policy on approval of training providers. At this time the EPA only approves providers of the "hands-on" mitigation training course (see below).

TABLE 3. RECOMMENDED REGISTRATION REQUIREMENTS OF RADON PROFESSIONALS BY STATE AND LOCAL GOVERNMENTS

Requirement	Professional Class Testing primary and secondary	 Diagnostics	 Mitigation
Health Agency Registration	Yes	Yes	Yes
EPA Radon Measurement Proficiency (RMP) Program	Yes	Yes	No
EPA Radon Contractor Proficiency (RCP) Program	No	Yes	Yes
Education	EPA-Equivalent Measurement	EPA-Equivalent Measurement & Mitigation	EPA Equivalent Mitigation
Consumer Agency Registration	No	No	Yes

Ideally the EPA would determine if a course provider is offering an EPA-equivalent course. EPA staff would review new course offerings submitted by the providers and make a determination of "equivalency". The EPA could also develop a model accreditation program for radon course providers. State agencies could determine if a course is considered EPA-equivalent by comparing the course outline to the EPA accreditation model. States with limited resources devoted to radon issues can make this determination by simple comparison of the course outline.

The measurement course should consist of a one day program while the mitigation course would include a "hands on" training component. A list of approved courses that include this "hands on" component will be maintained by the EPA. This course will include actual practice in assembling radon mitigation systems. Diagnosticians would be required to complete both courses, since they must be both proficient with testing methods and knowledgeable about mitigation systems.

A second proposed change would require diagnosticians to participate in the RMP Program as a primary company using a radon testing device capable of obtaining real-time pinpoint radon measurements. This type of device is needed to conduct accurate diagnostic evaluations of homes and other buildings. This requirement would ensure that diagnosticians will not try to conduct diagnostic radon measurements with passive radon detection devices.

Perhaps the most significant changes would have these requirements mandated not only for professionals who wish to be listed, but for all professionals conducting business in a state.

SUGGESTIONS FOR THE EPA RADON MEASUREMENT PROFICIENCY (RMP) PROGRAM

The EPA's Radon Measurement Proficiency Program has proven extremely useful for states such as Connecticut in providing information on competent radon professionals. The authors have identified a few minor changes that would improve the RMP's Program's ability to provide useful information to states. These changes are summarized on Table 4.

The most significant changes again relate to educational requirements. The authors recommend both prerequisite and continuing education requirements for all radon testing company personnel involved with placement and retrieval of radon measurement devices. This requirement will help to ensure that accurate testing procedures are followed by professional radon testers. In addition, laboratory directors will be required to complete a course on techniques and procedures used in radon analysis. This requirement will ensure that accurate analysis will be conducted by using appropriate quality assurance techniques. Both a continuous RMP Program application process and a continuous randomly selected blind testing are also recommended. A continuous testing round policy will allow newly-formed companies to immediately participate in the RMP program. The current system of periodic "test rounds" has resulted in waiting periods of up to one year. The continuous blind testing plan will ensure that laboratories maintain a high level of proficiency throughout the year.

TABLE 4. CURRENT AND RECOMMENDED REQUIREMENTS FOR RADON TESTING COMPANIES PARTICIPATING IN THE U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA) RADON MEASUREMENT PROFICIENCY (RMP) PROGRAM

Company Type & Requirements	Current	Recommended
PRIMARY COMPANY:		
Education	None	EPA Lab. Analysis*, EPA Measurement** or Equivalent
QA Program (Analysis)	Yes	Yes
Chamber Testing (Submitted)	Yes	Yes
Chamber Testing (Blind)	Selected (test round period only)	Random (year-long)
SECONDARY COMPANY:		
Documentation of Approval by the Primary Co.	Listing Only	Yes
Education	None	EPA Measurement** or Equivalent
QA Program (Sampling)	No	Yes
Chamber Testing (Blind)	No	Random (year-long)

* Prerequisite and continuing educational requirement for laboratory director only

** Educational requirement for all staff involved with testing device placement
and retrieval

RECOMMENDATIONS FOR THE EPA RADON CONTRACTOR (RCP) PROFICIENCY PROGRAM

The authors have found the EPA Radon Contractor Proficiency Program (RCP) to be a useful addition to the RMP Program. We have some minor recommendations for improving this program's value in providing information to consumers who wish to contract for installation of mitigation systems. Table 5 summarizes these changes which again emphasize prerequisite and continuous educational requirements. The authors have recommended that the EPA emphasize the separation of the radon diagnostician and mitigation contractor services. This separation should be used in both the registration requirements of the RCP Program, where the Radon Program would recommend a separate listing, and within the text of EPA literature on radon reduction techniques (6,7).

An example of a document where a text change is needed can be seen in Section 4.1 of the EPA booklet "Application of Radon Reduction Methods" (7). This section, entitled "Choice of Diagnostician/Mitigator," describes the diagnostician but does not emphasize the distinction:

> "The person primarily responsible for the diagnosis of the problem is called the "diagnostician." The person who will be primarily responsible for the design, installation, and post-installation evaluation of the radon reduction system is referred to here as the "mitigator." These may or may not be the same person (7)."

The authors also recommend that participants in the RCP Program must agree to follow the "RCP Program Guidelines" in all their mitigation activities. These guidelines are designed to insure that only well-designed, efficient systems are installed in homes and only when needed.

CONCLUSIONS

The authors are of the opinion that adoption of these changes would increase the value of EPA's Proficiency Programs by providing useful information which would enable our nation's consumers to make informed decisions regarding the selection of radon professionals. By requiring participating in the EPA proficiency programs and following the recommendations listed on Table 3, states can offer better protection to their residents. Consumers in those states will know that all listed professionals possess a minimum level of knowledge and training in proper testing diagnostic and mitigation procedures. It is our belief that such information and consumer protection safeguards contribute to reducing radon exposure and decreased mortality among our nation's citizens.

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TABLE 5. CURRENT AND RECOMMENDED REQUIREMENTS FOR RADON DIAGNOSTICIAN SPECIALISTS AND MITIGATION CONTRACTORS PARTICIPATING IN THE U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA) RADON CONTRACTOR PROFICIENCY (RCP) PROGRAM

Professional Class and Requirements	Current	Recommended
Diagnostician:		
Prerequisite Education	No*	EPA Measurement and Mitigation Courses or Equivalent
Participation in the EPA Radon Measurement Proficiency (RMP) Program	No*	Yes
Participation in the EPA Radon Contractor Proficiency (RCP) Program	No*	Yes
Continuing Education	No*	Yes
Mitigation Contractor:		
Prerequisite Education	Rec.**	EPA Mitigation Course*** or Equivalent
Participation in the EPA Radon Contractor Proficiency (RCP) Program	Yes	yes
including use of the RCP Guidelines (see text)	Rec.	Yes
Continuing Education	Rec.**	Yes

* Current EPA proficiency programs do not recognize diagnostic specialists as a separate professional class
** Will be required after July 1991
*** Required for on-site supervisor only, recommended for all staff
Rec. - Recommended

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TITLE: New Jersey's Program - A three-tiered Approach to Radon

AUTHOR: Jill A. Lapoti, New Jersey Department of Environmental Protection

This paper was not received in time to be included in the preprints and the abstract was not available. Please check your registration packet for a complete copy of the paper.

Session VII:

State Programs and Policies Relating to Radon -- POSTERS

Quality Assurance - The Key to Successful Radon Programs in the 1990's

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In order to reach EPA's goals for radon abatement in the United States during this decade, Federal and state programs, as well as those of private industry will need a strong commitment to quality. To deal with public apathy and to assure credibility for convincing government agencies and school districts to take action will require a partnership for quality among those agencies, professional and trade associations, and the radon industry. Most people will not commit their hard earned resources when they perceive poor quality or uncertainty in health risk analyses, radon measurements, or mitigation technology.

During the 1980's, thousands of companies entered the radon industry. Many of these businesses have succeeded, many have failed. The factor determining success or failure was most often a matter of quality; quality of management, quality of service, quality of products, quality of analyses, and quality of technology. Continuing success for these companies will depend on their emphasis on quality in every aspect of their business. This statement also applies to Federal and state programs. Successful programs will implement the principles of good quality assurance, not just in their measurement programs, but also in their customer service programs, their written and verbal communications, their staff training, in production and sales, in accounting, in management, in state-of-the-art technology, in ethics, and in professionalism.

For credibility with the general public, Federal and state programs need to work with the private sector to assure the highest quality in communications. With so many demands on their attention, an increasingly knowledgeable public will not respond to anything less than the highest quality in print, voice, or video media. Customer service for both the government and the radon industry will need to be prompt, efficient, courteous, careful, knowledgeable, cheerful, and follow-up on commitments. The public has no patience for anything less in service. Staff people must be well trained. Companies in the radon industry must realize that radon measurement and mitigation are sciences that require careful attention to technology. Learning this technology and keeping up with new developments requires a commitment to training.

Successful federal and private programs will need high quality management. The public will not support programs when they have doubts about the integrity, ethics, professionalism, and competence of management. It is up to management to set the standards for quality and to demonstrate quality by their own example. To achieve a quality revolution in radon abatement programs will require that management at every level become obsessed with quality. A commitment to quality means that quality is at the top of every agenda. It means insisting on quality in every aspect of radon programs. It means measuring every action, service, or product for quality, and constantly striving for improvements. It means training everyone to assess quality and establishing rewards for quality. It means involving all the players in the government, professional, and private sectors. Furthermore, quality improvement never ends. To recognize and implement all of these attributes of quality programs is the surest road to successful radon programs in the 1990's.

Radon In Illinois: A Status Report

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ABSTRACT

The Illinois Department of Nuclear Safety (IDNS) has performed radon screening measurements in approximately 4,100 homes in 98 counties. Results indicate about 39 percent of the basements tested have radon levels that exceed the U.S. Environmental Protection Agency (EPA) guideline of 4 picocuries per liter (pCi/L) and 1 percent have levels greater than 20 pCi/L. About 11 percent of first floor areas tested have levels greater than 4 pCi/L and less than 1 percent have levels greater than 20 pCi/L. In total, about 31 percent of all homes tested have radon levels greater than 4 pCi/L. If these results represent the entire state, this could mean as many as one million homes in Illinois have levels above EPA guidelines.

The screening program has not indicated any areas in Illinois that face a serious health risk from radon, but there are some areas with a significant percentage of homes with screening results in excess of 4 pCi/L, which merit additional study. Radon may, however, cause significant economic problems for those homeowners with homes greater than the action level. Comparisons between house construction characteristics and radon concentrations show no particular feature or combination of features clearly contributes to high radon concentrations.

Although radon concentrations in Illinois are not as high as in some other states (e.g., Pennsylvania), there is still the potential for a health hazard needing to be addressed by IDNS and other agencies. Publicity has increased public concern about radon, proper methods for measuring radon levels and the ability of private companies to provide effective services for reducing levels of radon. There is also considerable concern over the need for and quality of radon measurements conducted when required for real estate transactions. IDNS is assisting the public in coping with these issues. Additional efforts which should be undertaken by IDNS include follow-up studies in neighborhoods identified as potentially exhibiting elevated levels of radon, and the sponsorship of a training and certification program for radon mitigation contractors.

INTRODUCTION

Because of the significance of radon, Governor James R. Thompson established a task force in June 1986, to investigate the problem of indoor radon in Illinois and report its findings and recommendations. The task force recommended that IDNS be designated the lead agency in the development, implementation and coordination of a comprehensive statewide indoor radon monitoring program. Since the task force recommendations were announced IDNS has conducted studies to 1. locate houses in Illinois with high radon levels; 2. estimate the number of houses in Illinois that might have elevated radon levels; 3. assess the range of indoor radon exposure to Illinois citizens; and 4. determine if any geographic regions that, because of particular geological or other conditions, have greater potential to increase public radon exposure (1). The current Illinois radon program also addresses the question of radon exposure potential in nonresidential structures such as schools and is involved in radon reduction projects, public education programs, and training and registering individuals that place radon detectors in structures.

NOTES ON 1990 UPDATE

This report is an update of the November 1988 version of "Radon in Illinois, A Status Report" (2). The Radon Mitigation Act of 1989 requires IDNS to submit a report to the General Assembly describing its findings and recommendations regarding the existence and nature of the risk from radon in dwellings and other buildings in Illinois. This update is intended to serve that purpose. The 1990 report contains new information on:

- Illinois residential screening project;
- Illinois legislation;
- IDNS sponsored training; and
- the State Indoor Radon Grant program

THE ILLINOIS RADON SCREENING PROGRAM

IDNS designed its radon program as a joint state/local effort wherever possible. To facilitate this effort, training programs for local government personnel were held in areas where these groups were interested, and radon monitoring was conducted as a joint study. IDNS completed such training programs in the city of Chicago and in more than 80 counties throughout the state, usually involving local or regional public health or environmental health agencies or the Illinois State University or the University of Illinois Cooperative Extension Service.

The first phase of the program was screening Illinois residences using alpha track detectors. The detectors were deployed for no less than two weeks, but no greater than three months. For logistical purposes, the statewide screening was conducted on a county-by-county basis. The number of detectors placed in each county was determined by using geographical and population density considerations but limited by the resources of the department. A minimum of 30 homes were monitored in each county screened with at least one home per township. In counties with city populations representing a majority of the county, the city was allocated detectors for an additional 30 homes. Greater numbers of detectors were allocated to the six northeastern counties, due to a high population density. The number placed was proportional to the county population.

IDNS SCREENING PROTOCOL

Detectors were placed in the lowest livable area of the home whenever possible according to EPA protocols (3). Houses with no livable basement were screened using first floor measurements. Most of the measurements were taken during the heating season. Although homeowners were not instructed to create artificial closed-house conditions, as they would during a 2-day charcoal screening, it is assumed that most homeowners kept their doors and windows closed during the heating seasons.

Homeowners participating in the screening were interviewed using a questionnaire that included questions on the structural features of their homes and use of living areas and appliances. The results of the interviews were compiled and related to the results of the screening measurements. Screening measurement results were forwarded to the homeowners and to IDNS.

EPA recommends follow-up measurements for any house which has a screening result at or above 4 pCi/L and a decision to mitigate be made on the basis of the follow-up measurement results (4). The higher the exposure rate, the sooner mitigation should be performed. IDNS recommended homeowners conduct annual follow-up measurements in any home which had a screening result of 4 to 20 pCi/L. Annual measurements can be made by using alpha track detectors for a year or can be made using a series of seasonal shorter measurements (4). For homes which had a screening result greater than 20 pCi/L, follow-up measurements were offered by the department to verify the screening result and to determine whether radon mitigation efforts should be recommended.

To standardize this process, an averaged annual living area exposure of the residents was calculated using the wintertime basement screening results and the ratio of spring living area to basement follow-up measurements. Three annual living area exposures were calulated then averaged for each home. The annual living area calculations were based on comparisons of 728 three-month measurements with year-long measurements made in the Reading Prong area and seasonal data collected in Illinois homes (5). If the averaged annual living area exposure was estimated to be greater than 8 pCi/L, then the homeowner was advised to take remedial action without further delay. If this average was between 4 pCi/L and 8 pCi/L, then an additional six-month measurement was recommended. Combined results of all measurements were then used to determine whether mitigation was indicated.

SCREENING RESULTS AND DISCUSSION

As of September 1990, IDNS had performed screening measurements in 4,063 homes in 98 Illinois counties, as illustrated in Figure 1. These screening data are summarized in Table 1. The indivual county radon averages are shown on Figure 2. The current data indicate 39 percent of the basements tested have radon levels that exceed the EPA guideline of 4 pCi/L and 11 percent of the first floor areas have such levels. In all, 1,263 homes sampled taken exceeded 4 pCi/L. This is about 31 percent of the total.

The sample of houses screened to date is a small fraction (about 0.16 percent) of the 2.5 million privately owned houses in Illinois, but if this sample is representative, about 975,000 of the houses in the state may have elevated basement levels and 275,000 houses may have elevated first floor levels. Since this is a significant number of homes from both a public health and an economic standpoint, and since there are yet no methods that reliably predict the radon concentration in a given house, IDNS continues to recommend that all homeowners conduct radon tests. The frequency distribution of the data is shown in Figure 3. The data suggest a log-normal distribution. This is consistent with Cohen's analysis of data taken nationwide (6).

RESULTS OF OTHER STUDIES

The EPA conducted a thirty four state joint EPA/state radon screening program (7). This study indicated that from 0.4 to 70 percent of the houses in those states have the potential for elevated radon levels, as compared to the current Illinois combined estimate of 31 percent. IDNS plans to participate with the EPA in a joint screening during the 1990-91 heating season. The results obtained during the EPA study cannot be compared directly to those obtained by IDNS because the EPA studies are performed using charcoal canisters.

Earlier results compiled by a major supplier of alpha track detectors showed 30 percent of all radon measurements across the country were above the 4 pCi/L level (8). These results are in good agreement with the radon levels in Illinois homes. The average concentration of indoor radon in this national study, 3.9 pCi/L, is approximately equal to the EPA guideline.

EFFECT OF HOUSE CONSTRUCTION CHARACTERISTICS ON INDOOR RADON

A closer examination of the distribution of radon results by house construction characteristics was done to develop a better understanding of the behavior of radon in various types of homes. The following information was provided by homeowners and compiled in a database along with the screening results:

- age of house;
- type of substructure (basement, slab or crawlspace);
- primary heating source (gas, oil, electric, others);
- basement characteristics such as cracks or drains; and
- crawlspace characteristics such as exposed earth.

Homeowners were also asked to rate their home subjectively according to its energy efficiency on an arbitrary linear scale.

An attempt was made to compare these features and characteristics with either high or low radon concentrations. Results are presented in Table 2.

The age of the house was not a good indicator. Homes less than 15 years old should be more energy efficient than older homes but no increase in radon concentration was found in these homes. On the other hand, homes greater than 50 years old are thought to be drafty but on the average they were not lower in radon concentration. Unfortunately more than 86 percent of the homeowners in the study rated their home energy efficiency as "good" or "excellent;" so little could be drawn from this information, although the average level in these houses (4.0 pCi/L) was slightly higher than those rated "not at all" or "somewhat" energy efficient (3.1 pCi/L).

Although successful radon mitigation efforts almost always depend on a well-sealed basement floor, there was little evidence that houses with basement floor leaks and cracks automatically have high radon concentrations. The presence of exposed earth either in a basement or accessible crawlspace seemed to be a common factor in many of the higher concentration homes. Homes with crawlspaces that are fully ventilated and not accessible from the basement tended to be lower in radon than the average.

Several studies have failed to show a correlation between certain home construction features and high radon concentrations. A survey conducted by Cohen of 453 houses in 42 states found only weak correlations between radon levels and home construction features (6). One of Cohen's conclusions was that geological factors might control radon levels to a greater degree than construction features. This poor correlation precluded public health officials from focusing efforts on specific types of houses or ruling out radon problems for significant numbers of homeowners.

EFFECT OF GEOLOGICAL FACTORS ON INDOOR RADON

It is not clear whether there are any particular geological formations in Illinois which contribute to high radon exposures. There is no evidence of any areas with radium concentrations similar to those in the Reading Prong area, but radium levels do vary across the state and Illinois soils do exhibit varying permeability and moisture content. Some investigators tried to link the National Uranium Resource Evaluation (NURE) data with indoor radon levels, but the NURE data is useful only for locating uranium and other nonspecific gamma ray anomalies.

Since IDNS did not have the resources to study geological factors directly on a statewide basis, the original approach was to rely on the statewide screening program to identify clusters of homes with elevated radon levels. This was to be done by screening neighborhoods around homes with confirmed radon levels above 20 pCi/L. It was then planned to study the geology in these local areas. Due to lack of resources, this neighborhood screening program was postponed. As indicated in Table 1, the department identified about 44 neighborhoods that should be studied.

There are no known areas of the state which exhibit consistently elevated radon levels, such as those found in Pennsylvania. The highest result recorded was 75.6 pCi/L in DeWitt County. Although no other homes in that county were above 20 pCi/L, the average result for the county was about 7 pCi/L. Other very high values were found in the state but they were due to the disposal of radium wastes and not due to natural conditions.

Illinois screening data identified regions of the state that exhibit higher than average radon concentrations. These regions are in north central and northwestern Illinois. IDNS identified 18 counties where the majority of the screening measurements were greater than 4 pCi/L (see Figure 4). The Chicago area was not identified as a problem area relative to the rest of the state, but there may be small local areas of higher than average radon. IDNS has attempted to develop a simple description of the geographical boundary of the area of greatest concern. This proved difficult. Note, however, that the area with zip codes beginning with "61" are about twice as likely to have a screening measurement in excess of 4 pCi/L than areas with zip codes beginning with "60" and "62".

RADON IN SCHOOLS

Not all personal radon exposure can be attributed to private residences. Studies are in progress to determine what fraction of personal radon exposure is due to exposure at home. Some factors that allow radon to enter houses also apply to commercial and public buildings. Some public buildings are of particular concern due to potential radon exposure to children. Because of this concern, IDNS initiated a screening program for schools. The program has had two phases thus far. In the first phase, for each of 21 counties screened, two elementary schools were selected for participation. Six detectors were placed in each school with at least two detectors placed on each level. Detectors were placed only in areas frequented by students, such as classrooms, libraries and lunchrooms. Some basement areas fell into this category. Detectors were left in place between one and two months. Screenings, conducted on this limited basis, indicate about 25 percent of the student areas contained radon levels exceeding 4 pCi/L.

Most recently, IDNS performed long term alpha track measurements in all public schools in Clark and Wayne counties. A total of 25 schools were tested. Only one student area had radon levels in excess of 4 pCi/L. Data for all schools are listed in Table 3.

IDNS has been involved in screening, follow-up and diagnostic measurements at a group of Peoria schools since February 1989. At that time, IDNS placed 125 EPA charcoal detectors in six schools for a three-day test. The results ranged from 0.5 to 19.6 pCi/L. Follow-up tests were conducted by IDNS using alpha track detectors in 26 student areas that had screening results in excess of 4 pCi/L.

In November 1989 the EPA Office of Research and Development (ORD) proposed a project to perform diagnostic measurements in schools to develop effective mitigation strategies. EPA Region V suggested a group of Peoria schools that were tested during the February 1989 study be considered for the ORD School Diagnostics and Mitigation Strategy Project. IDNS contacted Peoria School District 150 administration, who agreed to participate. EPA and IDNS representatives conducted a walk-through audit and made radon diagnostic measurements at the Harrison, Tyng and Calvin Coolidge schools and determined these schools were suitable for the ORD project.

In February 1990, the IDNS officially proposed to ORD that the Peoria schools should be considered for the project. IDNS staff recommended the radon levels in one room of Harrison and Tyng and three rooms in Calvin Coolidge be reduced to below 4 pCi/l based upon their three-season averages. In May 1990, the ORD team performed the diagnostic measurements in Harrison, Tyng and Calvin Coolidge schools. The team reviewed the diagnostic data and developed a report that recommends an optimum radon mitigation strategy for each school. The report suggests the radon problems are caused to some degree by inoperable HVAC systems.

Schools are not yet required by either federal or state law to test for radon. However, IDNS encourages all schools to conduct screenings for the same reasons home testing is recommended. Some school districts voluntarily tested for radon, but many others are reluctant to do so for two reasons. First, while radon screening costs may be relatively low, school officials do not believe they have sufficient resources to mitigate radon problems if they are discovered. Secondly, since there are no mandatory protocols for radon testing, school officials are concerned that tests conducted now may not be valid once mandatory protocols are adopted. Even when voluntary tests are conducted, school officials are reluctant to disclose results to IDNS. As a result, IDNS has little information regarding the scope and results of voluntary testing.

RADON IN PUBLIC BUILDINGS AND IN THE WORKPLACE

Very little testing in public buildings and workplaces has been conducted. As with private residences, commercial properties are being tested for radon when sold, but there is not a significant effort on the part of employers to characterize employee workplaces. To our knowledge, the Occupational Safety and Health Administration has not made radon exposure a high priority compliance item. More research is needed to determine the nature and extent of radon problems in commercial and industrial structures.

The Illinois Secretary of State (SOS) is the custodian of many of the state government buildings in Springfield. IDNS and SOS conducted a screening study of 26 buildings in Springfield in 1989. The results ranged from 0.3 to 15.2 pCi/L. As a result of this screening, IDNS recommended follow-up measurements be made at three locations. SOS took follow-up steps at all three locations. The most interesting mitigation was conducted in the basement of the state capitol. Grab samples in the electrical shop of the capitol ranged from 13.4 to 21.7 pCi/L. The capitol is a complex structure with underground passageways and ventilation plenums exposed to soil. Very little fresh air was being routed to the shop area. In this case, changes in the HVAC system were needed to solve the radon problem in the shop and bring radon concentration down below 4 pCi/L.

REDUCING RADON EXPOSURE

The objective of the statewide radon program is not only to identify any problems related to radon exposure, but to provide recommendations for remedial action to reduce radon exposure. Most IDNS follow-up studies in houses with elevated radon levels involve evaluating causes, as well as confirming screening measurements. Radon is not only a significant public health issue, but also an economic issue. If 31 percent of Illinois residences ultimately prove to have levels greater than 4 pCi/L, this translates to about one million homes. The cost of reducing radon levels could range from $200 to $2,000 or more per home, meaning a potential cost of $200 million to $2 billion to Illinois citizens. These cost estimates apply only to private residences and do not include public or commercial buildings.

IDNS EXPERIENCE IN RADON MITIGATION EFFORTS

In 1988 IDNS staff completed a remediation project at a home in Schaumburg. At the request of the village of Schaumburg, IDNS provided technical assistance including evaluation of the radon levels; diagnosis of the source; and routes of entry and recommendations on a reduction method. Grab sample measurements indicated that a basement sump and the heating ductwork beneath the slab-on-grade portion of the house which penetrated the adjacent basement wall were the major entry routes. Sealing the sump hole and other minor radon entry routes was not effective in reducing the basement radon levels to below 4 pCi/L. A drain tile ventilation system using the existing drain tile loop and sump hole was then installed. This active system reduced the radon levels to about 2 pCi/L. Details of this mitigation effort are reported elsewhere (9).

At the request of the Illinois Department of Energy and Natural Resources (ENR), IDNS monitored radon levels and assisted in a remedial action project at the Springfield Energy House. This house was designed and built by ENR to demonstrate the value of energy efficient building techniques and features. The features include a super-insulated shell to reduce heat loss and an underground ice storage cooling system to provide air conditioning in the summer (10). Since it is suspected that homes with low air exchange rates have high radon levels, the house was screened and found to have high concentrations in localized areas. The main route of entry for radon was the penetration from the basement to the ice storage unit. Once this penetration was sealed, an annual follow-up measurement was made. The average general living area concentration was found to be 3.8 pCi/L.

IDNS is concerned about the availability and reliability of radon mitigation contractors. Currently there is no requirement for radon mitigation contractors to register with the state, nor is there a mandatory certification program run by the federal government. IDNS recommends that homeowners employ contractors who have successfully completed the EPA Radon Contractor Proficiency Program. This program is available to Illinois contractors through the Midwest Universities Radon Consortium (MURC). Some radon mitigation work is currently being done by contractors with previous experience in home renovation and remodeling, but whose education and experience in radon detection and mitigation techniques are not known.

PUBLIC EDUCATION PROGRAMS

A major objective of the Illinois program has been to inform and educate the public about radon. As part of this program, IDNS provides basic information about indoor radon and its associated health risks, together with information about radon monitoring. A total of 30 presentations were given between January 1989, and July 1990, on general radon awareness. Another 30 presentations were given in conjunction with the statewide residential radon screening study. These presentations were designed to train local volunteers to place radon detectors in accordance with IDNS protocols and to complete the documentation needed for the study. Because the results of the statewide monitoring program cannot be used to predict radon levels in specific houses, IDNS encourages occupants to monitor their own houses and to report high results to IDNS.

In order to facilitate this process, IDNS distributes a list of firms supplying devices that passed the EPA radon monitoring proficiency test. A variety of additional radon-related instructional materials have been distributed to the public, including over 15,000 copies of the "Citizens Guide to Radon" (1986 edition) prepared by the EPA and reprinted by IDNS.

Information about radon mitigation contractors has been only recently avaiable though the EPA radon contractor proficiency program. At the federal level, the EPA has started a radon contractor proficiency program, but participation is voluntary and therefore limited. IDNS has received citizen complaints against contractors, but the department does not have any regulatory authority over radon mitigation contractors. Both specific regulatory authority and the resources to sponsor training to contractors would provide significant consumer protection and increase public confidence in the program.

From July 1986, to February 1988, the department funded and staffed a toll-free radon information "hotline" to provide information on radon to Illinois citizens. During this period, an average of 500 calls per month were received. Funding and staffing were suspended for this program in 1988 but resumed in August 1990.

In March 1987, the department sponsored a conference on radon, radium and environmental radioactivity. One full day was devoted to talks on radon in homes, radon risk evaluation, geological considerations, monitoring procedures and mitigation techniques. The conference was designed for Illinois citizens, public health agencies and environmental groups, and was attended by about 500 people.

County and other local government agencies have expressed interest in assisting with public education, but have limited resources to conduct large scale programs. IDNS supplies these agencies with speakers, technical advice and printed information for distribution by their offices.

ILLINOIS LEGISLATION

Two key pieces of radon-related legislation were passed during 1989. The Radon Mitigation Act authorizes the IDNS to establish and coordinate a comprehensive program for detecting and reducing the amount of radon in homes and other buildings in Illinois. The act exempts radon results obtained by IDNS from disclosure requirements of the Freedom of Information Act. This is an important step forward allowing IDNS staff to continue radon studies while protecting the participants' property values. The bill also enabled IDNS to secure independent general revenue funding from the Illinois General Assembly for radon related projects.

House Bill 1611, "An Act in Relation to Radon Testing", authorizes IDNS to establish a registration program for persons selling any device or performing any service for compensation to detect radon or its decay products. The program is intended to regulate those who place passive detectors in structures or who perform measurements using working level monitors, grab samplers and other active methods. Rules for implementation of this program (32 Illinois Administrative Code 420) were published in the Illinois Register on November 30, 1990. IDNS estimates there will be 300 registrants in this program.

IDNS SPONSORED TRAINING

In anticipation of the implementation of these rules, IDNS and the MURC co-sponsored three training sessions on radon measurements for potential registrants. The sessions were held in Mt. Vernon, Bloomington and Des Plaines during the week of April 9, 1990. A total of 110 people attended, but the sessions were overbooked by a considerable margin. IDNS plans to repeat the sessions as soon as the rules are final.

EPA GRANT

On May 1, 1990, IDNS was awarded a grant under the State Indoor Radon Grants program administered by the EPA. Under the provisions of the grant, IDNS will undertake a greater number of projects than it would using only state funding. Some of these projects include participating in the EPA/state screening program; providing a limited number of free radon detectors to low income school districts identified by the state Board of Education; coordinating a school mitigation demonstration project; conducting a follow-up study in neighborhoods identified as potentially exhibiting elevated levels of radon and conducting a study of Illinois building codes as they relate to radon resistant new construction.

CONCLUSIONS

1. IDNS has performed radon screening measurements in approximately 4,100 homes in 98 counties. Results indicate about about 31 percent of all homes tested have radon levels greater than the EPA standard of 4 picocuries per liter. The screening program identified certain areas in Illinois with significant percentages of homes with screening results in excess of the standard that merit additional study.

2. Schools are not yet required to conduct radon testing. IDNS has little information regarding the scope and results of voluntary testing, but is concerned that the uncertainties regarding costs of mitigation and testing are forcing school officials to postpone testing until it is mandatory.

3. IDNS is providing a wide variety of educational information in response to public inquiries. This effort is, for the most part, a reactive effort and therefore limited in scope. Although radon has received considerable publicity, most members of the public still need basic information about radon. News reports and public service announcements provided by the media have been

either misleading or ineffective.

4. The registration and training of persons performing radon measurement services are good initial steps toward assuring consumer confidence in radon services in Illinois. Radon mitigation services are still not covered under the program.

5. Radon reduction in homes is still primarily a post-construction activity in Illinois. There is no significant effort on the part of builders or architects to incorporate radon resistant features in new construction.

6. Radon measurements made for the purpose of satisfying provisions of a real estate contracts are not being conducted according to any specific protocols or quality assurance guidelines. This causes considerable difficulty for homeowners whose transactions depend on accurate results. Erroneous results may cause delays in the transaction, or may force a homeowner to install costly mitigation equipment where it is not needed.

RECOMMENDATIONS

1. Complete the radon screening of all Illinois counties. Four counties remain to be screened before the project is considered complete.

2. Conduct follow-up studies in neighborhoods where local clusters of homes with potential radon problems are suspected. This would help to identify localized areas where the geological conditions could be studied.

3. Encourage and support voluntary testing by schools. This could be done by conducting briefings for school administrators, conducting mitigation demonstration projects and by providing free detectors to a limited number of low-income school districts.

4. Continue to develop more active approaches to public education. This might include providing radon information to large numbers of schools and libraries. More effort is needed to educate the media as well. IDNS staff should continue to respond by sending radon information to members of the media and by making department representatives available for interviews.

5. Develop and implement a certification program for persons or companies who perform radon mitigation services. Although EPA conducts a voluntary program, Illinois has no mechanism for formally recognizing participation in the program. In conjunction, IDNS should continue to develop and conduct training programs for those who offer mitigation services as well as measurement services.

6. Evaluate the need for changes in building codes in Illinois, since the construction of radon resistant structures is the only long term solution to the indoor radon problem. Illinois should follow the lead of states in the eastern U.S. that have adopted radon resistant features in building codes.

7. Work with the EPA and with the Illinois Association of Realtors to arrive at a consensus regarding protocols and quality assurance associated with radon measurements made for real estate transactions.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

ACKNOWLEDGEMENTS

For their assistance in providing the field staff for the Illinois radon screening program the authors thank the Illinois State University, the University of Illinois Extension Service and local county health departments.

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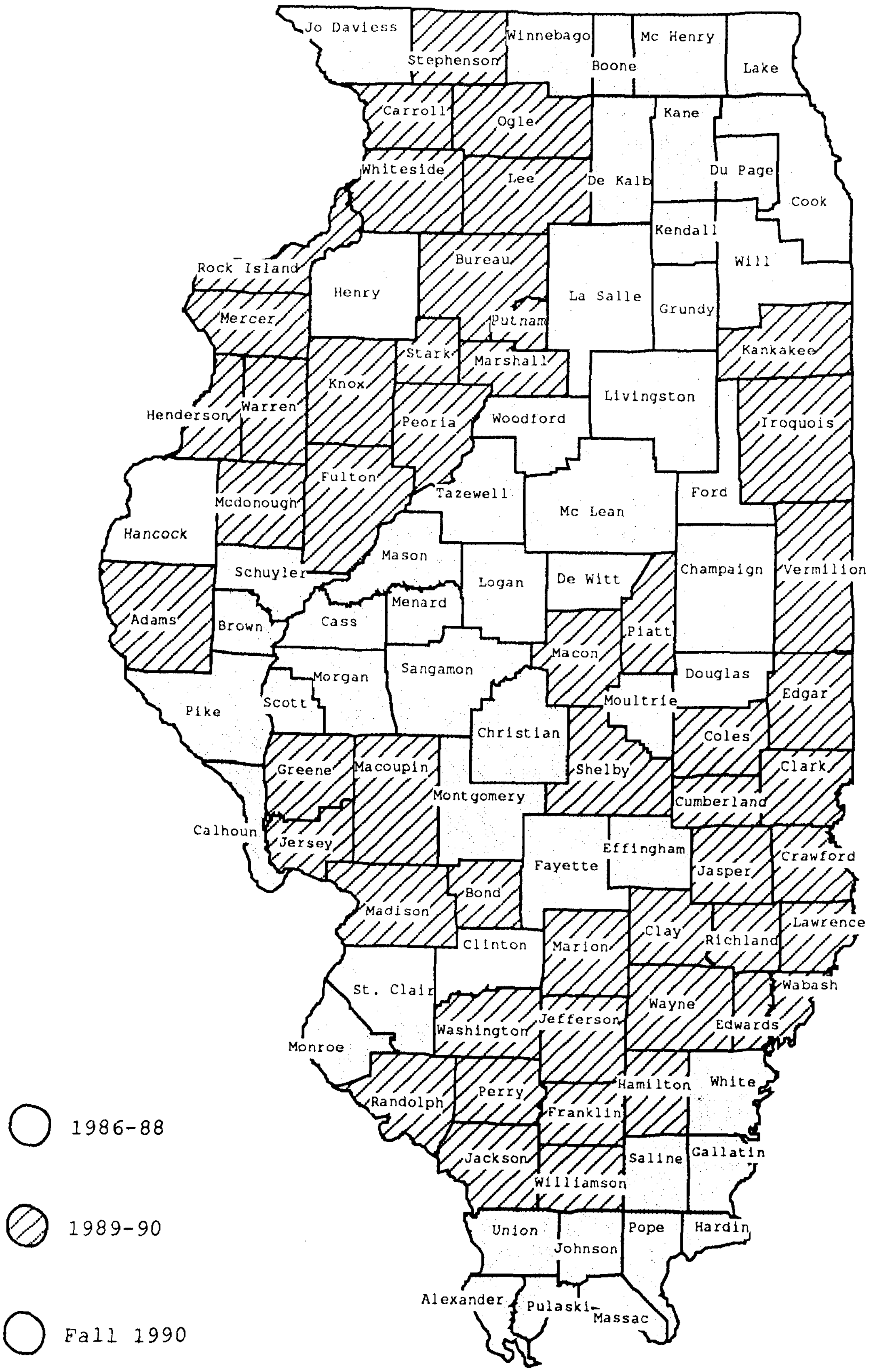

Figure 1. Illinois Radon Screening Status September 1990

Figure 2. Average Radon Concentration (pCi/L) by County

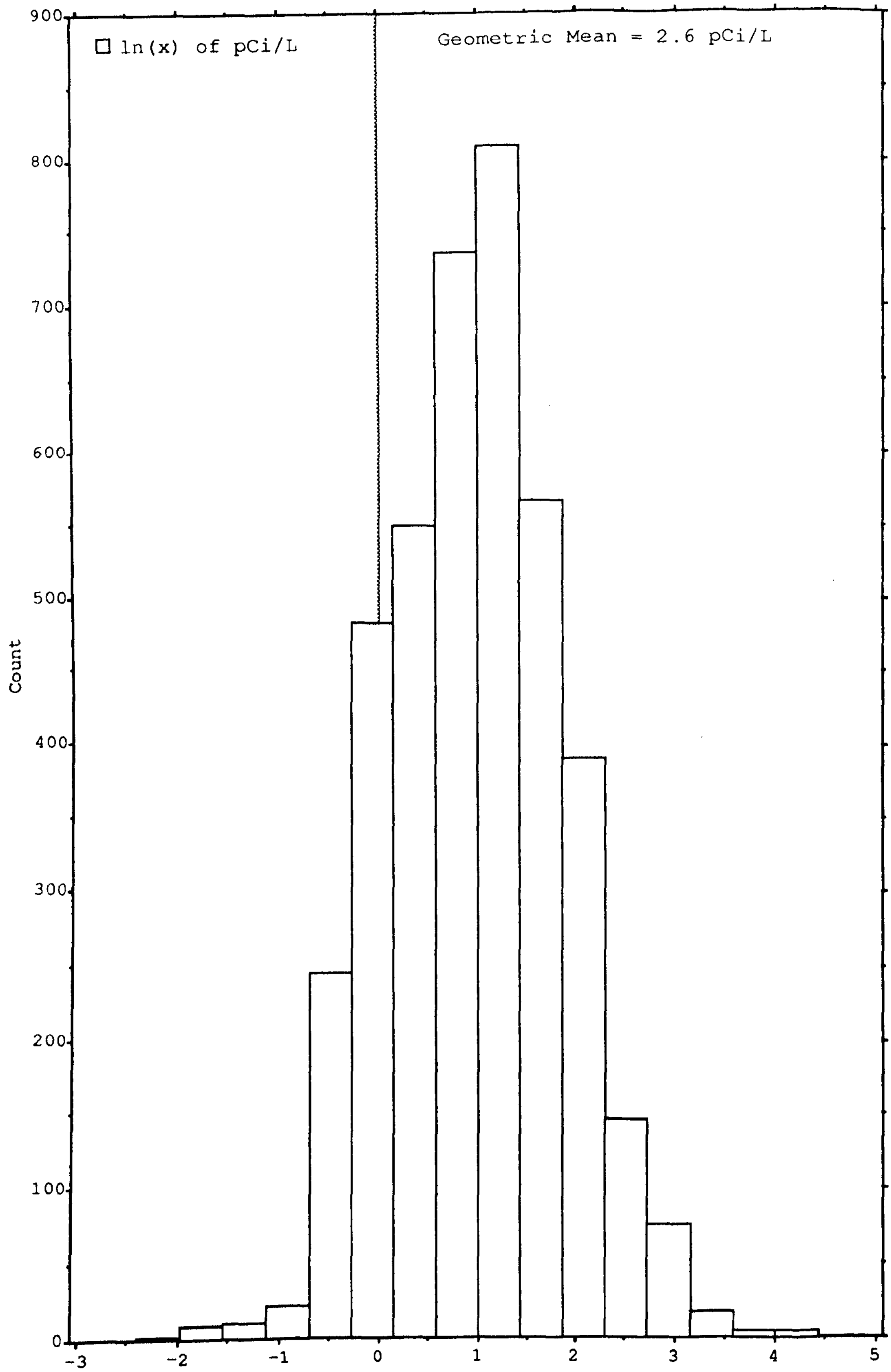

Figure 3. Frequency Distribution of Radon Results

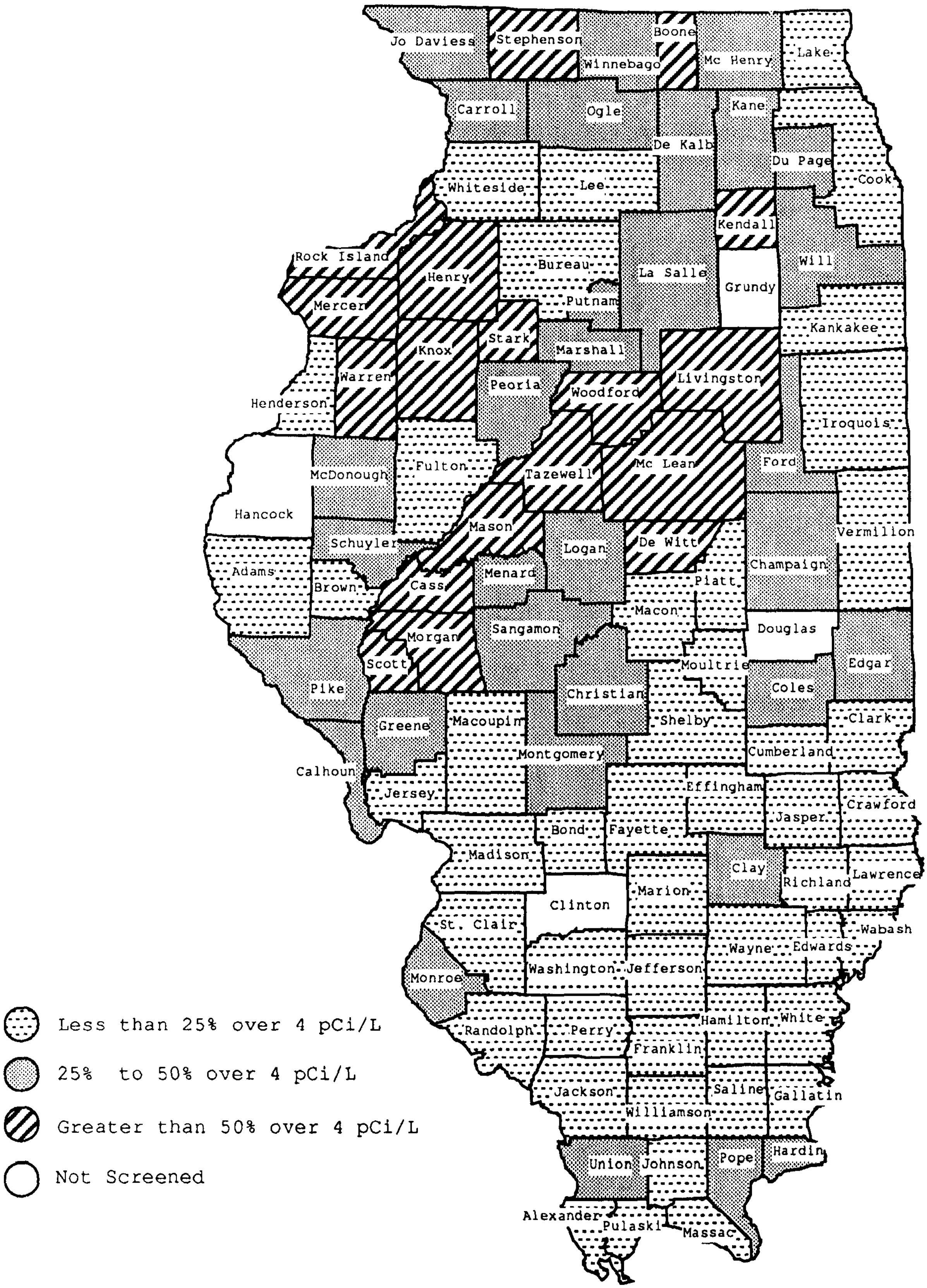

Figure 4. Illinois Screening Program December 1990

Table 1

SUMMARY OF ILLINOIS RADON SCREENING RESULTS BY LIVING AREA

Living Area	Number	Min Result	Avg Result	Max Result	#>4 pCi/L	%>4 pCi/L	#>20 pCi/L	%>20 pCi/L
Basement	2920	0.1	4.6	75.6	1132	39	43	1
First Floor Bedroom	650	0.3	2.3	19.3	81	12	0	0
First Floor Living Area	467	0.1	2.1	23.2	47	10	1	0
Other	26	0.6	2.3	12.2	3	12	0	0
Total	4063	0.1	3.9	75.6	1263	31	44	1

Table 2

COMPARISON BETWEEN RADON CONCENTRATIONS AND BUILDING CHARACTERISTICS

Age of House	Number	Average (pCi/L)
Less than 15 years old	919	3.9
Greater than 50 years old	1388	4.1
Substructure Type	**Number**	**Average (pCi/L)**
100% Basement	1760	4.1
100% Slab	164	3.4
100% Crawlspace	535	2.0
Basement and Slab	223	5.1
Basement and Crawl Space	880	4.6
Subjective Energy Efficiency	**Number**	**Average (pCi/L)**
Not at all	184	3.2
Somewhat	37	2.5
Adequate	333	3.6
Good	1302	3.9
Excellent	2272	4.0
Basement Characteristics	**Number**	**Average (pCi/L)**
Exposed Earth	239	5.3
Sump(s)	885	4.5
Crack(s)	784	4.6
Drain(s)	1660	4.6
None of the above	50	3.5
All of the above	39	5.6
Crawlspace Characteristics	**Number**	**Average (pCi/L)**
Crawlspace Entry & Exposed Earth	480	4.7
Crawlspace Vented	504	3.1
Primary Heating Source	**Number**	**Average (pCi/L)**
Solar	5	7.5
Oil	174	4.8
Electric	421	3.8
Natural Gas	2689	4.0
Propane	448	3.8
Wood	174	3.0
Coal	6	1.5
Other Factors	**Number**	**Average (pCi/L)**
Central Air Conditioning	1367	4.2

Table 3

SCHOOL RADON SCREENING RESULTS
pCi/L

County	Basement		1st Floor		2nd Floor		3rd Floor	
	n	Range	n	Range	n	Range	n	Range
Calhoun	3	2.1-3.8	13	1.1-3.3	2	0.5*-1.9	0	
Champaign	2	3.2-4.5	3	1.7-4.2	3	1.4-3.7	2	0.8*-1.2
Clark	0		204	0.1*-4.3	0		0	
DeWitt	2	3.4-3.9	6	1.4-3.2	2	2.0-2.8	0	
Effingham	0		4	0.8*-1.2	4	0.8*-1.2	0	
Ford	1	4.6	7	1.5*-2.9	2	0.8*-1.4	2	0.7*-2.4
Gallatin	0		4	1.3-2.1	2	1.4-1.7	2	1.4-1.5
Henry	0		8	1.2*-10.0	2	0.8*-2.2	2	1.1-1.5
LaSalle	1	2.3	10	0.8*-2.2	1	0.8*	0	
Livingston	0		7	0.7*-1.5	2	1.9-3.8	2	0.7*-0.7*
McLean	0		5	4.3-9.2	5	3.3-8.0	2	3.2-5.0
Monroe	0		6	0.9-3.0	6	1.0-2.7	0	
Montgomery	0		8	1.6-3.2	2	1.7-1.8	2	1.0-1.5
Moultrie	0		2	2.3-4.5	2	1.0-1.2	2	1.7-1.8
Pike	2	2.3-6.0	15	0.2*-5.8	1	1.3	0	

Table 3 (cont'd)

SCHOOL RADON SCREENING RESULTS
pCi/L

County	Basement		1st Floor		2nd Floor		3rd Floor	
	n	Range	n	Range	n	Range	n	Range
Saline	3	1.5-4.4	3	0.7-1.6	3	0.7*-1.4	0	
Sangamon	1	25.8	1	1.9	1	3.1	0	
Schuyler	0		8	1.1-6.3	2	1.1-2.2	2	1.5-1.7
St. Clair	0		6	1.6-3.1	0		0	
Wayne	36	0.1*-1.4	241	0.1*-3.6	0		0	
White	0		4	0.7-1.6	4	0.7-2.2	0	
Will	0		8	0.9*-2.3	2	0.5*-0.9*	2	1.4-1.4
Woodford	0		4	0.8*-5.6	4	1.0-3.4	3	1.2-2.7

* Less Than Minimum Detectable Concentration
n = Number of rooms measured.

Session VIII:

Radon Prevention in New Construction

TITLE: Long Term Monitoring of the Effect of Soil and Construction Type on Radon Mitigation Systems in New Houses

AUTHOR: D.B. Harris, EPA - Office of Research and Development

This paper was not received in time to be included in the preprints so only the abstract has been included. Please check your registration packet for a complete copy of the paper.

ABSTRACT The influence of 3 soil conditions and 3 new home construction types on the performance of radon mitigation systems has been monitored for more than 6 months. Data collected in 2 homes of each combination included soil radon sub-slab and in the surrounding yard, slab movement and indoor radon. 2 unmitigated homes were used as controls. A master home was monitored with continuous instrumentation including radon, differential pressures and temperatures as well as weather data. Initial anaysis shows a strong increase of indoor radon with precipitation events or frontal passage. Significant slab movement has been seen in three houses with the polyurethane floor-to-wall seal rupturing in two and severe cracking in one necessitating replacement of the entire slab. Further analyses of these data are presented.

A COMPARISON OF INDOOR RADON CONCENTRATIONS BETWEEN PRECONSTRUCTION AND POST-CONSTRUCTION MITIGATED SINGLE FAMILY DWELLINGS

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ABSTRACT

We have done a detailed study comparing indoor radon concentrations among single family dwellings in Colorado Springs that were mitigated prior to the completion of construction and similar buildings that were mitigated after construction. There appears to be evidence which indicates that "preconstruction" mitigation is more effective at lowering indoor radon concentrations than "post-construction" mitigation.

A total of 102 owners of single family dwellings, in two different areas within the city, agreed to participate in the study. Thirty-nine homes formed the preconstruction mitigation category (with 14 of these homes having only passive systems), 24 had been mitigated after construction and the final 39, chosen as a control group, had never been mitigated but shared similar soil and surficial geological features with the mitigated homes (including distance to nearby faults). Eighty nine homeowners successfully completed the test. All of theses houses were tested over the same 48-hour period, under closed-house conditions, thereby controlling the variables of weather and, to some extent, occupants' usage.

By analyzing the data obtained, we can conclude that there is a statistically significant difference in post-mitigation indoor radon concentrations (as measured by simultaneous charcoal screening tests) between the preconstruction and the post-construction mitigated homes. The preconstruction category exhibited the lower radon average, although both mitigation categories had averages below 4.0 pCi/L. Such a conclusion could have an impact on current mitigation practices, especially as they pertain to new housing construction.

Esthetics, installation costs and operating costs of the two mitigation techniques (pre and post-construction) are also discussed herein.

INTRODUCTION

The purpose of this study is to assess the relative effectiveness of radon reduction methods in residential structures when they are utilized after the home is constructed as opposed to when the home is mitigated prior to the completion of construction. It is hoped that the results discussed herein will provide information for the building industry and those agencies which assist it in developing approaches to mitigating new and existing homes.

This study was conceived by the authors when it was noted that data collected from post-mitigation testing over the last three years were giving the indication that post-construction mitigation provided similar results to mitigations performed prior to the completion of construction. However, such a conclusion was difficult to make due to varying environmental conditions which affected test results. Consequently, this study was designed to remove many of the typical testing variables by testing all subject homes simultaneously and on the same floor. As will be seen later, the hypothesis that active mitigation, whether performed during or after construction, had essentially the same results proved to be incorrect based upon the total data obtained.

The study was conducted concurrently within two different areas of Colorado Springs, Colorado, which we refer to as Area 1 and Area 2. The two study areas offer a unique opportunity for comparison since they are both infill subdivisions where a significant number of homes have no radon mitigation system at all (Category 1). These unmitigated homes serve as a basis for reference as to what a mitigated home might have been if no radon reduction techniques had been used. Furthermore, these same areas had a relatively large number of homes that had been mitigated with active systems (i.e.; operating fans installed) after construction (Category 2) and prior to the completion of construction (Category 3). A fourth category was necessary to distinguish between these homes mitigated during construction using active systems and homes using only caulking, membranes or sub-slab ventilation without fans. In this region, these latter homes are called "radon ready" by the authors. We designated these radon ready houses as category 4.

Homeowner participation was voluntary and solicited on a neighborhood-wide basis through the two appropriate homeowner's associations, therefore no preselection of mitigation techniques occurred. However, subsequent interviews with participants indicated that all mitigated homes with active systems (Categories 2 and 3) employed sub-slab or sub-membrane depressurization techniques as the primary mitigation method. No attempt has been made to determine relative ventilation rates within test homes.

Homes in Area 1 were all within a half mile radius while homes in Area 2 were within a one-quarter mile radius. The homes in both areas were custom homes, ranging in size from 3,000 to 4,000 square feet of livable area. Most homes had finished walk-out basements.

The number of homes initially participating in this study fell into the four categories as noted in Table 1 below. The numbers in the brackets, on this same chart, show the number of participants who conducted the charcoal canister test correctly and who were subsequently used as our data base.

TABLE 1. NUMBER OF HOMES PARTICIPATING IN THE STUDY

Category		Area 1	Area 2	Total
1	Homes never mitigated	26 (22)	13 (13)	39 (35)
2	Homes mitigated after construction	12 (12)	12 (11)	24 (23)
3	Homes mitigated during construction	19 (15)	6 (4)	25 (19)
4	Homes made "radon-ready" for future mitigation	10 (8)	4 (4)	14 (12)

GEOLOGY OF THE TEST AREAS

A previous study (1) had already shown correlations between certain characteristics of the soils and geology of these two areas and the indoor radon concentrations as measured by screening tests. Specifically, elevated radon concentrations are predicted for these two areas because of low shrink-swell potential (indicating very little clays) and relatively high permeability of the soil as determined from the Soil Conservation Service County Soil Surveys (2). The surficial geology of both areas is made up of rock derived from the Pikes Peak batholith (3) which is known to contain 5.0 ppm of uranium (4). Finally, Area 2 is known to be relatively close to a major fault system. This fact is believed to contribute to enhanced radon transport.

A more precise breakdown of the above characteristics for each of the two areas is as follows:

Area 1 soil has a low shrink-swell potential with a permeability of 2 to 6 inches of water per hour. The surficial geology is a Dawson Arkose with some Verdos alluvium (both dervived from the Pikes Peak granite). The average distance of these homes to a major fault is 2.8 km.

Area 2 soil has a low shrink-swell potential, also, with a permeability of 6 to 20 inches of water per hour. The surficial geology is Rocky Flats alluvium (which is also derived from the Pikes Peak granite). The average distance of these houses from a major fault is .75 km.

Ignoring house construction details completely, the above characteristics would lead one to predict elevated radon in homes in both areas and the higher permeability and closer distance to a fault in Area 2 would suggest even higher radon levels in those homes. These predictions will be seen to be verified when the actual measurements are discussed in the Statistics section, below.

TESTING METHODOLOGY

Radon Measurements Laboratory, housed at the University of Colorado-Colorado Springs, is a primary lab for the evaluation of radon concentrations using the 48 hour, four-inch, open faced charcoal canister. These canisters are of typical design with approximately 70 grams of 8 X 16 mesh Calgon charcoal encased in a four-inch diameter canister, one-and-five-sixteenths inches high, covered with a 30-50 % open-mesh retainer screen. The laboratory has analyzed over 8,000 canisters over the last three years.

Canisters are read using a three inch by three inch NaI(Tl) crystal housed within a commercial lead shield. A 1,024 channel MCA is used to look at the three most intense lead-214 and one bismuth-214 photopeak lying between 220 and 692 KeV. The minimum detectable activity (MDA) at the 3 σ level was calculated to be 0.13 pCi/l for canisters measured 3 hours after closing and slightly higher for the balance of the canisters.

The usual quality assurance procedures were in place during this testing period with 100 % of the blanks being identified and duplicates above 4.0 pCi/l all within the 10 % precision expected. The 2 σ error was 0.17 pCi/l at 1.0 pCi/l and 0.4 pCi/l at 30 pCi/l. This low error was maintained by measuring all the canisters (after equilibrating) the same day the test concluded.

The canisters were delivered to the participants by the authors along with a detailed instruction sheet. The instruction sheet augmented prior phone conversations and further oral instructions at the time the canisters were delivered. The tests were all to begin on the morning of December 17th and conclude on the morning of December 19th, 1990. The canisters were placed in an open area in the basement (in most cases, the family room), 30 inches off of the floor in the center of the room. The canisters were sealed by the homeowner and placed outside for pick-up by the authors. Non-compliance with the instructions, or failure to perform the test, led to 13 of the original 102 participants being dropped from the subsequent data base. This gave us an 87 % compliance with the fairly stringent test requirements.

THE WEATHER DURING THE TESTING PERIOD

Since all of the homes were tested during the same time period and the distance between the two test areas is only a few kilometers, the weather was identical for all houses. It is probably safe to assume, therefore, that pressure differentials brought on by outside temperatures, wind, surface conditions (i.e.; frozen soils) and atmospheric disturbances were also similar.

Nonetheless, it is instructive to review the climatological data for that 48 hour period because the weather conditions were clearly such as to promote an honest screening test by discouraging surreptitious ventilation. Table 2 below shows the weather data from the morning of December 17th through the morning of December 19th. Not shown on this table is the fact that the winds were gusty for a short time on the morning of the 18th, with a peak gust of 48 mph from the northwest.

TABLE 2. CLIMATALOGICAL DATA FOR THE TEST PERIOD

Date	temp (high	and low)	pressure	winds	precipitation
Dec 17	30°F	17°F	29.78 ↓	8.2mph	light snow
Dec 18	49°F	17°F	29.62 →	10.8mph	none
Dec 19	27°F	21°F	29.60 →	8.0mph	light snow

STATISTICS

This section is in two parts. First, the raw data will be presented in histogram form for each area separately and then both areas combined. Second, the results of the t-tests (testing the means of two populations to see if the populations are the same or different) will be given after each histogram.

RAW DATA IN HISTOGRAM FORM

Figure 1 below compares the indoor radon concentrations as measured during the testing period in Area 1 with the number of houses having a particular radon concentration. The black bars refer to those houses which were never mitigated (Category 1) and the bars with hash marks within them refer to houses which have passive systems only (Category 4), the so-called "radon ready" homes.

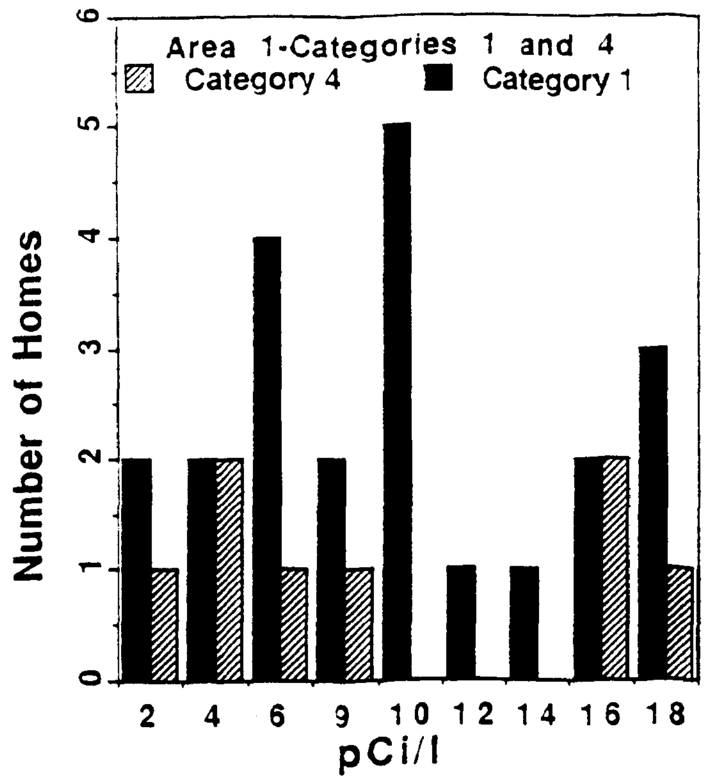

Figure 1. Radon in homes in Area 1, Categories 1 and 4

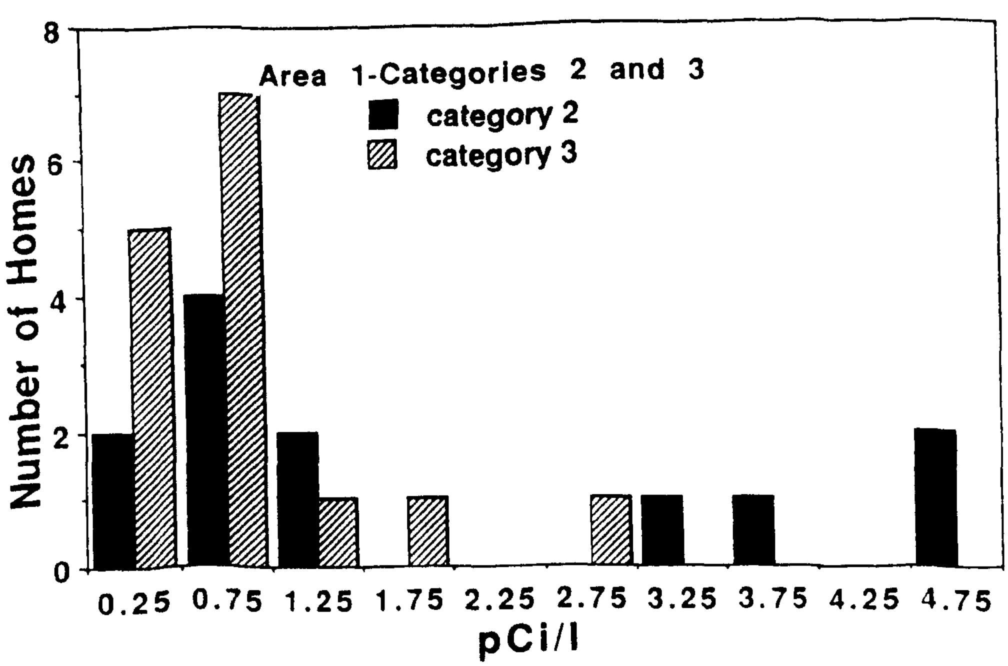

Figure 2. Radon in homes in Area 1, Categories 2 and 3

Figure 2 above makes the same comparison between number of houses and radon concentrations in Area 1 only using houses mitigated after construction (Category 2) and houses mitigated during construction (Category 3).

Comparing Category 1 and Category 4, in Area 1, and using the null hypothesis that the two categories represented the same population, a t-test was performed. The t-test, with a t value of .017, tells us that the two categories are indistinguishable. It would appear that "radon ready" houses have the same radon as unmitigated houses. The statistics are given in Table 3.

Comparing Category 2 and Category 3, in Area 1, and using the null hypothesis that the two categories represented the same population, a single tailed t-test, with a t value of 2.416 indicates that the two populations are indeed different at the 95% confidence level with the houses mitigated during construction (category 3) having the lower radon mean. The statistics are summarized in Table 3

Figure 3 below compares the indoor radon concentrations as measured during the testing period in Area 2 with the number of houses having a particular radon concentration. The black bars refer to those houses which were never mitigated (Category 1) while the bars with hash marks within them refer to houses which have passive systems only (Category 4).

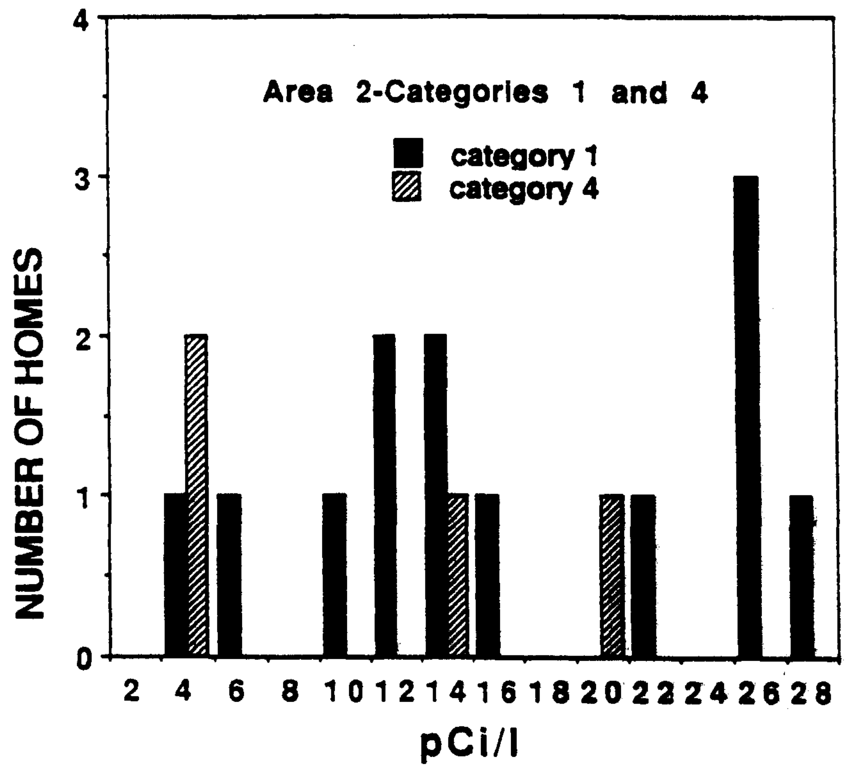

Figure 3. Radon in homes in Area 2, Categories 1 and 4

Figure 4 compares the indoor radon concentrations in Area 2 with the number of homes at a particular radon concentration. Here, the black bars refer to homes mitigated after construction (Category 2) while the hash mark bars refer to homes mitigated during construction (category 3).

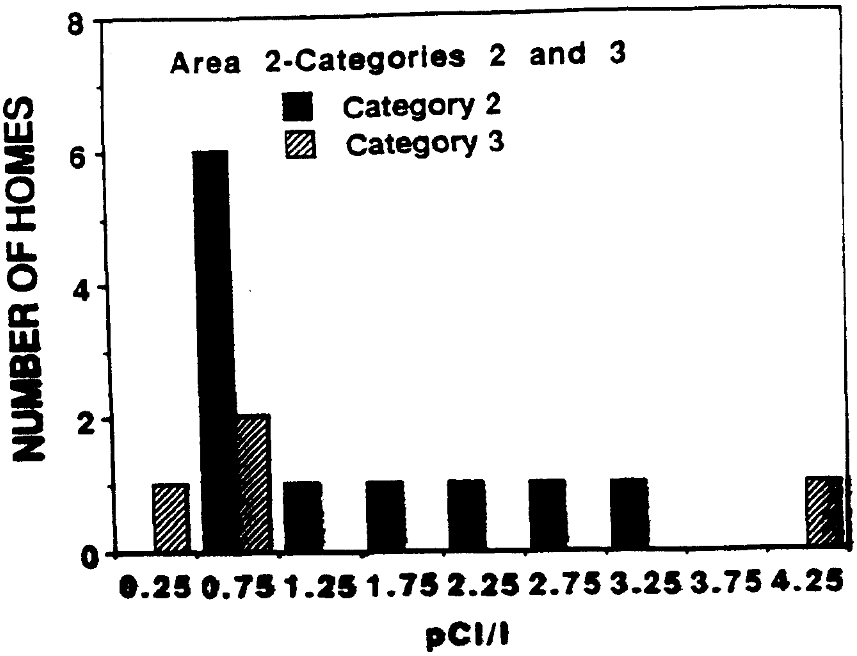

Figure 4. Radon in homes in Area 2, Categories 2 and 3

Comparing Category 1 and Category 4, in Area 2, and using the null hypothesis that the two categories represented the same population, a one-tail t-distribution, with a t value of 1.304, seems to confirm the null hypothesis. That is, as in Area 1, "radon ready" homes have the same average radon as do unmitigated homes. The statistics are shown later in Table 4.

Comparing Category 2 and Category 3, in Area 2, and using the null hypothesis that the two categories represented the same population, a one-tail t-test, with a t value of .091, seems to confirm the null hypothesis. That is, homes mitigated during construction have the same average radon as do homes mitigated after construction. It should be mentioned that the small number of homes (only 4) in category 3 make this conclusion far from certain, although statistically justified. The statistics are shown later in Table 4.

Finally, the data from the two areas is combined, thereby making any conclusions more general and, because of the larger numbers involved, more convincing. We begin by showing a histogram of the combined data, Categories 1 and 4 in figure 5.

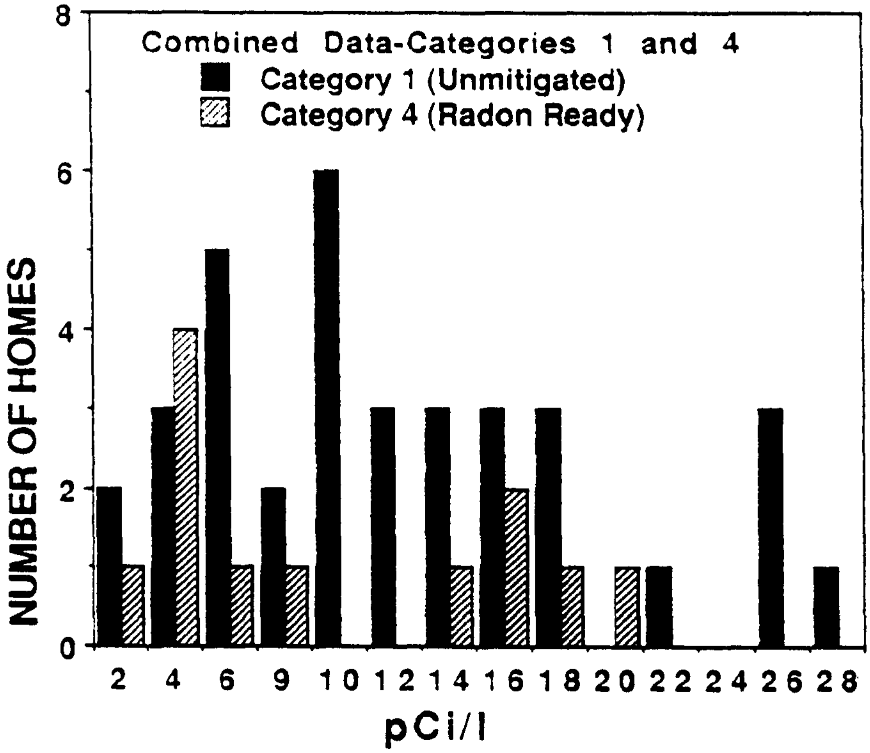

Figure 5. Radon in all the homes combined, Categories 1 and 4

When we combine all the data from both areas, we can also compare radon levels in homes which were mitigated during construction (Category 3) and homes mitigated after construction (Category 2). This comparison is given below in figure 6.

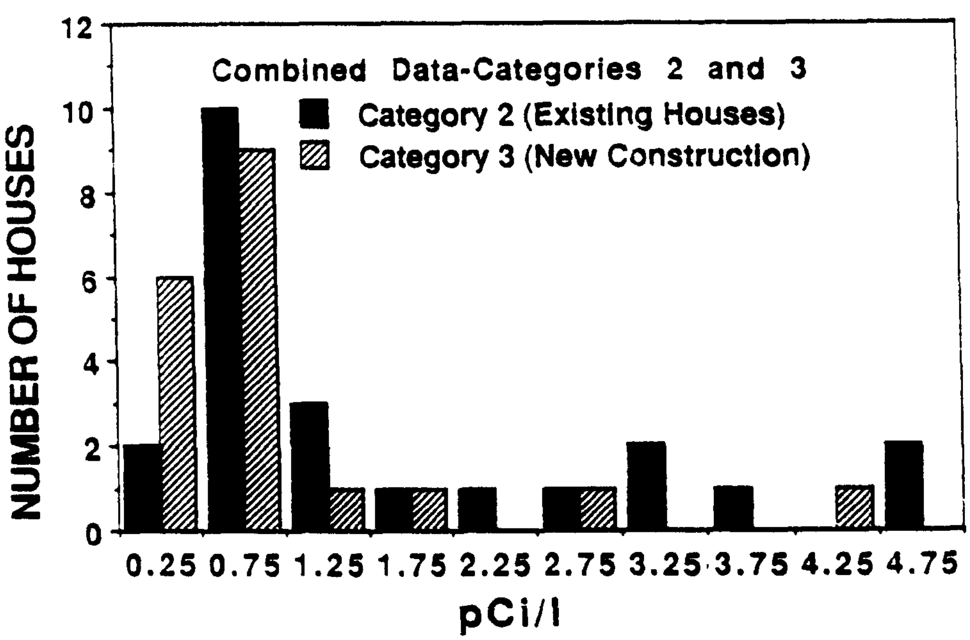

Figure 6. Radon in all the homes combined, Categories 2 and 3

Comparing unmitigated homes (Category 1) with "radon ready" homes (Category 4) in the combined data, and using the null hypothesis that the two categories really represent the same population, a single tailed t-test with a t value of .987 seems to confirm the null hypothesis. At this point, it seems safe to say that "radon ready" homes are no better at reducing radon concentrations than are unmitigated homes. The statistics are shown in Table 5.

A last comparison is now made. This is comparing houses mitigated during construction (Category 3) with houses mitigated after construction (Category 2) with all data combined. Again, the null hypothesis is that the two categories will represent populations with similar averages and standard deviations, i.e.; that it makes no difference in indoor radon levels if a house is mitigated during or after construction. This time, it is probably safe to reject the null hypothesis because a single tailed t-test indicates that the two are separate populations at the 98% confidence level, with a t value of 2.059. The statistics are shown in Table 5.

To show the effectiveness of the radon prevention measures in the three mitigation categories, a final histogram is presented. Figure 7 compares the average of each of the categories when all of the data is combined.

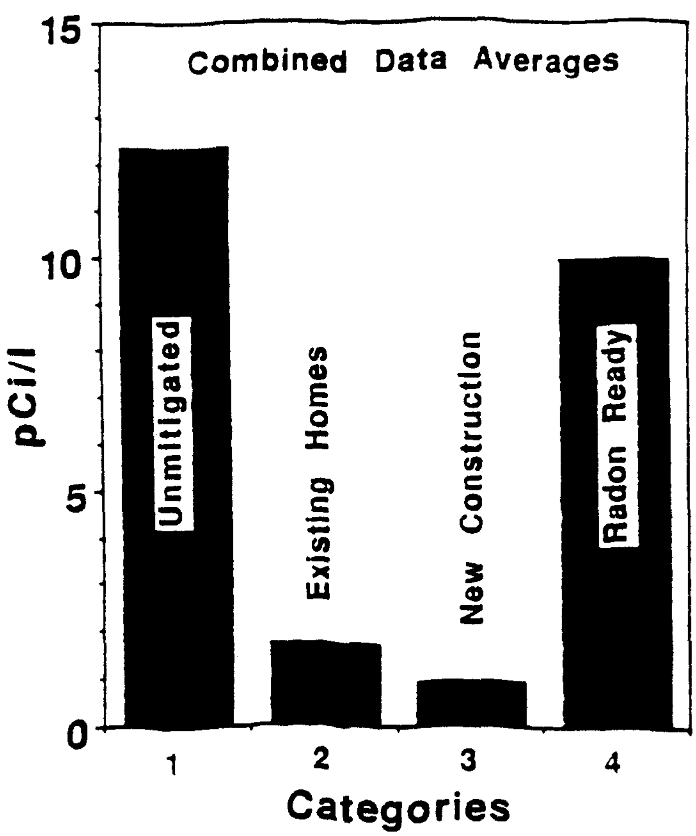

Figure 7. Average radon in all homes combined, broken down by category

DATA REVIEW

After receiving the questionnaires and the exposed canisters, the authors found several conflicting comments regarding descriptions of the type of system installed. Consequently, a combination of participant interviews, site visits and construction files were reviewed to verify which category each house really belonged within. All mitigated houses were reviewed in this manner which yielded some additional insights for this study:

1) Several new home owners were under the impression that adequate systems had been installed in their homes by the builders. Some of these systems turned out to be only barrier techniques (sealing or sub-concrete polyethylene). Perhaps more notable were homes that had sub-slab perforate piping systems that were stubbed up in the basement (most were sealed and one was open into the home). As an interesting note, this survey was the first time some of the homes were tested after occupation. For the purpose of the study, these homes were moved into Category 4 with Category 3 retaining only active sub-structure depressurization systems.

2) Two homes had utilized a sub-concrete mesh system where all of the rest of the survey utilized foundation drains or a combination of foundation drain and interior piping approaches for negative field propagation. These two homes were more than twice the mean of the other existing homes. Inspection of these homes indicated that the problem was not necessarily with the membrane, but rather with the installation. Fans were installed inside with extensive positive side piping. Non-standard fittings were utilized, which discharged beneath windows and near dryer vent openings. As the purpose of the study was to distinguish between during- and post-construction techniques as they are actually being installed, these two houses were maintained in the Area 2 data pool. The balance of the mitigated properties were carried out by the same RCPP listed contractor. Although it is not the purpose of this paper to distinguish between installers, it reinforces the need for proper training of those involved in radon mitigation.

3) Some homes which had active mitigation systems installed, after construction, had inoperable fans. These homes were moved to Category 4 since the authors felt that they represented a passively vented system as in a "radon ready" approach. At this time, no attempt has been made to distinguish between barrier versus passive systems. As an interesting side light, one homeowner insisted that her system was operating because it was not unplugged. She was only convinced when she inspected the fan. This system was installed three years ago before the present EPA mitigation guidelines requiring certain operating indicators for the homeowners were developed (5).

RESULTS OF THE STUDY

What follows is a discussion of each area separately, culminating in a discussion of both areas combined. However, it should be kept in mind that because of the smaller data base of Area 2, conclusions based upon this smaller data base may prove to be less convincing.

RESULTS FROM AREA 1

A comparison of the mean radon levels listed in Table 3 clearly indicates that mitigation during or after construction had beneficial effects. In fact, the means of both Categories 2 and 3 were well below the current EPA guideline of 4.0 pCi/L. As these were screening measurements taken at the lowest living area, current approaches would recommend no further action by the homeowner (6).

TABLE 3. RADON LEVEL MEANS AND STANDARD DEVIATIONS FROM AREA 1

Category	Description	Number	Mean	Standard Deviation
1	Unmitigated	22	9.8	5.26
2	Post-construction mitigation	12	1.94	1.72
3	During construction mitigation	15	0.78	0.64
4	Radon ready	8	9.77	6.63

Homes that were mitigated during construction with active sub-slab systems (Category 3) outperformed those active systems that were installed after construction (Category 2). This conclusion is based on a one-tail t-distribution at the 95% confidence level.

Homes that were built with radon ready systems or had passively vented systems showed statistically no benefit over homes that had no mitigation work done.

RESULTS FROM AREA 2

As was seen in Area 1 using unmitigated houses as reference (Category 1), mitigation which occurred during or after construction showed significant beneficial reductions. Additionally, both the mean of Categories 2 and 3 were well below the current screen action level of 4.0 pCi/L (Table 4).

TABLE 4. RADON LEVEL MEANS AND STANDARD DEVIATIONS FROM AREA 2

Category	Description	Number	Mean	Standard Deviation
1	Unmitigated	13	16.57	± 8.39
2	Post-construction mitigation	11	1.43	0.86
3	During construction mitigation	4	1.49	1.74
4	Radon ready	4	10.27	8.71

Homes that were mitigated during construction with active systems (Category 3) did not show a statistical difference from those homes that were mitigated after construction (Category 2). This result is certainly different from that obtained in Area 1. This may be due to the smaller sample volume and the effect of the non-mitigation guideline homes. One might also speculate that the higher soil porosity in Area 2 allows equal propagation of a sub-slab negative pressure field regardless of the use of a perimeter drain system (Category 2) or a perimeter drain system plus a sub-slab pipe network (Category 3).

Although the mean of radon ready homes (Category 4) in Area 2 was lower than non-mitigated homes (Category 1), no statistical difference can be demonstrated. Therefore, the conclusion for Area 2 is the same as for Area 1 in that no reduction benefit was seen on radon ready installations.

RESULTS FROM BOTH AREAS COMBINED

In order to better answer the question that served as the hypothesis for this paper, both data sets were combined. This approach can be justified due to similarity of home construction, unmitigated levels and soil type. The only difference noted, however, was slightly different soil porosity. The comments made above regarding unmitigated homes (Category 1) with respect to mitigated homes (Categories 2, 3 and 4) remain the same when the data is combined. That is, any active mitigation system is beneficial and no benefit was derived from radon ready homes (See Table 5 below).

TABLE 5. RADON LEVEL MEANS AND STANDARD DEVIATIONS FROM BOTH AREAS

Category	Description	Number	Mean	Standard Deviation
1	Unmitigated	35	12.32	± 7.28
2	Post-construction mitigation	23	1.70	1.37
3	During construction mitigation	19	0.93	0.96
4	Radon ready	12	9.94	6.98

When all data is combined, including the anomalies mentioned earlier, one can determine statistically that systems installed during construction (Category 3) outperformed systems installed after construction (Category 2). Categories 2 and 3 are two distinctly different populations as verified by the one-tail t-test at the 98% confidence level.

IMPLICATIONS OF RESULTS

It is interesting to note that the existing homes that were mitigated after construction (Category 2) had a mean screening result of 1.70 pCi/L ± 1.40. Although this is at a level below the current EPA action level of 4.0 pCi/L, it is right at contemplated values for the new proposed guideline of 2.0 pCi/L. (Ref 7). Although it is reasonable to assume upper floors of these homes would be at lower concentrations of radon, it should be noted that due to terrain and architectural plans, many of these lower level floors contain family rooms and bedrooms. The adoption of 2.0 pCi/L guideline for living areas may be difficult to consistently achieve with mitigation techniques observed in this study.

Similarly, the homes that had active mitigation system installed during construction exhibited a mean result of 0.93 pCi/L ± 0.96. Within one standard deviation all of these Category 3 homes would exhibit screening levels beneath both the existing guideline of 4.0 pCi/L and the proposed guideline of 2.0 pCi/L.

The overall mean of new homes constructed with active systems (Category 3, mean 0.93) would lend partial credence to the (Option 1) prescriptive approach proposed in the draft model standards for new buildings. (Ref 8). However, the approach of not requiring, or not emphasizing post-occupancy testing may result in not identifying improper installations, as this study did. This may, on the other hand, speak to proper education of installers and the extension of the RCPP program to home builders as well as specialty radon mitigation sub-constractors.

The inability to distinguish between "radon ready" systems (Category 4) and non-mitigated homes reinforces the need for testing within 30 days of occupancy for a non-activated radon ready home. This is referred to as Option 2 of the Draft Model Standards for New Buildings. Furthermore, the results of Category 3 indicate the ability to reduce levels to below 2.0 pCi/L once the radon ready system is made active by addition of a fan. It would be prudent to emphasize testing after actuation of the system fan for the same reasons as indicated above.

Homeowners' understanding of proper system operation was inadequate in some cases. Interviews with participants indicated little information was passed on from previous homeowners or building contractors. This comment is more pertinent with respect to homes which were constructed with radon ready systems. In this case, some homeowners felt that a complete system had been installed. This can be dealt with either in a regulatory manner or perhaps a greater emphasis can be placed on the present Radon Contractor's Proficiency Program and particularly the Mitigation Guidelines (5).

The data made available from this study will, with further evaluation, offer opportunities to assess differences between finer points of mitigation installations. A more detailed review of homes in Categories 2 and 3 that fell outside the standard deviation of the mean can be made to assess these installation differences. A comparison of individual results to soil porosity and soil gas measurements can also be made in order to assist in developing a predictive model, at least for this geological area.

Furthermore, a more detailed review of Category 4 homes needs to be made to determine which radon ready approaches may offer the most cost effective benefit.

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RADON REDUCTION IN NEW CONSTRUCTION: DOUBLE-BARRIER APPROACH

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ABSTRACT

A double-barrier design with the space between the barriers having little resistance to gas flow is described for those parts of homes and buildings that interface with the soil or surficial rock to reduce soil-gas (radon) entry into structures. The outside or soil-side barrier interfaces with the soil. A barrier placed on the soil under the subslab aggregate is an important element in this design. This forms the outer barrier for the floor. The subslab aggregate forms a permeable layer, while a plastic membrane above the aggregate, the slab, and caulking form the inner barrier. If hollow block are used, barrier coatings can be placed on both the soil side and interior wall of the blocks, while the hollow space in the blocks forms the permeable space. The hollow-block walls are connected to the subslab aggregate to form a small interconnected permeable volume that can be managed in the following ways to reduce soil-gas entry into the structure.

1. Sealed.
2. Passively vented to outdoor air.
3. Passively depressurized using an internal stack.
4. Actively depressurized.
5. Actively pressurized.

In addition to basements with hollow-block walls, the double-barrier technique can be adapted to solid wall, crawl space and slab-on-grade construction including various combinations.

INTRODUCTION

In the long term, substantial reduction in radon exposure can result from improved new home and building construction techniques that reduce radon entry. In addressing this approach to reducing radon exposure, the EPA has published a report "Radon-Resistant Residential New Construction" (1) in which construction techniques to minimize radon entry in new structures and to facilitate its removal after construction are described. This report is the first edition of technical guidance for constructing radon-resistant structures to be issued by the EPA, and they anticipate future editions as additional experience and approaches become available. The EPA report includes a section on barriers to reduce radon entry including wall coatings, sub-slab membranes, caulking, sealing and prevention of slab cracking. Another section discusses designs for post-construction active or passive sub-slab ventilation. A primary element in these designs is a minimum of 4 in. of aggregate under the slab. The preferred material is crushed aggregate with a minimum of 80% of the aggregate at least 3/4 in. in diameter. This highly permeable bed under the slab is necessary for good communication in the event that sub-slab ventilation is needed. The aggregate is placed directly on the soil and represents a large permeable volume into which radon can diffuse or flow from the soil and rock under and around the foundation. The radon that accumulates in the permeable aggregate can then flow with little resistance to any penetrations in the barriers above the aggregate. These barriers include the membrane placed over the aggregate, the slab and any caulking and sealing of the wall floor joint, cracks and penetrations. Having a permeable volume between the soil and the barriers reduces the effectiveness of the barriers. Barriers are most effective when interfacing with the soil. A similar situation occurs when hollow blocks are used to construct the foundation walls. Radon that infiltrates through the outer wall and into the hollow cavity of the block walls can then flow with little resistance to any penetrations of the inside wall barriers. Again, barriers to radon entry are most effective on the outside or soil-side of the wall.

An indication that aggregate under the slab increases radon entry into structures was obtained in a survey of over 6,000 homes in New Jersey (2). The data collected in this study show a definite relationship between age and radon concentration. On average, houses built since World War II tend to have higher indoor radon concentrations than houses built between 1900 and about 1945. Initially, it was suspected that newer houses had higher indoor radon concentrations because newer houses tend to be tighter and have lower air exchange rates. However, closer examination of the data indicated that the differences in radon concentrations associated with tightness did not fully account for the decline in radon concentration with increasing age in 20th-century houses. The authors speculated that the use of sub-slab aggregate, which increased in the post-World War II era, could also contribute to the higher indoor radon observed in newer homes.

It is difficult to determine the effectiveness of the barriers to radon entry suggested by the EPA, when used in the passive mode, since it is not possible to know what the indoor radon concentrations would be for a house if the radon-resistant techniques were not employed. The initial results, however, have led the EPA to conclude "that in the presence of a moderate-to-high radon source, radon prevention techniques that are passive only may not produce indoor radon levels consistently below 4 pCi/l." In a study of 15 full-basement homes in New York State which were built employing radon-resistant techniques in an area with above-average levels of indoor radon, most of the homes required active sub-slab ventilation systems (3). The results from the New Jersey survey and the initial results of the homes built with radon-resistant construction indicate that sub-slab aggregate interfacing directly with the soil or rock under a home can increase radon entry into the home and decrease the effectiveness of barriers placed above the aggregate.

DOUBLE-BARRIER CONSTRUCTION

It is the purpose of this paper to suggest a design for new home construction that is more effective in reducing radon entry in the passive mode but one that can be readily adapted to active mitigation systems if needed. The design proposes to reduce soil-gas entry by using double-barrier construction for the sub-grade structure of homes and buildings. A primary element in this approach is to have a radon barrier under the subslab aggregate at the soil interface.

The double-barrier approach is illustrated in Figure 1 for a basement with block walls and a sump. The hollow space in the block walls is connected to the subslab aggregate via weeping holes or some other low resistance pathway for air flow, to form an interconnected permeable space that surrounds the entire subgrade structure. Barriers to radon transport such as membranes, coatings, caulking, sealing, etc., are placed on both the soil side and inside of the permeable space. Since radon barriers are most effective at the soil interface, most of the barrier effort should be concentrated on the sub-aggregate and outside wall barriers. The barrier below the aggregate may be a composite of materials such as cement, tar, plastic film, fine sand, and clay. Barriers at the soil interface should be resistant to both diffusive and convective flow. A special effort should be made to seal the outside wall barrier at the wall-footing joint and the barrier below the aggregate at the footing-aggregate and aggregate-sump joints.

The double-barrier subgrade construction creates a reasonably small volume between the inside and outside barriers that can be managed in several ways to reduce radon entry. Without a barrier below the aggregate, the soil and rock under and around the house will be directly connected to any mitigation system used to reduce radon entry. The double-barrier approach works toward decoupling this direct connection. For the double-barrier system shown in Figure 1, passively venting the hollow-block walls to outdoor air will allow outdoor air to flow with little resistance into the permeable space. As gas from the permeable space is drawn through any penetrations in the interior or upper barriers into the basement by indoor-outdoor pressure differentials, outdoor air can flow into the permeable space with little resistance. The outside air flow reduces the draw on soil-gas at any penetration in the outer or below barriers and thereby reduces the flow of soil-gas radon into the permeable space. Alternatively, the permeable space could be treated by depressurization (passive or active) or pressurization (active). For these approaches it would be best to not vent the block walls to outside air. Radon entry reduction can then be accomplished by creating either a reduced pressure or increased pressure in the permeable space. Having created a reasonably small interconnected permeable space with sealing

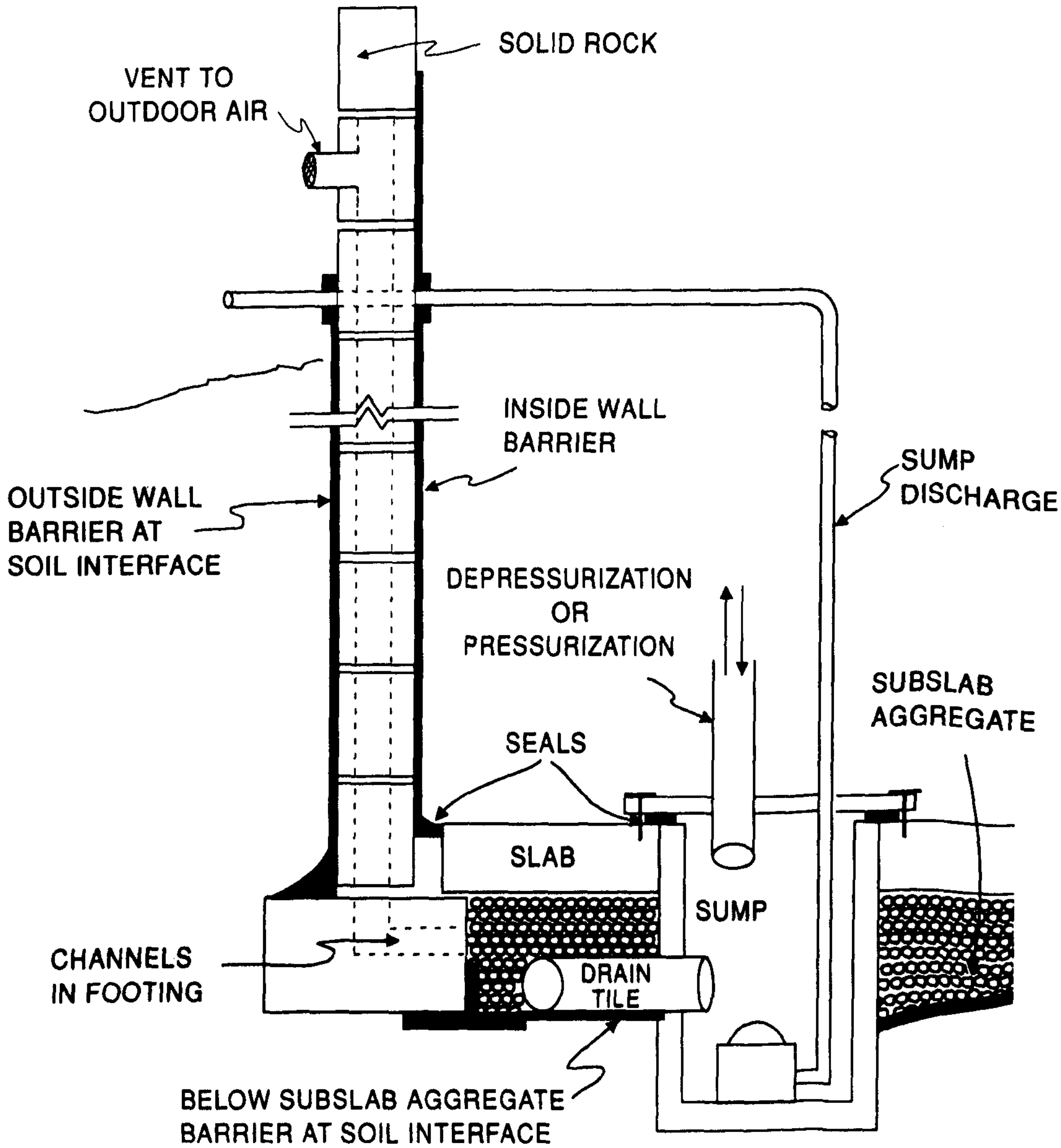

Figure 1. Double-barrier construction for a basement with sump.

on both the soil side and inside, it is expected that, if passive venting (using a stack through the house interior), active suction, or positive pressure flow is necessary to reduce indoor radon to acceptable concentrations, then relatively low flow rates would be successful.

An example for an active pressurization system would be to draw air from ceiling vents in the highest level of the house and blow this air into the permeable space between the double barriers (Figure 2). The fan could be located in the basement and relatively low flow rates (~20 cfm) should suffice. In this manner, heated air from the highest interior level of the house would be used to pressurize the double-barrier system heating the floor and walls of the basement while reducing heat loss via exfiltration from the higher levels of the house.

It is of primary importance to ensure that water effectively drains from the permeable substructure space between the double barriers. This can be accomplished with a sump as shown in Figure 1. It may be necessary to grade the soil forming the base of the subslab aggregate toward the drain tiles and the sump to aid in preventing the accumulation of water in the subslab aggregate. If it is possible to drain the subslab aggregate to grade or to a sewer, then this drainage option could be used instead of or with a sump. Solid pipe should be used and it should be sealed at the outside or soil-side barrier.

Exterior footing drainage of gravel and/or perforated piping is used by many builders and presents a problem to the double-barrier design approach. The gravel and/or perforated piping of the exterior drainage system runs around the outside perimeter of the wall-footing joint. It represents a permeable volume in which radon can accumulate and flow to any penetrations in the wall and wall-footing joint. To minimize radon entry, the exterior drainage system should be drained to daylight or to a sewer and not connected to the subslab aggregate and sump via weeping holes or other methods. Connecting the exterior drainage system to the subslab aggregate would provide a pathway for soil-gas radon to enter the permeable zone of the double-barrier system. Exterior perimeter drainage systems increase the need for careful sealing at the exterior wall-footing joint.

The double-barrier approach is illustrated for slab-on-grade and crawl space construction in Figure 3. Drainage of water that might accumulate in the sub-slab-on-grade aggregate can be accomplished using a sealed sump as shown in Figure 1 or by drainage to grade or a sewer using solid pipe. If the double-barrier system is not effective in the passive mode (sealed, vented to outdoor air, or passively depressurized using stack ventilation), then active pressurization or depressurization can be employed. When a barrier is placed directly on the soil of a crawl space and the floor of the house is sealed, one obtains a double-barrier system with the space between the soil barrier and the floor being the permeable space. The crawl space can then be vented to outdoor air or the crawl space can be sealed and passively depressurized, or actively pressurized or depressurized. To reduce the volume of air to be pressurized or depressurized, a permeable layer of aggregate or other construction to form a permeable space with barriers on both the soil side and house side can be used as shown in Figure 3. Sealing the floor and using a double barrier at the soil surface results in a triple-barrier system where the two permeable spaces could be treated independently.

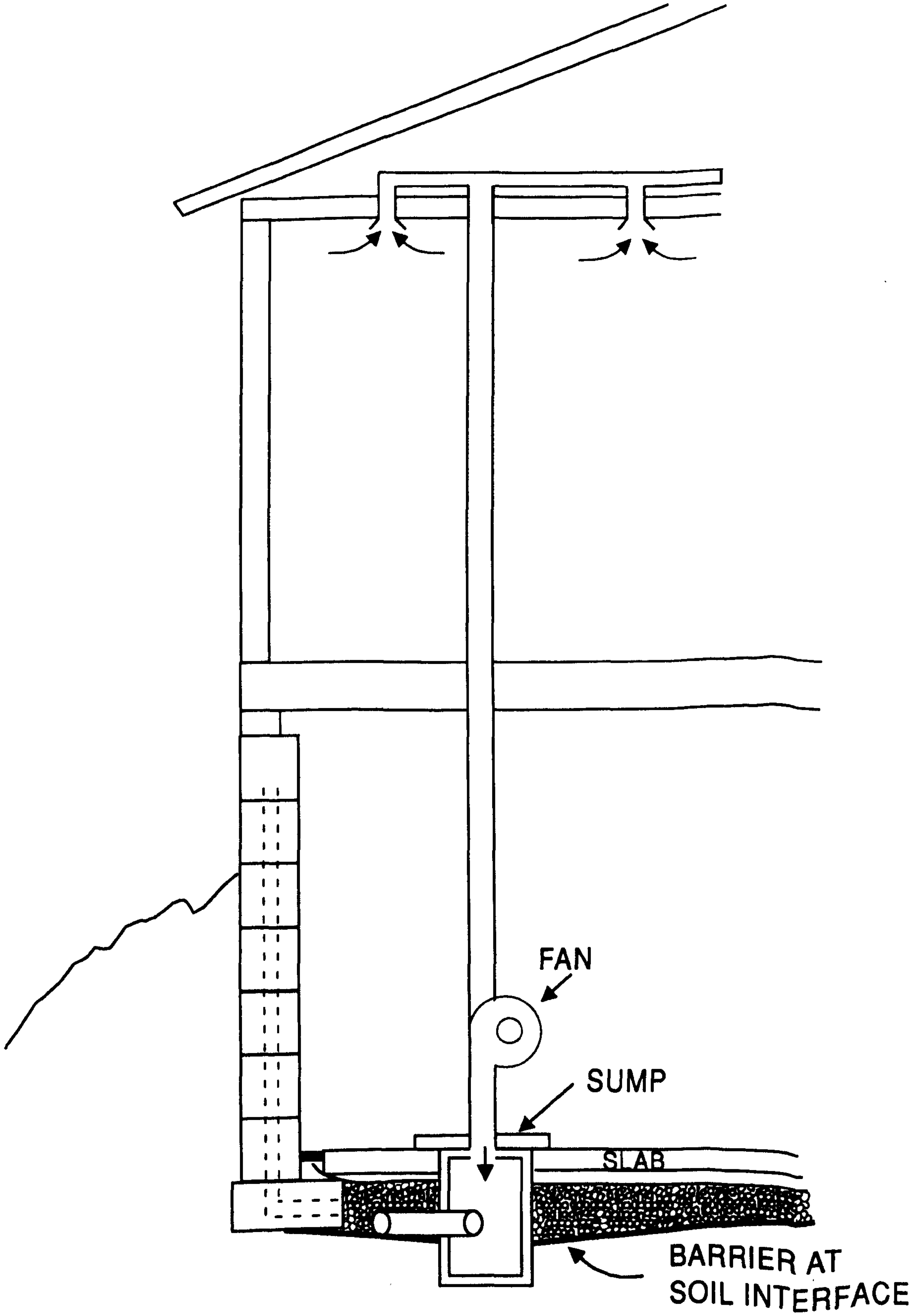

Figure 2. Double-barrier pressurization using interior air.

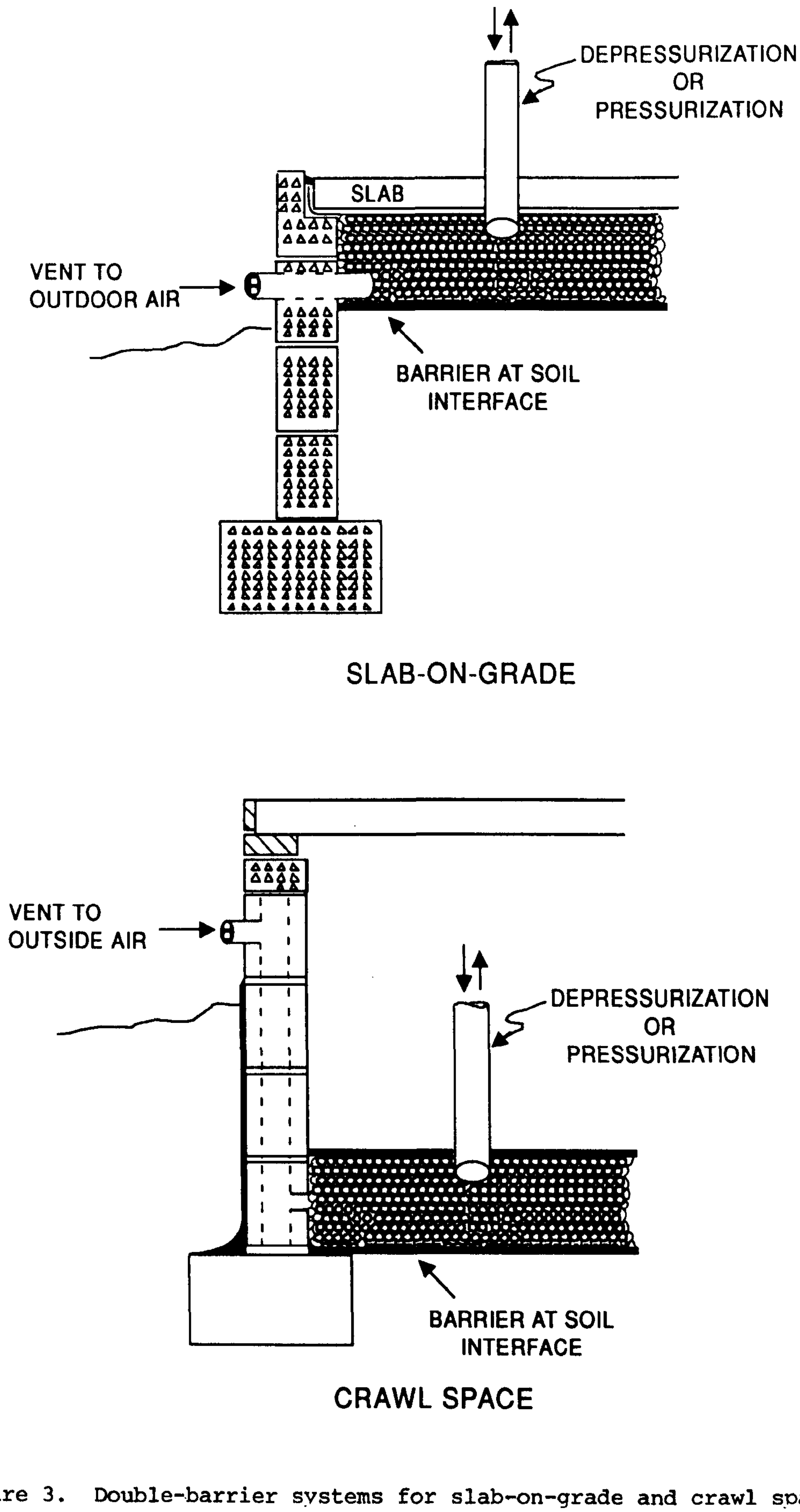

Figure 3. Double-barrier systems for slab-on-grade and crawl space construction.

For example, the aggregate could be passively depressurized and the space below the floor could be vented to outdoor air.

SUMMARY

Radon-resistant construction designed to decouple houses from the soil has been suggested and used in various forms. The EPA refers to constructing a pressure break between the foundation and the soil. Brennan and Osborne (4) suggested that a drainage mat be used to form an air curtain around the foundation. A Denver builder excavates to a depth of 10 ft. and constructs a crawl space under a wood basement floor (1). The crawl space is then actively ventilated. Walkinshaw (5) constructs a shell inside the basement and then ventilates the space between the interior shell and the basement floor and walls.

The double-barrier approach described in this paper attempts to modify normal building practices to be more radon-resistant at moderate cost. Barriers under the aggregate and on the outside of hollow-block walls interfacing with the soil and rock will be the most effective barriers in reducing radon entry. The double-barrier construction creates a relatively small permeable volume between the inside and outside barriers that can be managed in several ways, either passively or actively, to reduce radon entry. A key element in this design is to maintain water drainage from the permeable space between the barriers and from around the foundation. There are many types and variations of house and foundation construction. Very often these variations are dictated by the local and regional surficial geology. It is not possible to describe a radon-resistant design readily applicable to all types of construction and water drainage conditions. However, a better understanding of how water drainage systems around foundations can increase the potential for radon entry will enable builders to make water drainage and radon-resistant construction more compatible. Double-barrier construction is such an attempt to make water drainage and radon resistance work together.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the agency and no official endorsement should be inferred.

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RADON CONTROL - TOWARDS A SYSTEMS APPROACH

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ABSTRACT

The normal operation of a continuous mechanical ventilation system, incorporated into a relatively airtight house, and designed to control pressure-differences, has been demonstrated to provide sufficient control of radon entry in a two story residential building.

This was accomplished via a "two-cell barrier-enhanced pressure-difference control system."

Ventilation rates, energy usage, moisture levels, pressure-differences, and radon concentrations were monitored. Changes in radon concentrations in several building locations, as a function of distinct pressure-difference configurations, have been measured.

Indications are that this design offers the new residential construction industry an opportunity to realize affordable control of radon entry, while simultaneously optimizing potentials for moisture control, energy efficiency, and control of other indoor air pollutants.

INTRODUCTION

This project explores the use of an airtight building envelope (and separately isolated airtight crawlspace) integrated with a continuously operating mechanical ventilation system, to enhance pressure-difference control strategies for minimizing soil-air entry into the indoor air.

This approach seeks to obtain robust control of radon entry, while concurrently optimizing potentials for several building design goals including: moisture control, energy efficiency, control of other indoor air pollutants.

CONTEXTING ASSUMPTIONS

There are several primary design goals for the environment control system "house:" safety, comfort, durability, healthy indoor air, and energy efficiency. These goals are not only increasingly achievable, but can be mutually advantaged in a manner that can reduce net system cost.

A systems approach that seeks to optimize a building's performance with regard to several desirable performance qualities might well include several very successful radon solutions.

The radon source of concern is soil-air. The primary goal with regard to control of indoor radon is the prevention of soil-air entry into the indoor air. Radon is a given component of soil-air though its concentration both varies from one site to another and is not readily predictable. In one case, measurements of soil radon within a distance of 9 meters varied by a factor of 250 (1). Hence, the degree of soil-air entry control required is neither constant nor predictable.

Two conditions are necessary for soil-air entry:

- There must be openings in the building envelope that couple the soil-air to the indoor air.
- There must be a driving force, a pressure-difference that results in a flow from the soil-air zone into the indoor air zone.

While significant reduction of all coupling pathways from the soil zone is reasonably achievable, elimination of them is not. It has been observed that even very small openings are sufficient to allow unacceptable radon levels (2). Control of pressure-differences may be the practical key to adequately limiting the entry of soil-air pollutants, including radon. Envelope tightness may be most important for its role in enabling and enhancing pressure-difference control.

The tight building envelope, coupled with a properly designed mechanical ventilation system, can play a central role in a systems approach that incorporates pressure-difference control to limit soil gas entry. The tighter the air barriers of the system, the more effective the pressure-difference control for a given amount of fan power. This dovetails nicely with the desirable advantages of a tight building envelope for several other building performance purposes, including:

- Comfort - fewer drafts; minimal temperature stratification; reduced noise, dust, pollen, insects.
- Energy efficiency - large net reduction in heating/cooling loads.

- Moisture control - structural durability and reduced maintenance costs.
- Enhanced dilution/removal of pollutants generated indoors - via improved ventilation effectiveness, control and capability.

Several of the design elements serve to advantage multiple design goals. This should be recognized when attempting to allocate costs. For example, soil-air may also contain other pollutants of concern, such as garbage gasses (methane), herbicides, fungicides, pesticides, spores of soil fungi, etc. (3). The cost of preventing soil-air entry should be life-cycled against the delivery of several health benefits. Also, in this particular project, the cost of mechanical ventilation and the tight envelope must be apportioned to comfort, energy performance, radon control, moisture control, and control of other pollutants.

SPECIFIC HYPOTHESIS

The normal operation of a commercially available continuous mechanical ventilation system incorporated into a tight house, and designed to control pressure-differences, can provide sufficient day-to-day control of those pressure-differences (induced by weather, internal household activities, and mechanical systems) to prevent entry of radon and other soil-air pollutants. This can be reasonably accomplished by developing a "two-cell, barrier-enhanced pressure-difference control system." (4).

BUILDING DESCRIPTION

In 1988, a tightly sealed and energy efficient two-story residential building was constructed with the intent to exceed any energy performance standards currently in place in the U.S. The building was among those instrumented and continuously monitored for one year as part of the Residential Construction Demonstration Program (RCDP), a multipurpose research and development effort of the Bonneville Power Administration and the Washington State Energy Office. As an RCDP Cycle II Future House, the expected energy performance of the building was designed to exceed that required by the Northwest Power Planning Council's Model Conservation Standards by 30%.

The building was constructed in Spokane, WA. Spokane has a winter outdoor design temperature of 4°F (-15°C), 6882 normal heating degree days, and 411 normal cooling degree days. Spokane weather has the characteristics of a mild arid climate in the summer and a cold coastal climate in winter. Winter solar potentials are limited by both the climate and the site. The building was calculated to have an annual need of 2.5 kWh/ft^2 (97 MJ/m^2) for space heating.

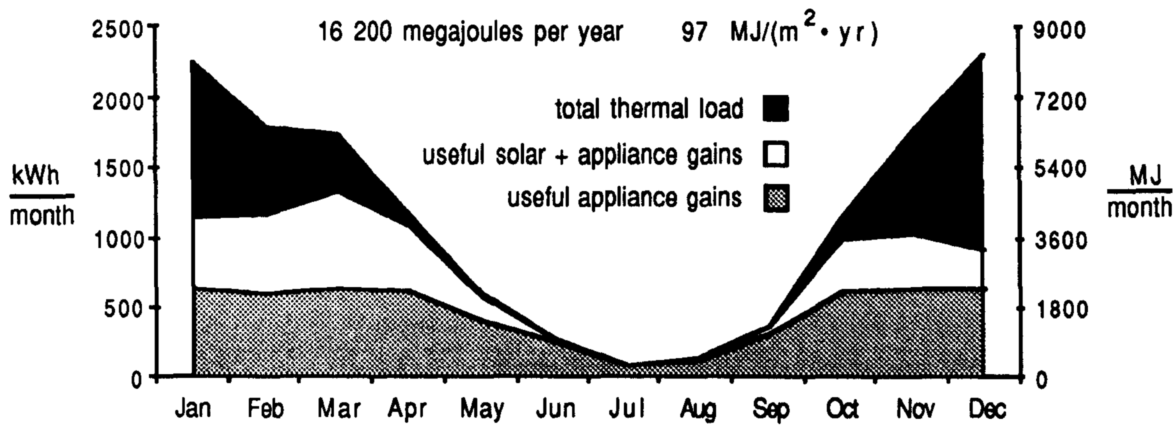

Figure 1. Predicted space heating profile.

The building is of double-wall construction and the wall thermal resistance is approximately R45 (.126 $W/[m^2 \bullet K]$). This insulation level extends from the ceiling to the concrete footing, except as interrupted by doors and glazing (Figure 2). The glazing area is 328 ft^2 (30.5 m^2) and is 18% of the conditioned floor area 1780 ft^2 (166 m^2). Fifty-five percent of the glazing faces south. The glazing thermal resistance is approximately R4 (1.5 $W/[m^2 \bullet K]$). The ceiling is insulated to R60 (0.095 $W/[m^2 \bullet K]$). The continuous thermal envelope is completed by R25 (0.227 $W[(m^2 \bullet K])$ fiberglass batt insulation laid directly upon the ground (over a gravel capillary break).

A continuous air barrier was established with the interior drywall by gasketing the drywall to the wood framing and sealing any penetrations through the drywall. Upon completion of construction, the building had a tested air leakage rate of 1.2 air changes per hour (ACH) at an induced indoor/outdoor pressure-difference of 50 pascals. One year later it was tested at 1.4 ACH at 50 pascals. The measured Pacific Northwest average is 9.3 ACH at 50 pascals (5). The vapor retarder was established on the interior surface of the drywall with a rated paint. The glue in the laminated subflooring provided the floor vapor retarder.

The building is divided into two distinct cells, that are atmospherically decoupled from both each other and the outdoor air (Figure 2). The tightness and isolation of these two "cells" enables pressure-difference control with the mechanical ventilation system (and prevents contamination of air in cell 1 by air in cell 2. Cell 1 contains all occupied space, so that the breathable indoor air is contained in cell 1. The volume of cell 1 is 16,500 ft^3 (467 m^3). Cell 2 is a plenum by which stale air from cell 1 is removed. Though atmospherically decoupled, it is thermally coupled to cell 1, so it provides warm floors. Cell 2 adds another 3000 ft^3 (85 m^3) to the conditioned volume.

The first floor subfloor was the selected air barrier between cell 1 and cell 2. All joints in the tongue and groove exterior grade plywood were sealed with urethane sealant during installation. Special care was taken to identify and seal any holes created in this barrier by the construction process (eg; temporary nailing for wall bracing, sawhorses, measuring and cutting tables). A tracer gas was injected into cell 2 prior to carpet installation and two small air leaks were located using a detection instrument.

HVAC SYSTEM

A small (5000 to 7000 btuh) commercially available integrated residential heat recovery ventilation system (HPV) provides continuous ventilation, partial space heating, space cooling, water heating, as well as the desired pressure-differences (6). The unit consists of a water heating tank and a space conditioning module (SCM). The SCM contains 2 constant speed fans, 2 coils, and utilizes a reversible refrigeration cycle to provide heating or cooling via the same ductwork. During the winter heating cycle, heat is extracted from stale exhaust air and delivered to either the domentic hot water tank or the mixed air supply. In summer, heat is extracted from the mixed air supply and either exhausted outside or used to heat domestic water.

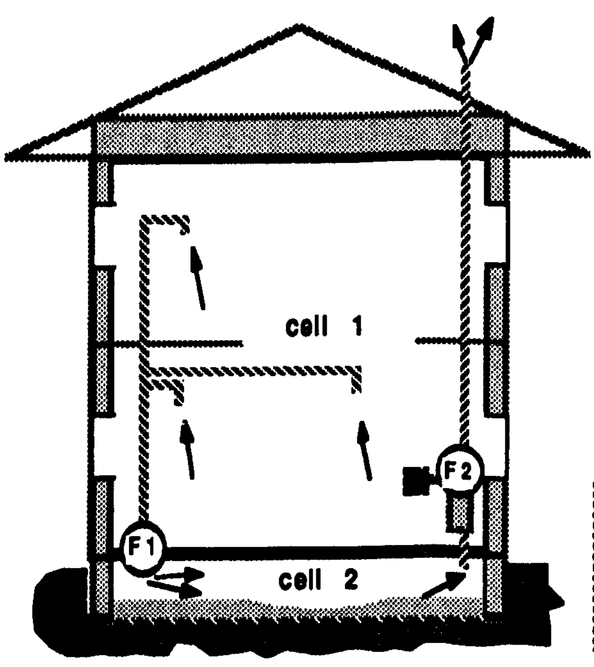

Figure 2. Exhaust Air Side.

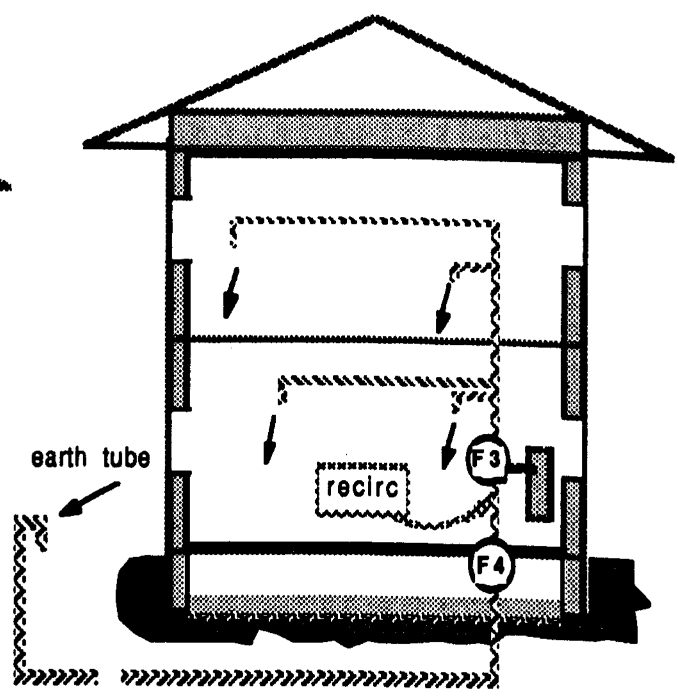

Figure 3. Supply Air Side.

On the supply air side, two 60 ft (18 m) long by 4 in (10 cm) diameter PVC earth tubes provide filtered outdoor air which is mixed with recirculating air before it passes over the supply-side coil and is distributed to individual living areas by fan F3 (Figure 3). The earth tubes are buried approximately 4 ft (1.2 m) below grade and serve to temper both winter and summer air.

On the exhaust air side, stale indoor air is removed from kitchen and bathrooms by fan F1 and ducted to cell 2. From this point it remains isolated from cell 1. The stale air travels across cell 2, then exits via a sealed duct which leads to the SCM. Continuous operation of fan F2 (SCM exhaust fan) is necessary to maintain a lower pressure inside the SCM than in the mechanical room, so that no leakage back into the indoor air occurs. After passing through the SCM the air is exhausted above the roof line.

TWO-CELL, BARRIER ENHANCED PRESSURE-DIFFERENCE CONTROL

Cells 1 and 2 are isolated from each other, from the outdoor air, and from the indoor air; by accessible and maintainable air barriers. Sealed ducts allow controlled air passage. Continuous mechanical ventilation removes stale air from cell 1 and delivers it outside via cell 2. Depending on which fans are selected to operate, cell 2 can be either pressurized or depressurized relative to cell 1 and/or the soil-air. This project incorporated four fans in the ventilation system in order to enable comparison between these two approaches, as well as other possible ventilation and pressure-difference configurations:

- Continuously pressurize and flush cell 2: This is the baseline operating condition. Fan F1 removes stale indoor air from cell 1, depressurizing cell 1 relative to outside and pressurizing cell 2. Fans F2 and F3 are part of the commercial unit and operate at a constant speed. Fan F1 must produce a greater flow than fan F2 in order to maintain cell 2 at a greater pressure than cell 1. A solid state speed control allows adjustment of fan F1. Dampers allow adjustment of the flows through the SCM, but adjustment is limited to the range of flows required by the SCM.

- Continuously depressurize and flush cell 2: Fan F1 does not operate, so fan F2 depressurizes both cell 1 and cell 2. Cell 2 is at a lower pressure than cell 1.

- Continuously pressurize cell 2: Fan F1 operates but no flushing of cell 2 occurs. Cell 2 is decoupled from the exhaust loop, and stale air is removed directly from cell 1.

- Mimic typical housing leakage and ventilate: Increase the envelope equivalent leakage area of cell 1 to typical levels by introducing deliberate openings in floor and ceiling (The northwest average is 125 in^2 (806 cm^2). The measured cell 1 leakage area is 16-20 in^2 (100-130 cm^2). The ventilation system operates (decoupled from cell 2). Leakage distribution can also be adjusted. Typical outside vents can be installed in the crawlspace.

- <u>Mimic typical housing leakage and do not ventilate</u>: Increase the envelope equivalent leakage area of cell 1 to typical levels by introducing deliberate openings in floor and ceiling. Typical outside vents can be installed in the crawlspace.

ENERGY PERFORMANCE

Limited data is available at this time and results should be considered preliminary. The building was completed and occupied during January of 1989. Shortly thereafter extensive energy performance monitoring was begun by the Washington State Energy Office, via a subcontract with W.S. Fleming Inc. Selected air and water temperatures, air and water flows, relative humidities, and electrical energy usage have been monitored and recorded (six second averages) on a multi-channel datalogger. Data collection for the first year has been completed. Once the data are analysed a more complete energy performance profile will become available.

Zoned electric resistance heaters were separately submetered. The integrated heat recovery ventilation system, which provides continuous ventilation, partial space heating, space cooling and water heating was also submetered. Electrical main and submeter data were recorded by the author. For the one year period between March 4, 1989 and March 3, 1990, electric resistance heating used 1.4 kWh/ft^2 (54 MJ/m^2). The HPV unit used 3.5 kWh/ft^2 (135 MJ/m^2) for continuous ventilation, space heating and cooling, water heating, and pressure-difference control. The HPV system is estimated to provide 44% of the space heating load. This brings the total cost of space heating to $216/year. The measured average Kwh consumption for heating conventional electrically heated homes in the Pacific Northwest is 12,420 Kwh, which amounts to $596 (5).

MOISTURE PERFORMANCE

Humidity sensors (7) were calibrated and placed inside structural wood framing in six locations prior to completion of construction. Two sensors were placed in the attic, two in the walls, and two in the floor of cell 1. An attempt was made to select locations with the greatest moisture potential; generally downwind from the prevailing wind direction, shaded areas on the north side, and (for walls) high in the building:

- Attic top chord - north side near center of building.
- Attic bottom chord - north side near center of building.
- East wall exterior framing stud - north side on upper level.

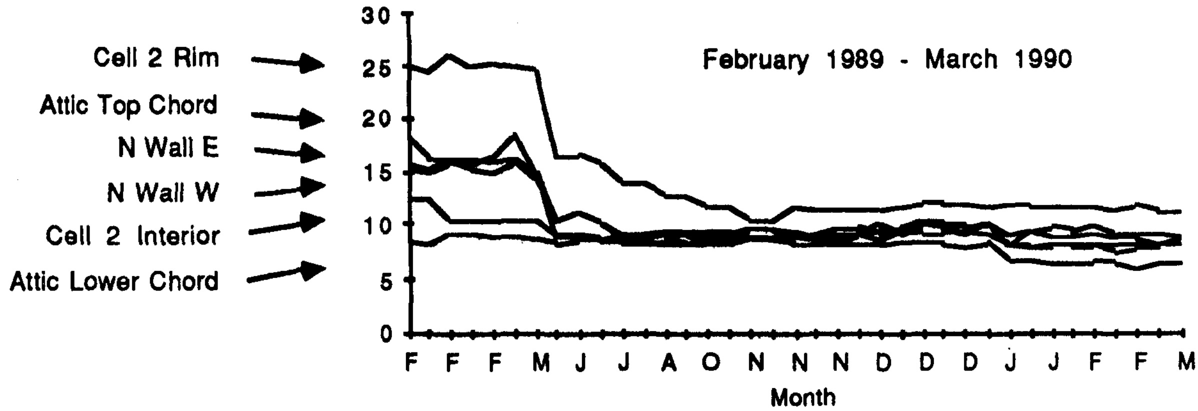

Figure 4. Percent wood moisture content in six locations.

- West wall exterior framing stud - north side on upper level and near electrical outlet.
- Warm joist in cell 2 - center of building.
- Cold joist cell 2 - next to north rim joist and on cold side of air-vapor barrier and insulation.

Thirty-seven intermittent readings were recorded (approximately weekly during the heating season) and corrected for temperature. Monitored moisture levels in all locations dropped by the end of the summer following completion of construction, and remained approximately constant through the following winter (Figure 4). Moisture levels remained constant during the second winter as well.

VENTILATION PERFORMANCE DYNAMICS

The clock timer on the HPV unit is set to provide continuous exhaust ventilation, so the unit's exhaust fan (F2) drawing stale air from cell 2 is always activated. If there is a demand for water heating the compressor also operates. If there is a demand for space heat or cooling the supply fan (F3) also activates. Both fans operate at a constant speed and flows must be adjusted by dampers.

The baseline mode of operation has been to adjust fan F1 to maintain a slightly lower pressure at the ceiling of cell 1 than that outside (thus also pressurizing cell 2). This typically resulted in a 2-13 Pa lower pressure at the ceiling of cell 1 relative to outdoors during space heating. The neutral pressure plane was maintained above the ceiling of cell 1, there was no exfiltration, and therefore all air exchange was induced by the HPV unit. The resultant pressure in cell 2 was generally 3 to 7 pascals greater than the pressure in cell 1, during space heating mode of operation. The supply air fan (F3) operates during space heating and cooling, and tends to pressuize the building, by increasing the flow of outside air through the earth tubes.

However, when it is off (during periods of ventilation and water heating), fans F1 and F2 remain on, so the cell 1/cell 2 pressure-difference increases (10 to 20 Pa) Additionally, a manual timer switch in the bathrooms enables short pulses of greatly increased ventilation by boosting fan F1 to full power, and the cell 1/cell 2 pressure-differences become even larger (45 to 60 Pa)

Intermittent measurements by the author indicate that the mechanically induced air exchange rate for the first year has been roughly 6 ACH, or equivalent outdoor air supply for 11 persons at 15 cfm (7 L/s) per person Since the pressure in cell 1 was lower than the pressure outside (therefore no exfiltration), all the air leaving cell 1 had to pass through fan F1. A Kurz Model 435 Linear Air Velocity Transducer was used to measure the mass flow of air in the duct downstream of fan F1.

The purpose of fan F4 is to pull outdoor air through the earth tubes and provide adequate outdoor air supply. It was found to be unecessary and was not operated The negative pressure of cell 1 induced sufficient flow in the earth tubes. When the unit's supply fan (F3) did not operate (ventilation and water heating modes) the earth tube flow averaged 27 cfm (13 L/s). When the supply fan operated the average earth tube flow was 57 cfm (27 L/s). Approximately one third of the outside air supply was via the earth tube. Envelope infiltration, due to the induced negative pressure of cell 1, provided the remaining outside air.

The pressure-difference control under these conditions appears to have been very robust Though pressure-differences were not continuously monitored, they were frequently observed during cold and windy periods. No reversals of the desired pressure-difference directions were observed.

CONTROL OF RADON

RADON PHASE ONE

Five continuous radon monitors (CRMs) were placed in the same location for five days to establish a comparison baseline The monitors were then placed in five different locations in the building for a thirteen day period between November 11, 1989 and November 23, 1989. Fan F1 was off during the first part of of this period, so that fan F2 depressurized both cell 1 and cell 2 relative to outside

After the first 112 hours, Fan F1 was activated and adjusted to maintain a slightly lower pressure at the ceiling of cell 1 relative to outside during the space heating mode This resulted in a 10 to 60 Pa greater pressure in cell 2 (depending on the HPV system's operating mode at time of read)

Cumulative CRM data were recorded intermittently and averaged over each elapsed time period Thirty-two readings were recorded Average radon levels in cell 2 decreased dramatically when fan F2 was activated, average radon levels in cell 1 also showed a tendency to decrease (Figure 5)

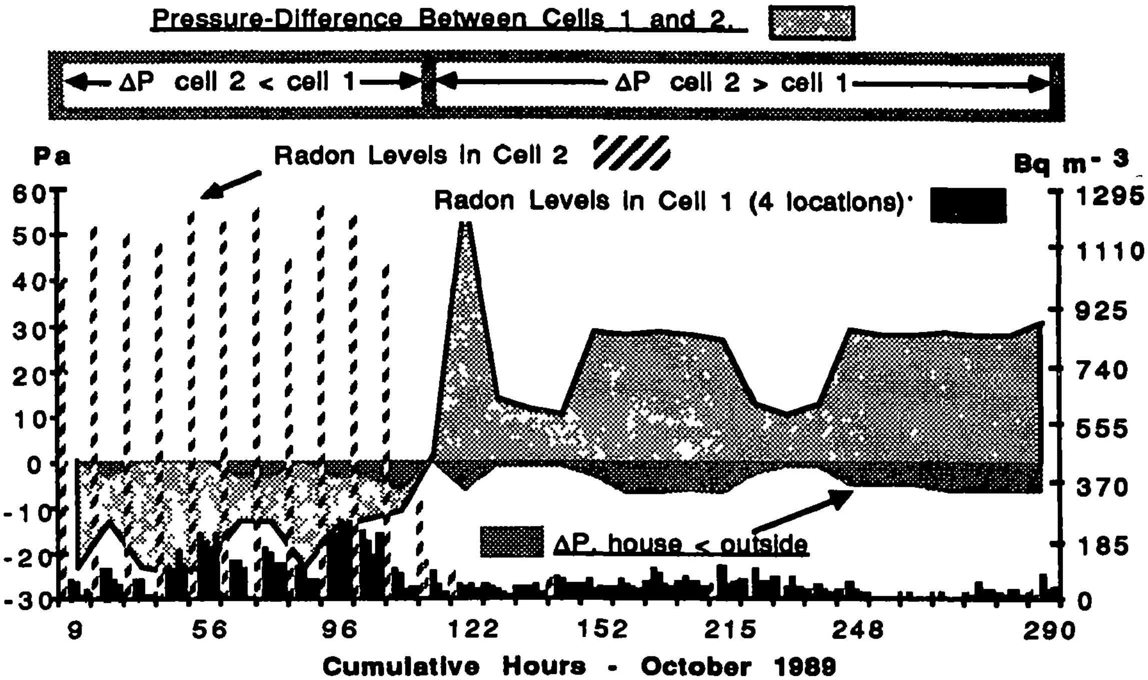

Figure 5 Radon levels in five locations.

RADON PHASE TWO

Two CRMs were placed in separate locations within cell 1 (CRMs 1a and 1b) and two CRMs were placed in separate locations within cell 2 (CRMs 2a and 2b). Hourly radon averages were recorded for the three month period between 17 February and 21 May 1990. During this period, the baseline system configuration (continuously pressurize and flush cell 2 while depressurizing cell 1) was held constant for the first 23 days Then 9 deliberate alterations in system configuration were made. After each alteration the system was returned to the baseline configuration, before the next alteration was initiated. Upon completion of the 9 alterations the system was returned to the baseline configuration for 22 days.

The alterations had powerful effects upon Cell 2 radon levels, and clear effects upon radon levels in Cell 1. Effects of wind, rainfall, and temperature did not appear to have noticeable influence on radon levels, except that Cell 2 radon levels may have showed some indication of response to temperature. Nonetheless the effect was subtle relative to the effects of system operation.

The baseline system configuration and the alterations to it are discussed below, and referenced in the following graphs.

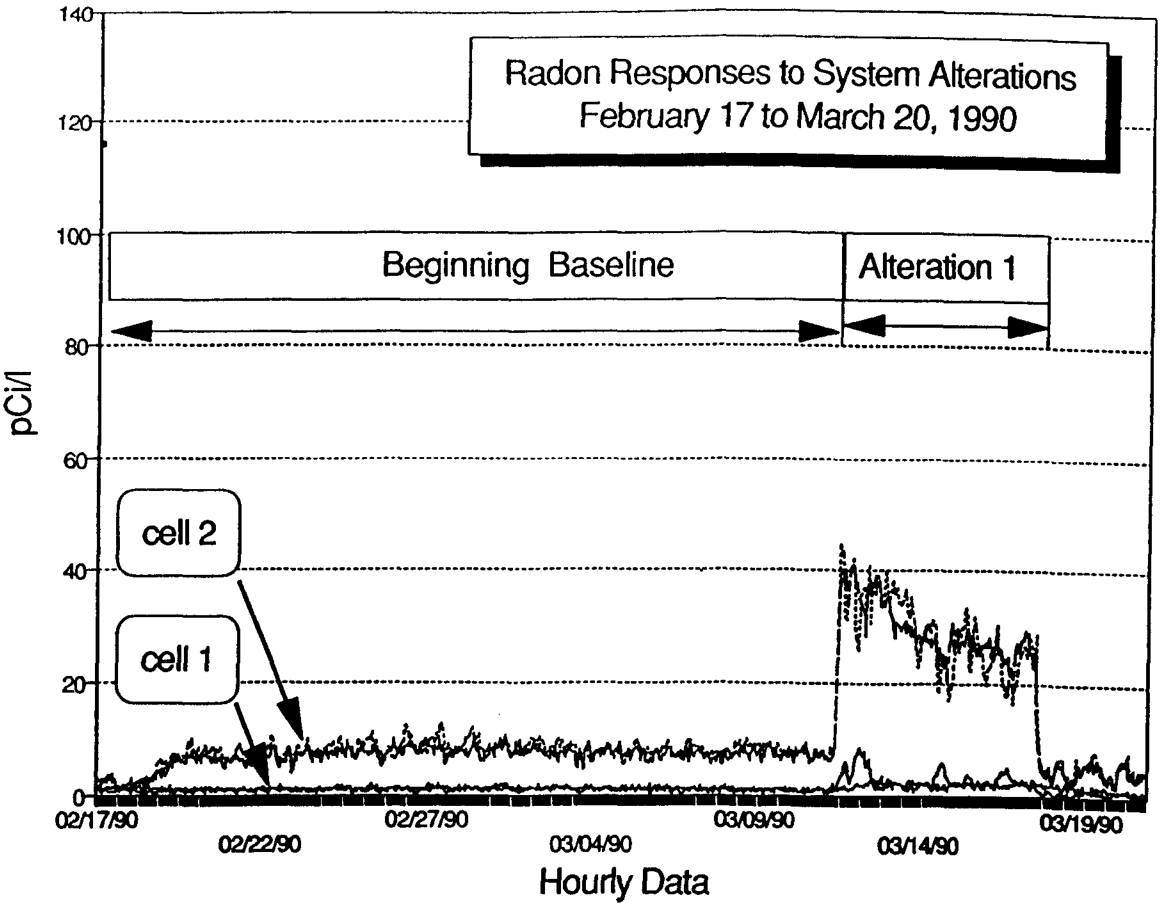

Figure 6. Baseline and Alteration 1.

__Baseline.__ The baseline operating condition was established for 23 days, from 2/17 to 3/11. During this period the average radon concentration in cell 1 was on the order of 1 pCi/l. The average radon concentration in cell 2 was 7 pCi/l. Intermittently recorded cell 2 pressures ranged from 1 to 7 pascals greater than those of cell 1. The average was 3 pascals. Cell 1 was 7 to 15 pascals lower in pressure than outside. The average was 9 pascals.

__Alteration 1.__ Fan F1 was turned off on 3/11 at 10:20 am. The pressure in cell 2 had been greater than the pressure in cell 1, but now shifted to about 30 pascals lower than cell 1, since F2 now pulled air through the cell 2 plenum. In two hours radon levels in cell 2 had increased by a factor of three. Radon levels in cell 2 averaged 29 pCi/l. Radon levels in cell 1 increased also to an average of about 2.5 pCi/l. On 3/17, six days later, fan F1 was turned back on. Pressure in cell 2 returned to 3-4 pascals greater than cell 1. Radon levels in cell 2 dropped by a factor of three in three hours and returned to baseline levels.

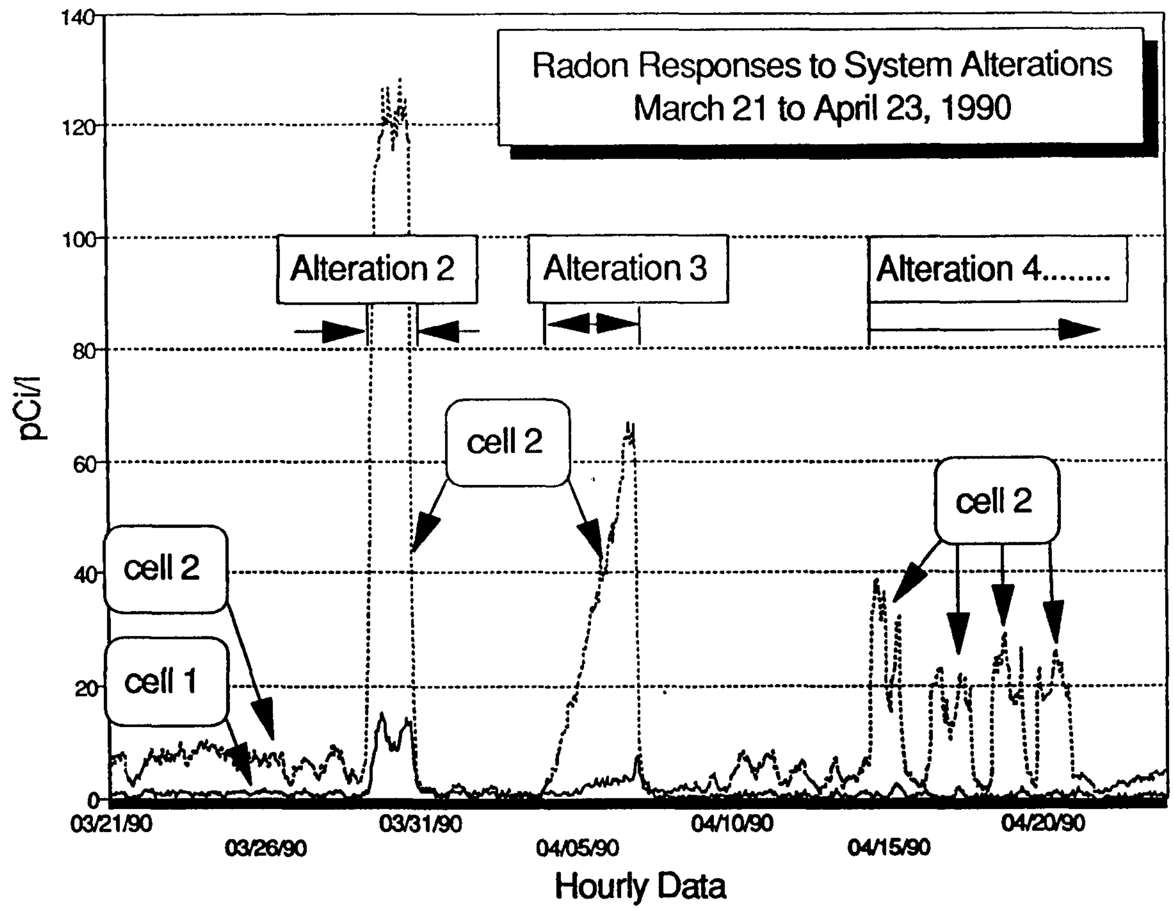

Figure 7. Alterations 2,3, and 4.

<u>Alteration 2.</u> On 3/29 fan F1 was turned off again for approximately 34 hours. F2 continued to operate, but the duct connection from F2 to cell 2 was disconnected and exhaust air taken from cell 1 instead. The ductwork joining the two cells remained open. Cell 2 was atmospherically coupled to cell 1, but was decoupled from the ventilation loop. During this condition the cell 1 pressure was 10 pascals lower than the outdoor pressure and cell 2 was about 7 pascal lower than than the outdoor pressure. Hence, both cells sucked on the ground, but only cell 1 recieved ventilation. Cell 1 radon levels increased by a factor of 12 to an average peak of 12 pCi/l. Cell 2 radon levels increased by roughly a factor of 20 to an average peak of 120 pCi/l. When the system configuration was returned to the baseline, radon levels quickly returned to baseline levels.

<u>Alteration 3.</u> On 4/4 fan F1 was turned off for 62 hours. Also F2 and F3 were turned off. There was no ventilation. The ductwork joining the two cells was sealed to atmospherically decouple the cells from each other. Radon levels in cell 2 rose gradually (whereas in the previous alterations they had risen abruptly) to a peak of

66 pCi/l. Then F1, F2, and F3 were reactivated and radon levels in both cells returned abruptly to baseline levels. The pattern of a more gradual rise in radon levels also seemed to occur in the cell 1 radon levels which rose to over 5 pCi/l. The gradual rise is assumed to be attributed to soil recharging and the slower response related to the lesser stack pressures.

The three fans were activated 62 hours after the initial alteration. However, cell 2 remained atmospherically decoupled from the ventilation cycle (F2 drew exhaust air from cell 1), as well as isolated from cell 1 by the sealed ductwork. The condition was that cell 2 was pressurized by fan F1 but there was no flushing of the air in cell 2. The resultant pressure in cell 2 was 45 pascals greater than that in cell 1. Radon levels returned to baseline in about 6 hours, hence were already at baseline levels when the ductwork was reconnected and the system configuration returned to baseline.

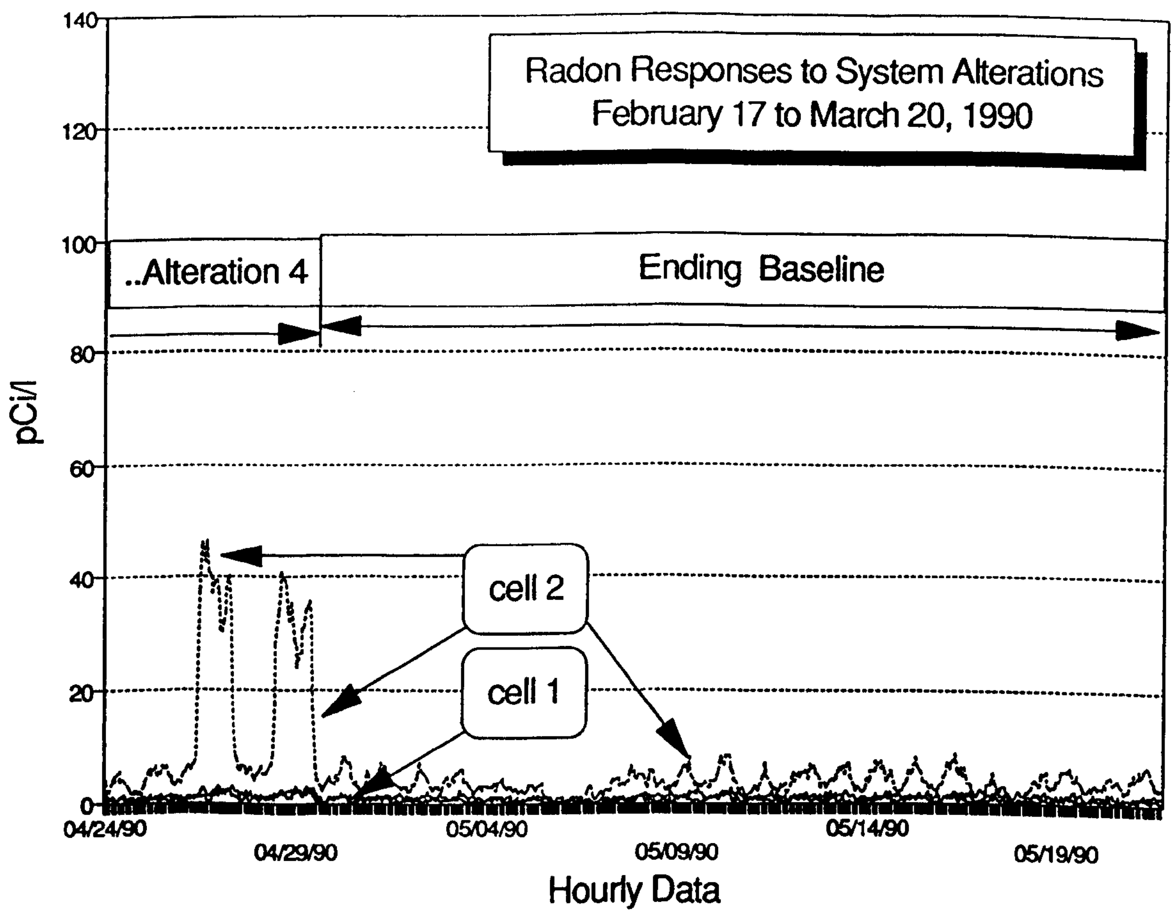

Figure 8. Alteration 4 and Baseline.

<u>Alteration 4.</u>. Fan F1 was turned off. The system was altered as described in alteration #2 for roughly 24 to 30 hours, then returned to the baseline configuration. This process was repeated six times. In each case cell 2 radon levels responded as they had in alteration #2.

Baseline. The baseline operating condition was restablished for 22 days, from 4/29 to 5/21. During this period the average radon concentration in cell 1 was less than one pCi/l. The average radon concentration in cell 2 was about 2.5 pCi/l.

There is some uncertainty associated with the radon measurements. The CRMs were research instruments that were not calibrated immediately prior to these measurements. However, they were compared to each other by operating them in the same location for six days at the beginning of this project. All 4 CRMs tracked radon levels consistently (Figure 9).

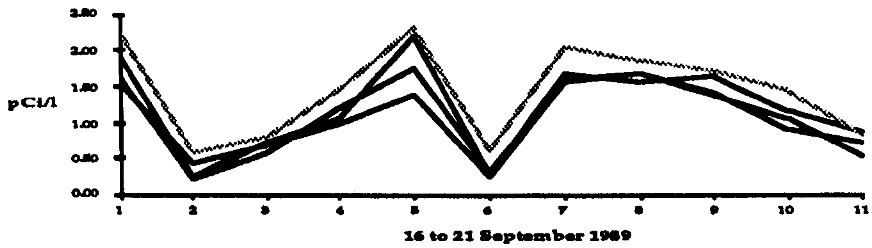

Figure 9. Radon instrument comparisons.

Several months after the project they were again compared to each other, and it was discovered that only CRM 1a had a correctly operating air pump. This CRM was then compared for about 30 hours to a Pylon AB5 with a PRD, which had been recently calibrated with a Pylon Calibration Standard. The two monitors tracked radon fluctuations consistently. When the data from this project was later reviewed*, it was discovered that CRMs 1b and 2b had diverged widely (radon levels declined) from their respective matched pairs and never recovered. These were suspected to be the points of pump failure. Data from these units was removed from the data set for the time periods after their responses suggested pump failures.

CRMs 1a and 2a did respond in a consistent manner throughout the entire measurement period. Fortunately one was located in cell 1 and the other in cell 2. It was also fortunate that CRM 1a -- which was recording the lowest and least variable radon levels -- was also the CRM that continued to have a correctly operating pump and was compared to the calibrated Pylon instrument after the study. Both the consistent response of these two remaining CRMs to the repetitive nature of alteration #4, and the similarity of their ending baseline responses to their starting baseline responses, suggest that these two CRMs responded with acceptable accuracy to radon fluctuations throughout the study.

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* This study was not funded and was conducted as time allowed.

It is not known when the the pump on CRM 2a began to fail. The data set suggests that CRM 2a was operating correctly during the study period and likely failed after the study period.

COST

It is very difficult to assign costs to the radon prevention and mitigation features of this building, since virtually all the features that control radon also enhance energy performance, durability, comfort, and the control of other pollutants. The simple energy-only payback for these features is 10 to 20 years. The building's useful life has also been extended due to such features as the vented rain screen designed to extend siding life, and the elimination of air transported moisture into the exterior walls. Since these features primarily address energy, and there is a clear energy payback for them, it can be argued that there is no incremental cost for the control of radon entry. The building cost $80,824, approximately $45 to $48 per square foot.

INDICATIONS

1. Control of soil-air entry with pressure-differences using a continuous mechanical ventilation system incorporated into a tight house is readily achievable.
2. The initial radon experiment indicates that the radon source at this building location may be sufficient to allow the demonstration of radon control, as well as the comparison and evaluation of the impact of different pressure-difference configurations on radon entry.
3. Airflows through the HPVAC-80 can be reduced by installation and adjustment of dampers so that the flows necessary to maintain required pressure-differences can be reduced (within the limits of the range of flows required by the HPV). The target goal of maintaining soil gas entry control with a mechanical system operating at .35 ACH may be achievable at this level of envelope tightness.
4. Careful attention to air-vapor barrier installation can enable sufficient control of moisture levels in the Spokane climate, even under conditions of constant and relatively large pressurization.

FUTURE DIRECTIONS

- Evaluate this concept at sites where the known soil radon source is high.
- Evaluate the degree of pressure-difference necessary to control radon and determine the associated air exchange rates, climatic conditions, and energy costs.
- Compare different pressure-difference scenarios and their impact on radon levels.

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MINI FAN FOR SSD RADON MITIGATION IN NEW CONSTRUCTION

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ABSTRACT

Subslab depressurization (SSD) systems in new houses constructed with well sealed slabs and good aggregate beds will probably achieve excellent radon mitigation performance with fans that are considerably smaller than the 80 Watt fans that are currently recommended. This paper describes the development, testing, and evaluation of a low power radon mitigation fan for installation in new houses. This "mini SSD fan" uses only 10 Watts of power, and its radon mitigation performance is shown to be almost as good as the larger fans. Since the EPA plans to recommend the installation of SSD systems in hundreds of thousands of houses that are constructed each year in high radon areas, the long term energy savings involved in reducing fan power could involve billions of dollars. In addition, the mini SSD fan lowers the installation cost of the radon mitigation system, and this might encourage more builders to follow with the EPA recommendations.

BACKGROUND

One strategy for radon mitigation in new construction is for builders in areas with high radon levels to install SSD systems in all the houses that they build. Experience with SSD in new construction suggests that when houses are constructed with SSD combined with a well sealed foundation and a porous aggregate layer, then the performance of SSD radon mitigation has been shown to be excellent. Although many houses with these systems would not have had a radon problem above the EPA action level of 4 pCi/L, even the lower level houses would probably experience some radon mitigation. Since most radon exposure occurs in these lower level houses (due to their large numbers), the net result of installing SSD in all houses in high radon areas is a substantial decrease in radon exposure for occupants of these houses.

A primary objection to installing SSD systems in all houses would be the costs, both for initial installation and for energy and eventual replacement. This objection could be reduced by using the lowest cost components consistent with good radon mitigation performance, long life, and low energy costs. This paper describes the development, test, and life cycle cost evaluation of a low power SSD radon mitigation fan for installation in new houses. This "mini SSD fan" uses 10 Watts of electric power compared to the 80 Watts of the standard fan, and its performance is shown to be almost as good as the larger fans. Since the EPA plans to recommend the installation of SSD systems in hundreds of thousands of houses that are constructed each year in high radon areas, the long term energy savings involved in reducing fan power could involve billions of dollars, and these energy savings might provide some assistance in solutions to problems such as global warming and U.S. energy independence. In addition, the mini SSD fan lowers the installation cost of the radon mitigation system, and this might encourage more builders to follow the EPA recommendations.

PREVIOUS EXPERIENCE

Although SSD is by far the most common radon mitigation technique, the details of its operation are not entirely clear and the size of the fan that is necessary for effective mitigation is not well understood. As a result, most mitigators use 80 Watt fans for most of their mitigation jobs, and most of the industry experience is based on the use of these fans. For new house construction, it seems that smaller fans might be successful if the builder provides a good site preparation by installing at least a 4" depth of large diameter aggregate under the slab, and by sealing all slab penetrations. Several documents have been written about construction details for radon resistant new construction, including: a new ASTM standard[1], a Bonneville Power Administration report[2], and the EPA new construction guide[3]. Unfortunately, these documents do not contain much discussion of fan performance versus size or of life cycle costs. The EPA will soon issue recommendations on model code language for radon resistant new construction, and there will be a technical support document with life cycle cost calculations.

However, there is one study that suggests that very small fans might provide good performance: the February 1990 EPA Symposium Paper

Radon Mitigation Performance of Passive Stacks in Residential New Construction[4] by Saum and Osborne. This research showed that one builder's passive stacks (SSD systems without any fans) offered significant radon mitigation performance in both summer and winter. Table 1 shows a summary of the radon mitigation results for this study. The passive stacks reduced the radon levels by about 66%, and 45 Watt SSD fans reduced radon levels by an average of 98% of the pre mitigation levels. Most performance reductions in these passive stack houses are thought to be due poor installation of the stacks, or to depressurization of the basement by leaky forced air return ducts which reversed the passive stack pressures. This suggests that a small SSD fan would boost the passive stack pressures enough to overcome most of these residual mitigation problems.

MINI FAN DESIGN

The first step in this project was to design a low power and low cost fan that could be used in a conventional new home SSD system. It was assumed that the builder would install a 4 inches of coarse aggregate under the slab, seal all slab penetrations, and run a stack pipe (3" or 4" PVC) up through the slab and exiting though the roof. In order to take advantage of the passive stack effect, the stack should run through the heated part of the house. The desirable fan characteristics were considered to be low power, long life, and low cost. Conventional radon fans use about 80 Watts, have an estimated 100,000 hour life, require 2 pipe couplings to connect to the stack pipe, and the total cost of fan and couplings is about $150.

The final mini SSD fan design is shown in Figure 1. The conventional radon fan system consists of a fan motor, fan housing, and two pipe couplings. To reduce noise, the conventional 45 or 90 Watt radon fans use a backward inclined blade, but 10 Watt fans are so quiet that a conventional low-cost axial fan blade can be used. For simplicity and lower cost, the mini fan is built into one pipe coupling which serves as a combined fan housing and pipe coupling. The final mini fan design consists of a high quality 10 Watt, 3" diameter, axial fan mounted in a 3" diameter PVC ring, and enclosed in a 3" flexible pipe coupling. When a 3" stack pipe is used, the fan housing serves as the pipe coupling. If a 4" stack pipe is used, then two 4" to 3" pipe couplings can be used to couple the fan to the 4" stack. The use of 3" stacks would be recommended because of the low air flows, the reduced costs, and the consistency with the use of 3" plumbing stacks already installed in houses. To complete the radon control system, a pressure gauge capable of monitoring the low expected stack pressures was developed from the commercially available "Fancheck" type pressure indicator. The Fancheck is a modified Dwyer air flow meter that consists of a small ball in a tapered clear-plastic tube. The conventional Fancheck indicates pressures greater than about 0.2" wc, but this device was modified for use with the mini SSD fan by using a much lighter ball so that it indicates pressures of only a few hundredths " wc.

COST ESTIMATES

FAN PARTS COSTS

The parts cost of the mini SSD fan is less than $20, and the modified pressure gauge is about the same cost (about $10) as the Fancheck gauge. Therefore the mini SSD fan could be sold to builders for considerably less than a standard radon mitigation fan system consists of an 80 Watt fan with 2 pipe couplings (about $150), and a pressure indicator ($10). It is anticipated that the mini SSD fan system could be sold to builders for about $75, half the cost of the standard 80 Watt fan system.

LIFE CYCLE COSTS

The largest cost savings are in the life-cycle costs, not the initial installation costs. Table 2 shows a comparison of life cycle costs between a 10 Watt SSD fan and a standard 80 Watt SSD fan. Three types of recurring costs are assumed: electric cost for running the fan continuously, wasted heat costs for warming house air that is exhausted through the fan, and fan replacement costs. These calculations show that the mini SSD fan would cost about $29 per average year, while the standard 80 Watt fan would cost about $135 per year to operate continuously.

If builders follow the forthcoming EPA recommendations that all houses in radon prone areas have radon resistant features built into them, then it is reasonable to assume that at least 100,000 of the 1,000,000 new home built every year will have SSD fans installed. Under these assumptions, the estimated savings for installing a 10 Watt fan, rather than an 80 Watt fan, are shown to be $11 million in the first year, $476 million in 10 years, and $4.6 billion in 30 years.

RADON MITIGATION PERFORMANCE

Ideally we would like to know the performance trade-off between fan power and radon mitigation performance under a wide variety of conditions: geology, climate zones, building practices, heating/cooling system variations, contractor variables, failure modes, etc. With this type of data, we could begin to make a calculation of the cost per life saved with different SSD fan systems. Unfortunately, this type of study is far beyond the scope of this project.

PASSIVE STACK PERFORMANCE

The passive stack experiment data shown in Table 1 suggests that the mini SSD fan radon reductions in new houses should be somewhere between the performance of the passive stack systems (about 66% reduction) and the performance of the 45 Watt fan systems (about 98% reductions). It seems likely that if the performance of the passive stacks is based on the extremely weak forces of stack effect, then the performance of 10 Watt fan systems will be much closer to the 45 Watt fan systems than to the passive stack systems. We believe that is not unreasonable to assume that the mini SSD fan will give at least a 90% average reduction of elevated radon levels in new construction, assuming the recommendation on the subslab aggregate layer and sealing is followed.

MINI FAN PERFORMANCE IN ONE HOUSE

Only one prototype fan was available for experiments until last month when an additional half dozen prototype units were received from the fan manufacturer. The original prototype has been tested for several months under worst case conditions: an older house with no slab sealing and a poor subslab aggregate bed. These conditions were expected to be much worse than would be found in new houses built for radon resistance. The data from these tests is shown in Figures 2-5. These Figures show that even in an older house with no sealing of cracks and an uneven subslab aggregate bed, the 10 Watt mini SSD fan lowers the radon level from 10 pCi/L to 2.1 pCi/L (a 79% reduction), versus a reduction to 0.8 pCi/L (a 92% reduction) for a 45 Watt fan. Figures 2 and 3 show the performance of the two fans over a month as the fans are being cycled off and on every 3.5 days. Figures 4 and 5 show the averages of 4 on/off cycles so that the variations are smoothed out. Note that both fans reduce radon levels within a few hours after the fans are turned on, but the larger fan seems to have depleted the radon under the slab more extensively than the smaller fan, and it takes longer for the radon levels to build up in the house after the larger fan is turned off.

PERFORMANCE LIMITATIONS

Some general limitations of SSD fans that may apply to the mini SSD fan have not been fully investigated yet: 1) problems with large slabs, 2) problems when sand or other low porosity aggregates are used below slabs, and 3) problems when the soil below the slab is very porous. These situations are not well understood for even the standard SSD radon mitigation systems. It seems likely that this type of problem could be addressed by written guidance that would be included with the mini SSD fan systems.

FUTURE DEVELOPMENT PLANS

The future plans for development of the mini SSD fan call for more field tests of the prototype, refinement of the design, field tests with cooperative builders, certification (UL or equivalent), volume purchase agreements, and eventual sale to builders and mitigators.

DISCLAIMER

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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Table 1 Radon Mitigation Performance Data from Passive Stack Study

HOUSES WITH PASSIVE STACKS, NO FANS

Test • House No.	Stack Open (pCi/L)	Stack Sealed (pCi/L)	Radon Reduction (%)	Comment
126	0.3	6.1	95%	summer data
126	0.1	13.6	99%	winter data
162	4.7	8.5	45%	duct leaks, poor communication
40	8.8	12.8	31%	duct leaks, poor communication
53	1.1	2.7	59%	
209	1.2	6.5	82%	
105	0.6	1.8	67%	
42	1.9	9.4	80%	duct leakage
84	4.9	5.8	16%	duct leaks, poor communication
206	2.9	19.9	85%	winter - duct leakage
206	0.6	2.4	75%	summer - duct leakage fixed
AVERAGE:	2.5	8.1	70%	

HOUSES WITH FANS IN PASSIVE STACKS, FANS OFF

Test House No.	Stack Open (pCi/L)	Stack Sealed (pCi/L)	Radon Reduction (%)	Comment
383	1.8	13.0	86%	winter
308	4.5 na	na	na	summer, duct leakage
308	8.0	33.5	76%	winter, duct leakage
221	1.5	12.0	88%	winter, duct leakage
181	6.7	7.4	9%	stack in unheated garage
233	na	18 na	1.9 na	not used, fan inside basement
237	7.4	13.7	46%	stack in unheated garage
184	12.7	26.4	52%	duct leakage
AVERAGE:	6.3	17.7	64%	

HOUSES WITH FANS IN PASSIVE STACKS, FANS ON

Test House No.	Fan On (pCi/L)	Stack Sealed (pCi/L)	Radon Reduction (%)	Comment
383	0.1	13.0	99%	winter
308	0.4	na	na	summer, duct leakage
308	0.2	33.5	99%	winter, duct leakage
221	0.3	12.0	98%	winter, duct leakage
181	0.1	7.4	99%	stack in unheated garage
233	na	18 na	na	not used, fan inside basement
237	0.6	13.7	96%	stack in unheated garage
184	0.8	26.4	97%	duct leakage
AVERAGE:	0.4	15.1	98%	

COMMENTS AND CONCLUSIONS

1. This data was collected by an EPA Office of Research & Development funded study conducted in 1989-90 and performed by Infiltec and Ryan Homes.
2. All radon measurements are averages of one or more weeks of hourly continuous radon data collected with Pylon or Femtotech monitors.
3. Passive stacks lowered radon by about 1/3, fan systems by about 1/40
4. Passive stacks provided mitigation in summer as well as winter.
5. Passive stack performace appeared to be reduced by duct leaks and poor subslab communication causing blocked pipes.
6. Passive stacks provided some mitigation in all cases.
7. A low power fan to assist the passive stack might overcome many of the the problems caused by house pressures or poor communication.
8. Limitations of study: one builder (Ryan Homes), one region (D.C. Metro), small number of houses (16), one HVAC type (heat pump).
9. All radon control systems were installed by the builder without supervision by a radon mitigation expert.
10. Houses with summer and winter data are included twice in averages.

Table 2 Life Cycle Costs of the Mini SSD Fan and Standard SSD Fan

CALCULATION ASSUMPTIONS:

GENERAL ASSUMPTIONS:	VALUE	COMMENT
Electric rate	$0.08 per kwh	approximate U.S. electric rate
Gas rate	$0.60 per therm	approximate U.S. gas rate
Oil rate	$1.00 per gallon	approximate U.S. oil rate
Fuel cost escalation	0.00%	to simplify long term calc.
Inflation rate	0.00%	to simplify long term calc.
New houses built	1 million/yr	approximate U.S. average
House lifetime	30 years	used as long term limit
New houses with SSD	10.00% of total	SSD = SubSlab Depres. system
New houses with SSD	0.1 million/yr	this is a guess

HEATING ASSUMPTIONS:	VALUE	COMMENT
Heating degree day	5000 deg F days	approximate U.S. degree days
Gas efficiency	70%	gas furnace and ducts
Gas heat for 1 cfm	$1.12 per year	gas cost/yr/cfm of exhaust
Oil efficiency	70%	oil furnace and distribution
Oil heat for 1 cfm	$1.36 per year	oil cost/yr/cfm of exhaust
Elec. efficiency	90%	elec. furnace & ducts
Elec. heat for 1 cfm	$4.60 per year	electric cost/yr/cfm exhaust
Heat pump efficiency	200%	heat pump and distribution
Heat pump for 1 cfm	$2.08 per year	heat pump cost/yr/cfm exhaust
Avg fuel for 1 cfm	$2.29 per yN /	average cost/yr/cfm exhaust

FAN ASSUMPTIONS:	STANDARD FAN	MINI FAN	COMMENT
Fan power	80 watts	10 watts	continuous electric
Exhausted house air	25 cfm	3.125 cfm	this is a guess
Exhaust heat cost	$57 /yr	$7	avg oil, gas & elec.
Fan life	11.42 yrs	11.42 yrs	rated @ 100,000 hrs
Fan & gauge cost	$150	$75	cost to builder
Fan replacement cost	$250	$175	fan plus install

ECONOMICS FOR SINGLE HOUSE:

	STANDARD FAN	MINI FAN	**$ SAVING**	**% SAVING**
electricity (/yr)	$56	$7	**$49**	**88%**
heat loss (/yr)	$57	$7	**$50**	**88%**
replacement (/yr)	$22	$15	**$7**	**30%**
Cost (/yr)	$135	$29	**$106**	**78%**
Cost (/house life)	$4,056	$885	**$3,172**	**78%**

ECONOMICS FOR U.S.:

	STANDARD FAN	MINI FAN	**$ SAVING**
Costs (1st year)	$14 million	$3 million	**$11 million**
Costs (10 years)	$608 million	$133 million	**$476 million**
Costs (30 years)	$5,882 million	$1,283 milllion	**$4,599 million**

NOTE:

1. Costs of pipe installation and slab sealing ignored since they are common to both SSD fan systems.
2. Exhaust air leakage of 25 cfm for 80 Watt fan is a guess.
3. The estimate of 10% of new home builders installing SSD systems assumes the EPA will recommend new home SSD in radon prone areas.

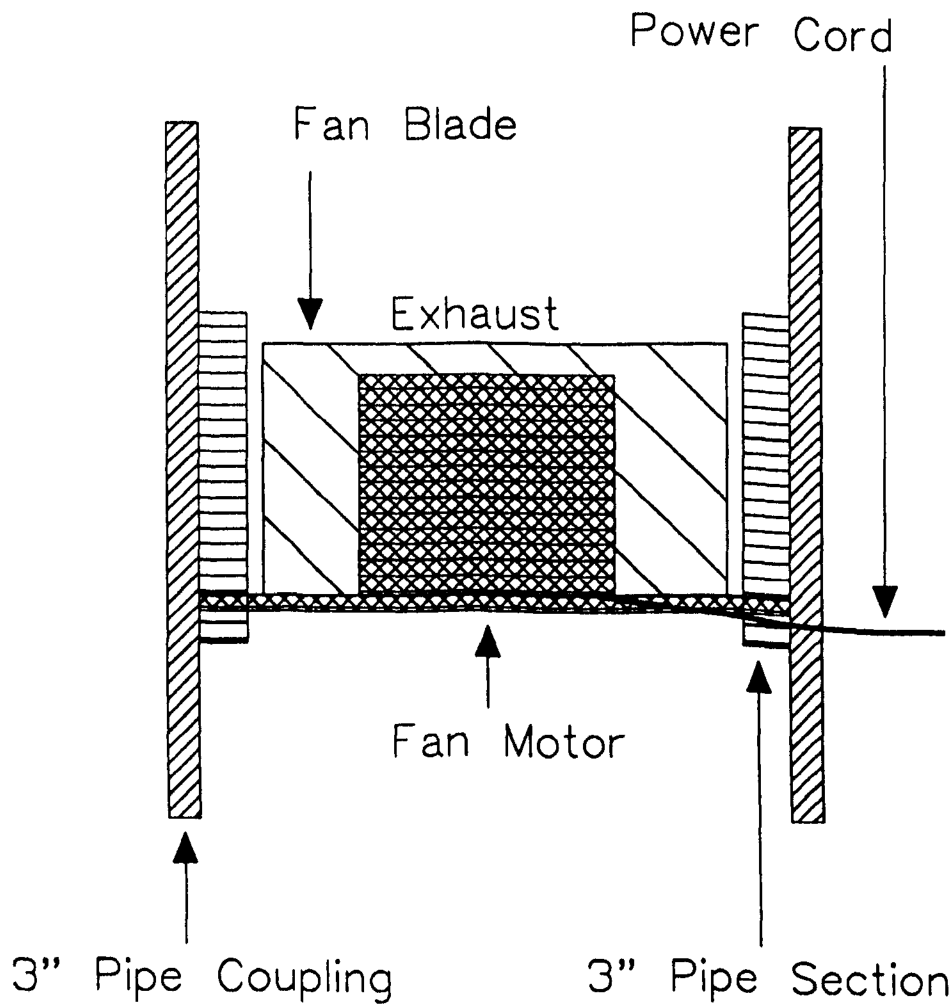
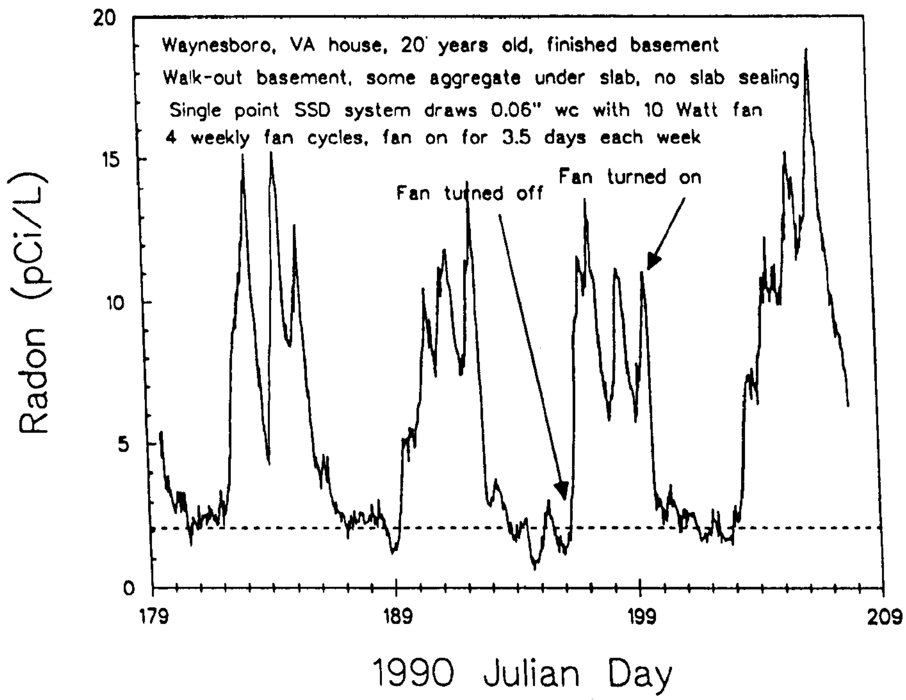
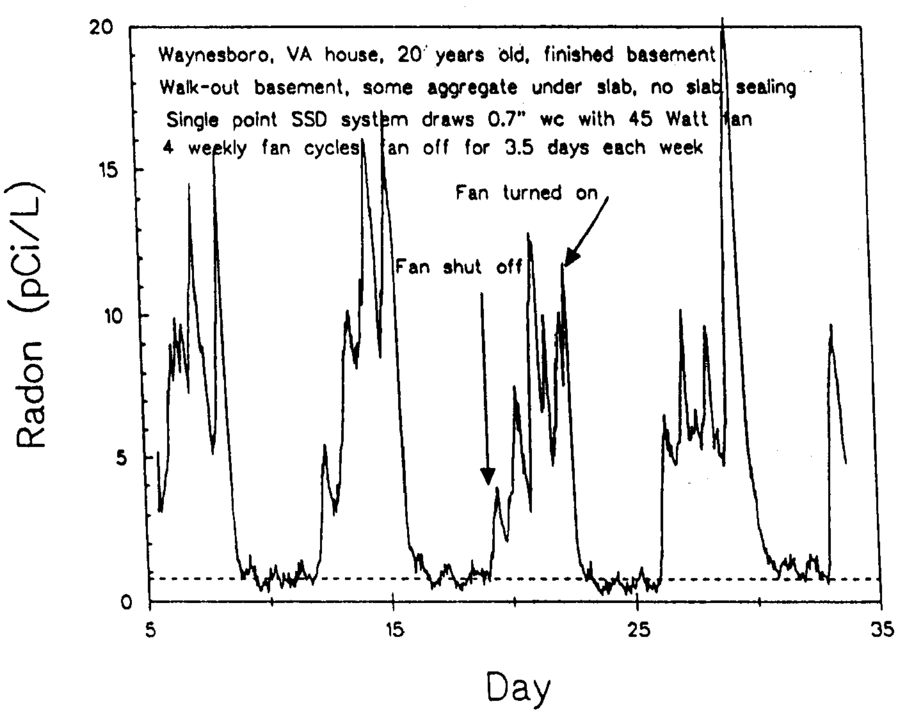


Figure 1 Vertical Cross-Section Schematic of Mini Fan



--- Estimated lower mitigation limit of 2.1 pCi/L
— Radon (pCi/L)

Figure 2 - Mitigation Performance of 10 Watt Fan



--- Estimated lower mitigation limit of 0.8 pCi/L
— Radon (pCi/L)

Figure 3 - Mitigation Performance of 45 Watt Fan

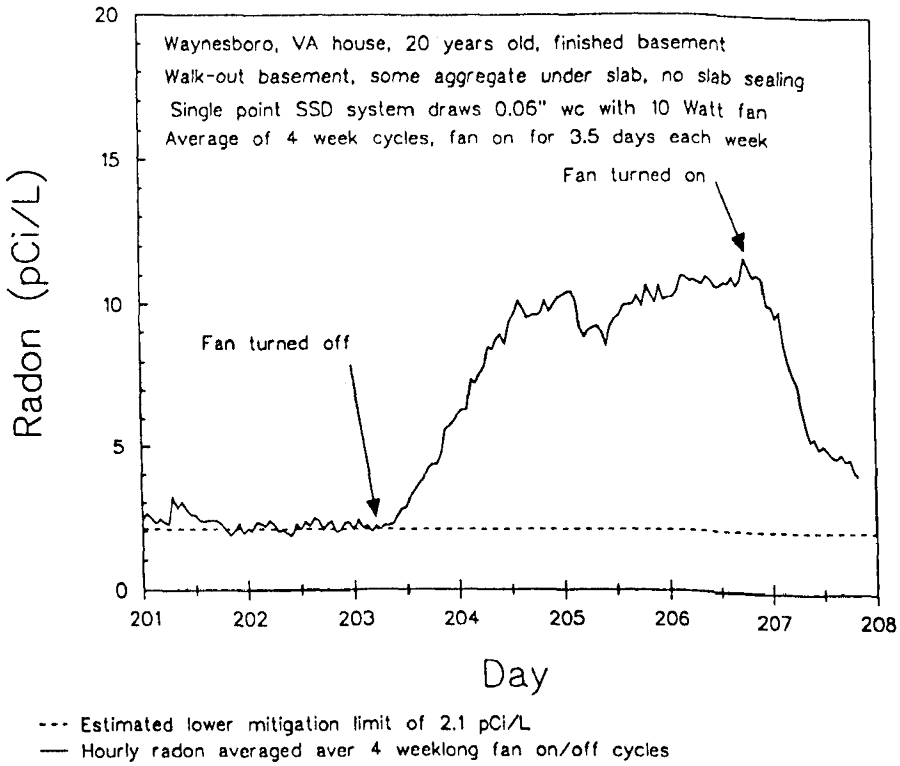


Figure 4 Average Mitigation Performance of 10 Watt Fan

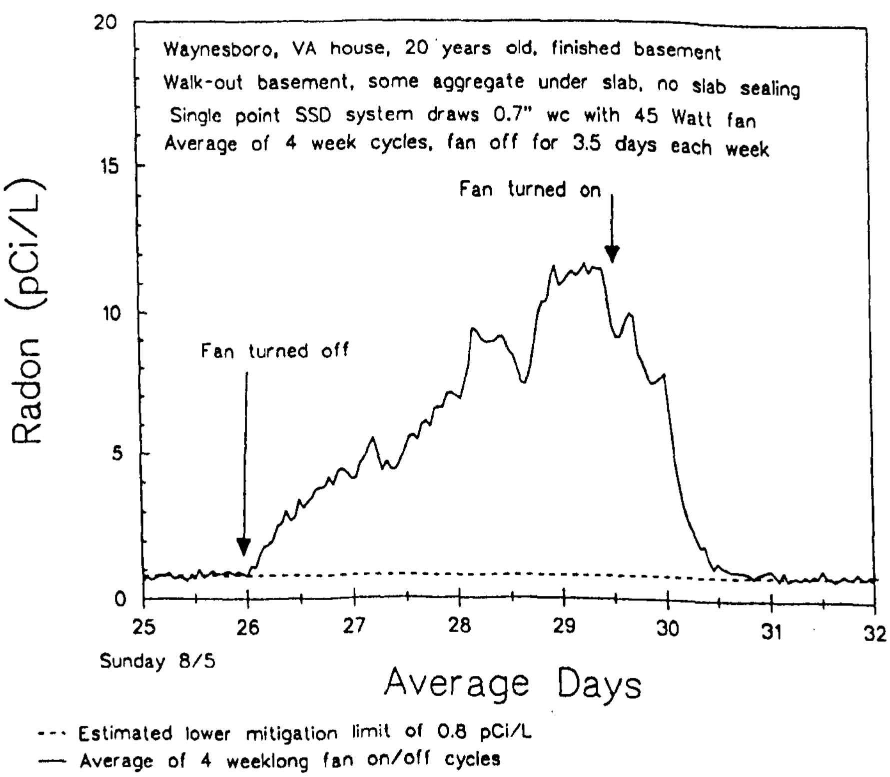


Figure 5 Average Mitigation Performance of 45 Watt Fan

BUILDING RADON MITIGATION INTO INACCESSIBLE CRAWLSPACE NEW RESIDENTIAL CONSTRUCTION

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ABSTRACT Specifications for new residential housing units for base personnel at Ellsworth Air Force Base, Rapid City, SD, called for demonstrated radon levels below 4 picocuries per liter (pCi/L) before they would be accepted by the Air Force. Hunt Building Corporation decided that it would be cheaper to build radon control systems into all the units than to have to retrofit some later. The Radon Mitigation Branch of EPA's Air and Energy Engineering Reasearch Laboratory assisted during the design and installation of the active soil depressurization (ASD) systems and followup measurements. The buildings utilized below grade wood floor construction over an inaccessible crawlspace because of the highly expansive soils. The initial installations demonstrated the need for complete sealing of the floor system. An effective quality control scheme was instituted which tested the negative pressure field established under every building and required additional sealing until each corner of the floor was under at least 2.5 pascals (Pa). Early data indicate that moderate levels of radon (100 pCi/L) exist in the crawlspace when the mitigation fan is off for several days and virtually none when it is on. Results from several buildings are presented.

This paper has been reviewed in accordance with the U. S. EPA's peer and administrative review policies and approved for presentation and publication.

BACKGROUND

A major housing project which will be leased by the Air Force at Ellsworth Air Force Base, Rapid City, SD, is being built by the Hunt Building Corporation. The housing project has 828 residential units in 251 buildings, consisting of singles, duplexes, and quadruplexes. The area where the houses are being built is known to be radon-prone. The Air Force had tested 30 of their 2500 houses and found about 60% of them above 4 pCi/L. As a result of this high radon incidence, the Air Force's initial Request for Proposal (RFP) contained a radon performance clause requiring the builder to test the houses before occupancy to guarantee that they were below 4 pCi/L. A unit testing below 4 pCi/L is accepted by the Air Force for occupancy and a 1-year alpha track test is commenced. If radon levels in the living area test below 4 pCi/L for the first year, then Hunt has met its performance requirement and no longer has any responsibility. If the house initially tests above 4 pCi/L, then Hunt must bring the level below 4 pCi/L before occupancy. When the 1 year test increases above 4 pCi/L, then the Air Force will stop payment until the level has been brought below 4 pCi/L.

With limited radon control experience, Hunt Building Corporation contacted EPA to seek advice on the best way to construct these multifamily housing units to ensure radon levels of below 4 pCi/L or to mitigate them to this level if they are found to contain higher levels when tested. The decision was made by Hunt to install a radon mitigation system in all units since retrofit into an inaccessible crawlspace would be very difficult and potentially expensive.

MITIGATION SYSTEM DESIGN

Most of the units are two-story quadruplexes with the lower level built approximately 3 ft (1 m) below grade (Figure 1). The individual units are separated by a double wall for sound deadening, but no firewall. Because the units are built on expansive soils the Air Force is requiring that the lower floors be treated plywood over joists with a crawlspace below. The units are built with a 6 in. (15 cm) crawlspace between the bottom of the joists and the clay under the units. The building site is being excavated to a depth of 5 ft (1.5 m) and backfilled with compacted glacial aggregate in an effort to stabilize the ground and minimize movement. This is moraine till which is quarried on site consisting of a moraine stone with a great deal of fine sand and some soil in it.

After reviewing the various techniques which AEERL has tested on the mitigation of radon in crawlspace houses, it was recommended that the most cost-effective way to mitigate the house with a high level of assurance of lowering levels to below 4 pCi/L was to use either suction under a polyethylene sheet in the crawlspace or suction on the crawlspace itself. It was decided that there was an excellent chance of making suction on the crawlspace satisfactory by doing a thorough job of sealing the plywood subfloor. The plywood is tongue and groove along the 8 ft (2.4 m) edge, and all 4 ft (1.2 m) edges are on joists. The plywood is screwed to the joists. No outside vents are in the crawlspace, and every effort is made to make the crawlspace as airtight as possible. Moisture should be controlled by the active mitigation system. The joint between the floor and the concrete wall is sealed with polyurethane caulk. Any cuts through the polyethylene and plywood for pipes are carefully sealed around the pipe with polyurethane foam. Hunt has built a box in the joists under the bathtub so the bathtub trap does not penetrate into the crawlspace and provide a possible radon entry route.

One suction pipe per unit is used. This 6 in. pipe, in the wall between the two middle units of each quadruplex, extends straight up to the fan in the attic and exits the roof immediately above.

TESTING FIRST UNITS

Since the building season is short in South Dakota, testing began as soon as the first crawlspace floor was installed. AEERL sent a team to Ellsworth Air Force Base to install a temporary fan on the system and to measure pressure reduction at the various points of the crawlspace below the plywood floor. When negative pressures can be achieved throughout the crawlspace as measured in all four of the corners, the greatest distances from the suction point, then no soil gas should be sucked into the house. A 6 in. pipe was installed through the deck of a quadruplex at the intersection of the central "party" wall and the central beam which ran the full length of the unit. An axial aligned centrifugal fan was mounted on the pipe with power provided through a speed controller. An electronic manometer measured the pressure under the deck at several locations. Once a few small leaks had been sealed, at least -0.010 in. WC (-2.5 Pa) was obtained at each corner of the building and more than 1.0 in. WC (248.8 Pa) fan suction was recorded.

A duplex was the second unit tested. No perimeter or penetration sealing had been done so this provided an excellent opportunity to test the effect the extra sealing had on the suction obtained. No suction was detected at the corners and only

0.2 in. WC (49.8 Pa) of fan suction was measured which was the pressure drop through the floor opening. The fan suction was monitored while the sealing crew proceeded to close the openings. Little change was noticed until most of the wall joint and the pipe penetrations were closed. As the final openings were closed, dramatic increases in the fan suction were seen. The installation crew understood the need for carefully sealing all openings as a result of this test. This effort also provided the basis for the strict quality control and quality assurance program instituted by Hunt.

Every deck was tested when it was sealed and all plumbing activity was finished. A separate crew performed the tests and repaired breaks in the seal. A temporary fan depressurized the crawlspace and the sub-floor suction was measured. Any unit that failed to draw at least 0.010 in. WC in the corners was checked for leaks and resealed before additional construction activities were allowed to proceed. All buildings completed so far have exceeded the requirements when the seal was completed and a 6 in. fan installed. It may be possible to reduce the power consumption further by adding a speed control to the fans.

RESULTS

As the first units were finished, an AB-5 Pylon radon monitor was used to check for radon in three units: a finished one with an operating mitigation system, a unit with a finished floor which had been sealed for 1 week, and a third with a just-completed floor without final sealing. No radon was found under the floor in the finished unit nor in the mitigation system duct.

Likewise, the completed but not sealed unit had no measurable radon in the crawlspace. The crawlspace under the sealed floor did yield levels of 100 pCi/L. This is a moderate source strength, but could be enough to elevate unmitigated units above the EPA action level of 4 pCi/L because the shell of each house is very tight and low dilution could be expected.

Acceptance testing of the first 130 unit section yielded levels between 0.8 and 2.4 pCi/L except for a single unit which had a carbon cannister reading of 16.0 pCi/L. A check of the system in this house found that the circuit breaker had been turned off; consequently, the reading was really an indication of the level that could have been expected if no mitigation system had been installed. A retest with the fan operating showed the levels reduced to 2.5 pCi/L. This fan inoperation showed that the effort and commitment of Hunt to install the mitigation systems and insist on an effective quality assurance program was well worth the investment. Retrofitting mitigation systems into these units would have been much more costly than doing it during the building phase.

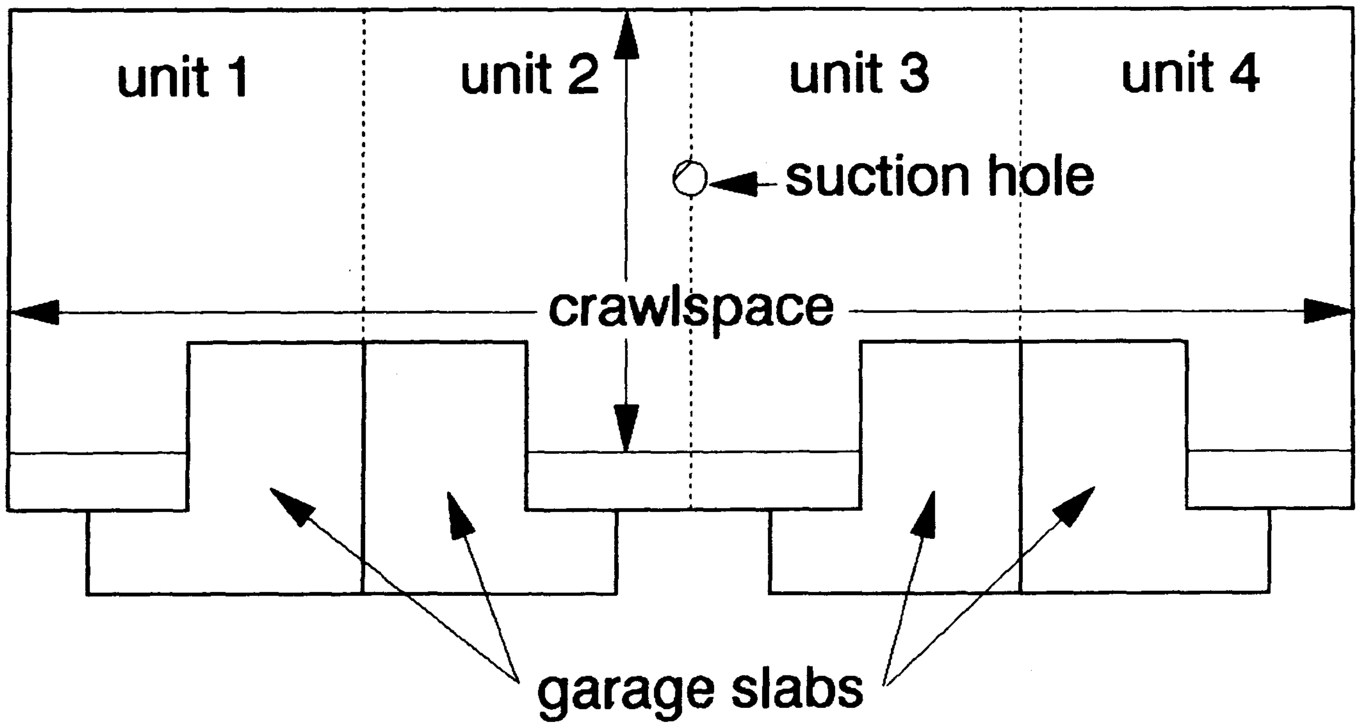

Figure 1. Quadruplex foundation plan

THE EFFECT OF SUBSLAB AGGREGATE SIZE ON PRESSURE FIELD EXTENSION

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ABSTRACT

Four sizes of commercially available crushed blue gravel aggregate (3/8, 1/2, 3/4, and 1 in. nominal diameter) were tested in a laboratory apparatus designed to experimentally determine the aerodynamic pressure drop coefficients of porous material such as soil and gravel. Permeability values for crushed stone of 1/2 and 3/4 in. nominal diameter were found to be 10-20 times higher than those reported in a previous study for river-run gravel of the same nominal diameter. Pressure field extension of this aggregate, when suction is applied to a single central suction hole (a practice widely used for mitigating buildings with elevated radon levels by the subslab depressurization technique), is also generated based on a disc flow model previously studied by the authors. Application of the disc flow model to residences with both basements and slab-on-grade construction is also described. Theoretical computations indicate that the permeability of soil around the foundation walls and periphery of the residence is a more crucial parameter affecting the pressure field extension than the permeability of the subslab gravel bed. The laboratory studies will be field verified in new construction of schools and houses in the future.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.[1]

[1]This work was funded by the U.S. Environmental Protection Agency under Cooperative Agreement No. CR-817013.

PROBLEM STATEMENT

Subslab air flow dynamics provide important diagnostic information for designing optimal radon mitigation systems based on the subslab depressurization (SSD) technique. An earlier study (Refs. 1 and 2) showed that subslab air flow induced by a central suction point can be mathematically treated as radial air flow through a porous bed contained between two impermeable discs. Subsequently, it was suggested that subslab material commonly found under residential buildings be categorized and tested in the laboratory in order to deduce their aerodynamic pressure drop coefficients. This would then permit the pressure field extensions to be inferred which would be of practical and realistic importance to radon mitigators. To this end, a laboratory apparatus was designed and built which is described fully in Ref. 3.

The scope of this study was limited to four aggregate mixes -- No. 600, 601, 602, and 603 -- provided by Vulcan Materials from their Manassas Quarry. The physical specifications provided by Vulcan Materials are given in Table 1. The aggregate is crushed blue gravel, a material commonly used as subslab material for residential and commercial housing.

This paper first reports aerodynamic flow coefficients of the four aggregate mixes obtained from EPA's laboratory apparatus. Subsequently, it describes how the disc flow model can be applied to residences with both basement and slab-on-grade construction. Finally, it shows generated pressure field extension plots for each aggregate in the framework of the above model and discusses the practical implications of these plots in the design of SSD systems.

EXPERIMENTAL RESULTS

The laboratory apparatus, described fully in Ref. (3), is shown in Fig. 1. It consists of a straight length of 8 in.* PVC pipe approximately 5 ft long to the bottom of which a 1/4 in. aluminum removable screen is fitted. The screen, which slides in and out along a groove machined into the PVC pipe, is perforated with a pattern of 1/4 in. diameter holes to permit air flow. The porous material is loaded into the test column from the top after which another sleeve, containing flow straighteners and the air supply inlet tube, is placed on top of the column. Air is supplied to the system from the top and several pressure taps provide information on the pressure drop in the porous bed as air flows down through the porous bed in the test column. The total air flow rate is accurately measured. The experimental procedure involves

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* For readers more familiar with metric units, 1 in. = 2.54 cm and 1 ft = 30.48 cm.

measuring the pressure drop (ΔP) through a known and predetermined bed length (ΔL) for a specific value of total flow rate (q). Several such tests are carried out over a range of q values for each sample of aggregate and for different samples of the same aggregate. A least-square regression finally provides estimates of the permeability (k) and the flow exponent (b) of the aggregate.

Table 2 assembles results of the porosity experiments, three different samples of each aggregate tested at least twice. This involved choosing a volume of the aggregate material and then finding the porosity by measuring the volume of water needed to completely saturate each sample (Ref. 4). The values of porosity (ϕ) specified by the supplier and those obtained from the tests are shown in Table 2. Note that, in general, standard deviation values are less than 2% of the mean value, thereby indicating reproducibility. As for the mean values of porosity, note that those of aggregates No. 602 and 603 are close (within 10%) to those quoted by the suppliers while those of No. 601 and 602 deviate by as much as 20% from the quoted values. This relatively large difference in porosity values has not been explained.

Table 3 presents the various experiments performed as well as the values of k and b obtained by regression. The third column presents values of (d_v/ϕ) which are needed to estimate the Reynolds number which gives an indication of the nature of the flow regime (whether laminar or turbulent) (Ref. 4). The value of gravel nominal size was assumed to be the diameter d_v and was taken from the supplier's specifications (simply the mean value), while the corresponding values of porosity ϕ were taken from the experiments (Table 2). Two or three samples of each aggregate mix were tested and 10-20 runs were performed for each mix. This duplication was to ensure that experimental results obtained were representative and robust.

The range of air flow rates at which the experiments were performed for each aggregate and the corresponding range of resulting Reynolds numbers are also shown in Table 3. Generally, the flow is turbulent when Reynolds numbers are greater than about 10 (Ref. 4). In the experiments, the Reynolds numbers were higher than 10 but less than 50, a range of Reynold numbers which is expected for SSD air flow in gravel beds of residential buildings (Refs. 1 and 2). A further advantage of the Reynolds number range chosen is that the statistical determination of the parameters k and b is likely to be more accurate. Other than for aggregate No. 603, the R^2 values of the regression model are very good ($R^2 > 0.9$). This is an indirect indication that the experimental design was satisfactory. The relatively lower R^2 values for mix No. 603, which is the largest gravel, could be a result of the fact that, in order to keep Reynolds numbers low, the pressure drop was measured close to the sensitivity of the instruments (which was 0.25 Pa or 0.001 in. WC).

The mean and the coefficient of variation (CV) in percentage values for k and b are also given in Table 3. Permeability values of mix No. 600 are around 10^{-7} m^2, gradually increasing to about 7 x 10^{-7} m^2 for mix No. 603. It is worth pointing out that mixes No. 601 and 602 (1/2 and 3/4 in., respectively) have k values which are 10-20 times larger than those of river-run gravel of the same nominal diameter, as reported in a previous study (Refs. 1 and 2). A possible explanation for this is that river-run gravel beds have lower porosity; i.e., they tend to pack more closely (Refs. 1 and 2). This important finding suggests that crushed aggregate is more suitable as a subslab material fill than river-run gravel for buildings to be mitigated using the SSD system since the former is likely to have a larger pressure field extension from the suction hole. The flow exponent b does not vary too much with mix. The relatively higher value for mix No. 602 does seem surprising since both No. 601 and 603 have lower values for b. A possible reason for the low b value for mix No. 603 is that it had relatively more fines in the aggregate. CV values for k are low (less than 3%), while those for b are high, as much as 12% for mix No. 603.

PRESSURE FIELD EXTENSION

This section gives results of computing the pressure field extension under the slab when the four crushed gravel sizes are used as subslab fill material, using the disc flow model described in Ref. 1. Consequently, the following conditions are assumed:

- only one suction hole is used,
- the suction hole is located at the center of the slab,
- the slab is circular, and
- the edges of the slab communicate uniformly with the ambient air.

Figure 2 illustrates how flow conditions in an actual house with a basement can be visualized in the framework of the disc model. The square basement is approximated as a circle of radius r_0 while the extra flow path H through the soil around the house is accounted for by effectively increasing the circle radius to R. Thus the flow is assumed to occur between two impermeable discs, the upper end being the underside of the basement slab and the lower end being the soil beneath the gravel bed. Since the material under the slab is gravel while the extra flow path around the sides of the house is through soil of different permeability than that of the gravel, this model was modified to represent a disc made up of two materials of different permeabilities: soil between radii r_0 and R, and gravel between r_0 and the central mitigation pipe. As pointed out in Ref. 1, the flow regime would likely be turbulent through the gravel bed and laminar through the soil.

Consequently the total pressure drop ΔP (in head of water) across the two-material bed is equal to the pressure drop through the gravel plus the pressure drop through the soil. From equations derived in Refs. 1 and 2:

$$\Delta P = \frac{1}{k_g} \cdot \frac{\nu_a}{g} \cdot \frac{\rho_a}{\rho_w} \cdot \left(\frac{q}{2\pi h}\right)^b \cdot \frac{1}{(1-b)} \cdot \left(r_o^{1-b} - r_s^{1-b}\right) + \frac{1}{k_s} \cdot \frac{\nu_a}{g} \cdot \frac{\rho_a}{\rho_w} \cdot \frac{q}{2\pi h} \cdot \ln\left(\frac{r_o}{R}\right)$$

where
k_g - permeability of the gravel bed,
ν - kinematic viscosity,
g - gravity
ρ - density,
q - total air flow rate,
h - thickness of the gravel bed,
b - flow exponent,
r_o - radius of the basement
r_s - radius of the suction pipe,
k_s - permeability of the soil surrounding the house,
R - total radius of flow (equal to that of the basement and of the extra flow path through the soil).

Note that the pressure drop given by Equation (1) is not the entire pressure drop to be overcome by the mitigation fan. The pressure drop due to entrance effects into the mitigation pipe and that due to the straight pipe, fittings, and bends could account for as much as 50% of the entire pressure drop in the mitigation system.

Two types of construction were studied: slab-on-grade and basement houses. In the framework of the disc model, the difference between the two is solely in terms of the extra flow path through the soil. Basement houses will tend to have higher H values (see Fig. 1) than slab-on-grade houses; consequently the ($R-r_o$) value will be correspondingly different. The following values, deemed representative, have been chosen in all calculations that follow:

slab-on-grade: $R = r_o + 1$ m

basement house: $R = r_o + 3$ m

Also selected were $r_s = 5$ cm (i.e., a 4 in. diameter suction pipe for the mitigation system) and a value of h = 0.05 m (which is based on experience and supported by tests in an actual house described in Ref. 1). Equation 1 cannot be directly used to compute the required suction pressure for different values of basement radius r_0, since the total air flow rate q is not an independent variable. It is determined by the practical criterion, which is that the pressure below the actual slab (i.e., up to a radius r_0) should be lower than the ambient pressure P_a by an amount larger than the depressurization of the house arising from natural causes (e.g., wind, stack effect, heating, ventilation, and air conditioning system (HVAC) depressurization). A realistic range for this depressurization is 3-10 Pa (Ref. 5). Consequently, the flow rate q should be such that a pressure drop equal to this depressurization occurs in the outer portion of the disc containing soil; i.e., between R and r_0. Since the flow is laminar in this region, q is computed from:

$$q = (\Delta P) \cdot k_s \cdot \frac{g}{\nu_a} \cdot \frac{\rho_w}{\rho_a} \cdot \frac{2\pi h}{\ln\left(\frac{r_o}{R}\right)} \tag{2}$$

where ΔP is the prespecified minimum depressurization below all points of the slab expressed in head of water.

The value of q is then used in Equation (1) to calculate the required suction pressure at different values of slab radius r_0. Note that the numerical value of k_s, soil permeability, greatly influences q and consequently the pressure field extension. Hence the two following cases were chosen in order to study the sensitivity of the pressure field extension on the type of boundary fill material (Ref. 6):

(i) $k_s = 10^{-8}$ m^2, corresponding to sand and gravel mixtures,

(ii) $k_s = 10^{-10}$ m^2, corresponding to fine sands.

Additionally, a value of 10 Pa has been selected as the required pressure drop through the soil between radii R and r_0 due to reasons discussed above.

Figures 3 and 4 present the computed suction pressures for cases (i) and (ii), respectively, for the four gravel sizes tested and for both basement and slab-on-grade type construction. Note that differences in field extension between gravel sizes for the subslab bed material, especially mixes No. 602 and 603, are much less important than those resulting from soil type selection. Figures 3 and 4 show that there is an order of magnitude difference in pressure requirements between the two construction types; it is lower for case (ii), lower permeability soil. This fact highlights the importance of having a ring of low permeability soil around the foundation walls and the periphery of the building. There is an important difference in suction pressures between basement and slab-on-grade construction for case (i), but this is so for the tighter soil (Fig. 4). This is because most of the pressure drop occurs across the outer ring of soil, with practically no drop through the gravel bed itself. Thus theoretically, for fine soils (case ii), the pressure field extension is very large (radius greater than 50 m). However, in practice, looseness in packing of the soil, short-circuiting of flow paths, or small holes or cracks in the slab will drastically decrease this value.

Finally, Fig. 5 presents the total air flow rate for case (i) for slab-on-grade and basement construction. These flows are independent of the gravel size since they have been computed from Equation (2) following the condition that the pressure drop in the outer ring consisting of soil is equal to a prespecified minimum amount taken as 10 Pa in this study. Note that the air flow rates between the slab-on-grade and basement cases differs by almost a factor of three.

FUTURE WORK

This study was undertaken to experimentally determine the aerodynamic flow coefficients (permeability and flow exponent) of four crushed aggregate mixes of commercially available stone. The sizes, ranging from 3/8 to 1 in. nominal diameter, are gravel sizes often used as subslab fill for residences and large buildings. An important finding of this study is that permeability values of 1/2 and 3/4 in. crushed gravel were 10-20 times higher that those reported in a previous study for river-run gravel of the same nominal diameter. Field validation of the computed pressure field extension using laboratory test results is important and such tests are currently being planned in newly constructed schools, commerical buildings, and houses. The results presented here should be used with caution until such time that the apparatus and experimental design are more fully validated.

ACKNOWLEDGEMENTS

D. Harrje and R. de Silva contributed generously during the design and construction of the laboratory column. Useful discussions with A. Cavallo and R. Sextro are also acknowledged.

NOMENCLATURE

b	flow exponent
d_v	equivalent diameter of gravel
CV	coefficient of variation
g	acceleration due to gravity
h	thickness of the porous bed
k	permeability of gravel
ΔL	length of porous bed in flow direction
ΔP	pressure drop
P	pressure
q	total volume air flow rate
R^2	coefficient of determination of regression
Re	Reynolds number
R	total radius of air flow path
r_o	effective radius of basement
r_s	radius of suction pipe
ρ	density
ν	kinematic viscosity
ϕ	porosity of porous bed

<u>Suffix</u>

a	ambient, air
g	gravel
s	suction pipe, soil
w	water

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TABLE 1. QC ANALYSIS OF VULCAN MATERIALS CRUSHED AGGREGATE AS SUPPLIED BY THE COMPANY

Vulcan No.	Description	% Passing Screen Size 1-1/2	1	3/4	1/2	3/8	3/16	3/32	Loose Bulk Density	Void Volume
600	3/8 in. clean				100	90	23	5	91.8	49.3
601	1/2 in. clean			100	83	27	3	1	89.4	50.6
602	3/4 in. clean		100	93	27	7	2		95.1	47.5
603	1 in. clean	100	94	40	6	2	1		93.0	48.6

TABLE 2. COMPARATIVE RESULTS OF POROSITY TESTS

Vulcan No.	Nominal Size (in.)	Porosity: From Supplier	Porosity: Present Tests
600	3/8	0.493	0.403 (0.006)*
601	1/2	0.506	0.419 (0.011)
602	3/4	0.475	0.436 (0.015)
603	1	0.486	0.452 (0.009)

*Values in parentheses are standard deviation values.

TABLE 3. SUMMARY OF EXPERIMENTAL DATA

Vulcan No.	Nominal Size (in.)	$\underline{d}_v$ ϕ (mm)	Number of Samples Tested	Flow Range (l/min)	Range of Reynolds Numbers	Number of Observations	Regression Model R^2	Permeability $k \times 10^9$ (m^2)	Exponent b
600	3/8	2.36	3	6 - 21	5 - 18	20	0.91	104.4 (2.5)*	1.14 (7.0)
601	1/2	3.03	2	19 - 28	20 - 30	11	0.99	193.6 (0.4)	1.15 (3.5)
602	3/4	4.37	2	19 - 28	29 - 42	10	0.92	336.3 (1.2)	1.29 (10.9)
603	1	5.62	3	19 - 30	37 - 58	16	0.84	683.9 (1.2)	1.17 (12.0)

* Values in parentheses are coefficient of variation (CV) values where CV = (Mean value/Standard error of the mean) x 100

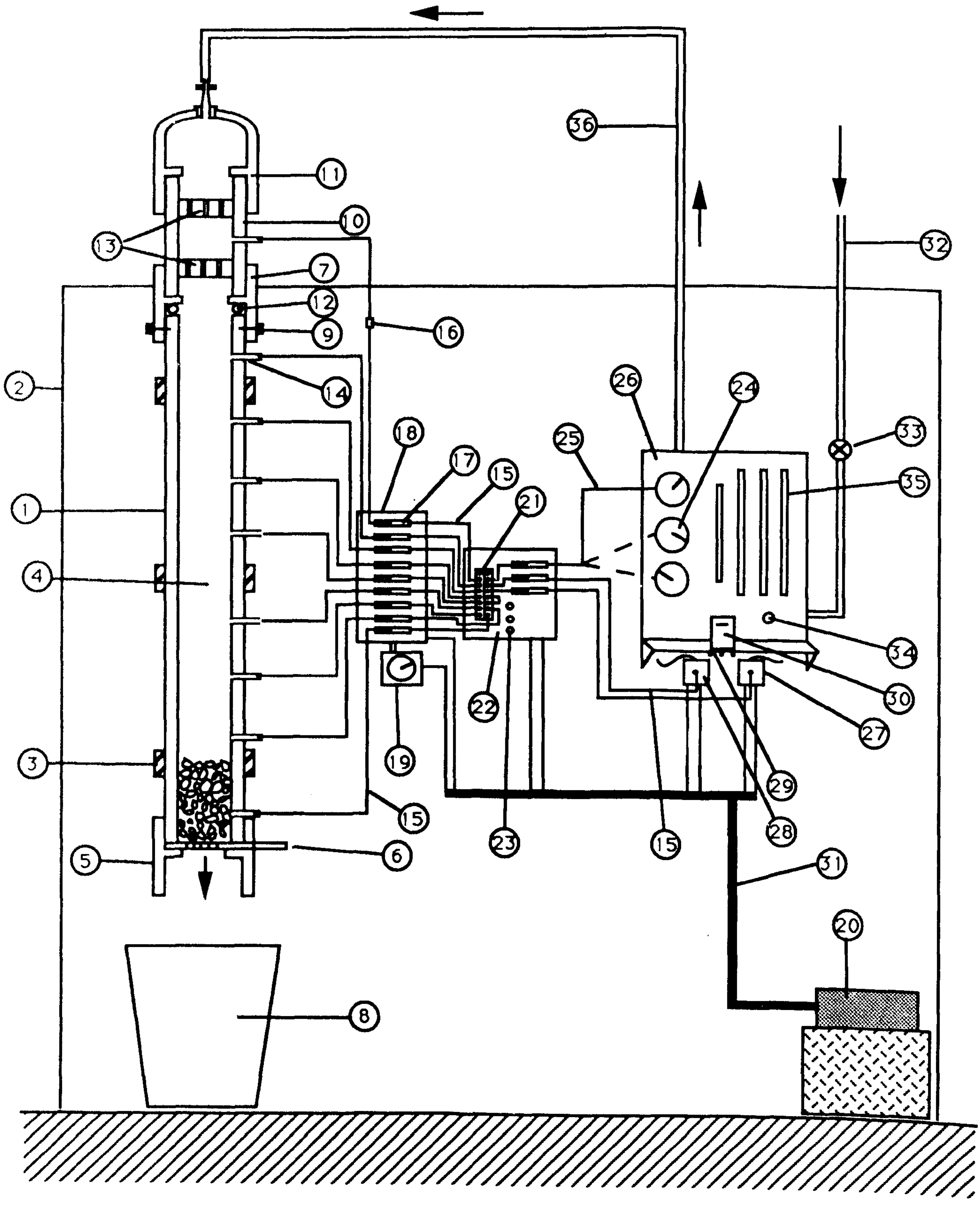

Figure 1. Sketch of the flow apparatus. List of components is attached.

Key for Figure 1

(1) Main Column - Schedule 40, PVC, 8 in. Pipe
(2) Test Rig Panel
(3) Support Blocks
(4) Test Material Cavity
(5) Lower Sleeve
(6) Movable 1/4 in. Aluminum Screen
(7) Upper Sleeve
(8) Collection Bin
(9) Assembly Bolts
(10) Short Pipe Section
(11) End Cap
(12) "O" Ring
(13) Flow Straighteners
(14) Pressure Taps
(15) Urethan Tubing
(16) Tubing Union
(17) Miniature Solenoid Valves
(18) Solenoid Panel
(19) Valve Selector Switch
(20) 12 Volt DC Power Supply
(21) Manifold
(22) Manifold Panel
(23) Transducer Selector Switches
(24) Pressure Gauges
(25) Interchangeable Connector Tubing
(26) Gauge and Flowmeter Panel
(27) High Pressure Transducer
(28) Low Pressure Transducer
(29) DVM Connector
(30) Digital Voltmeter (DVM)
(31) Wiring Harness
(32) Air Supply
(33) Shutoff Valve
(34) Flow Control Valve
(35) Flowmeters
(36) Tubing from Flowmeter to Column

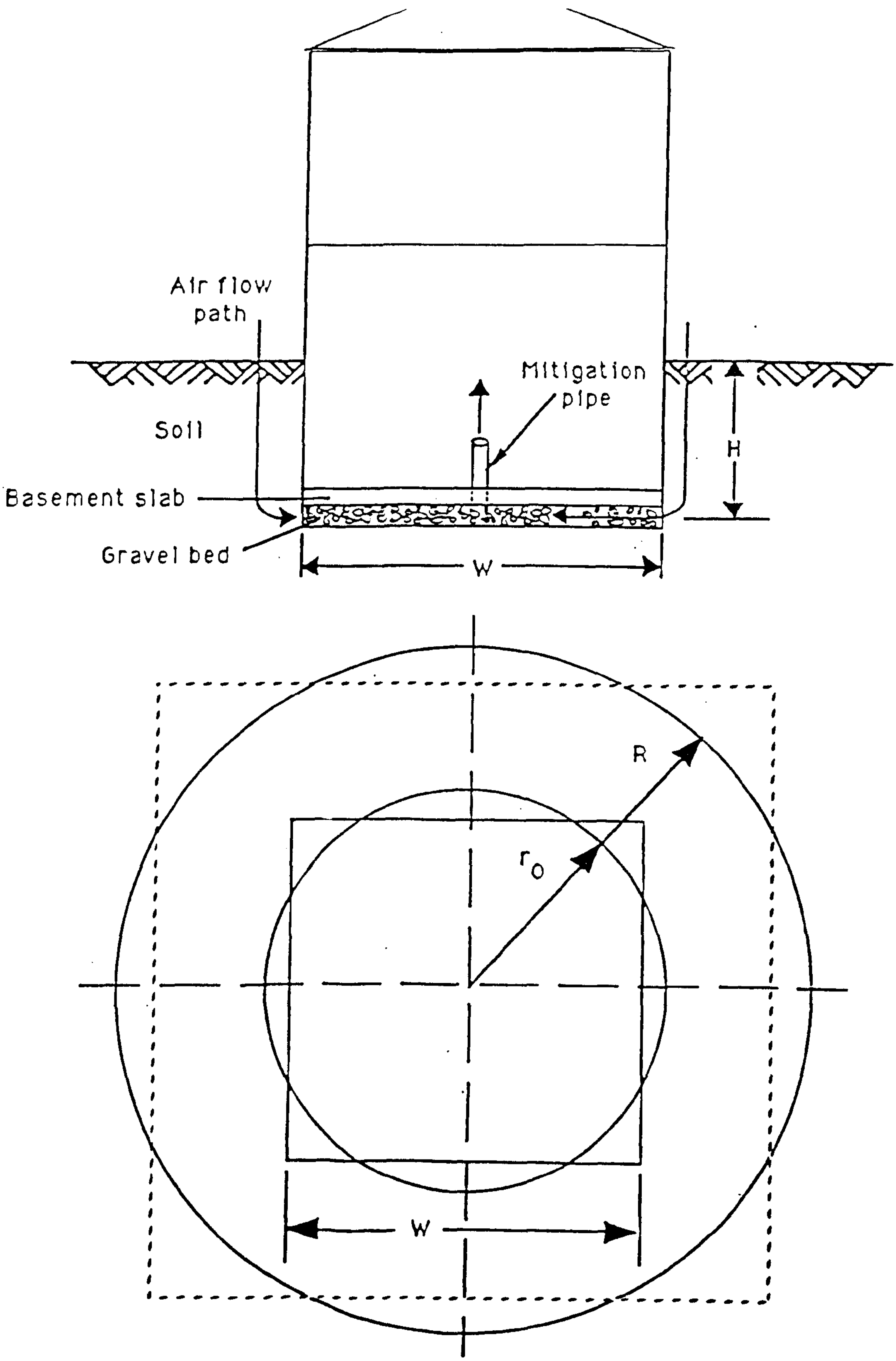

Figure 2. Disc model of a SSD mitigation system in a basement house.

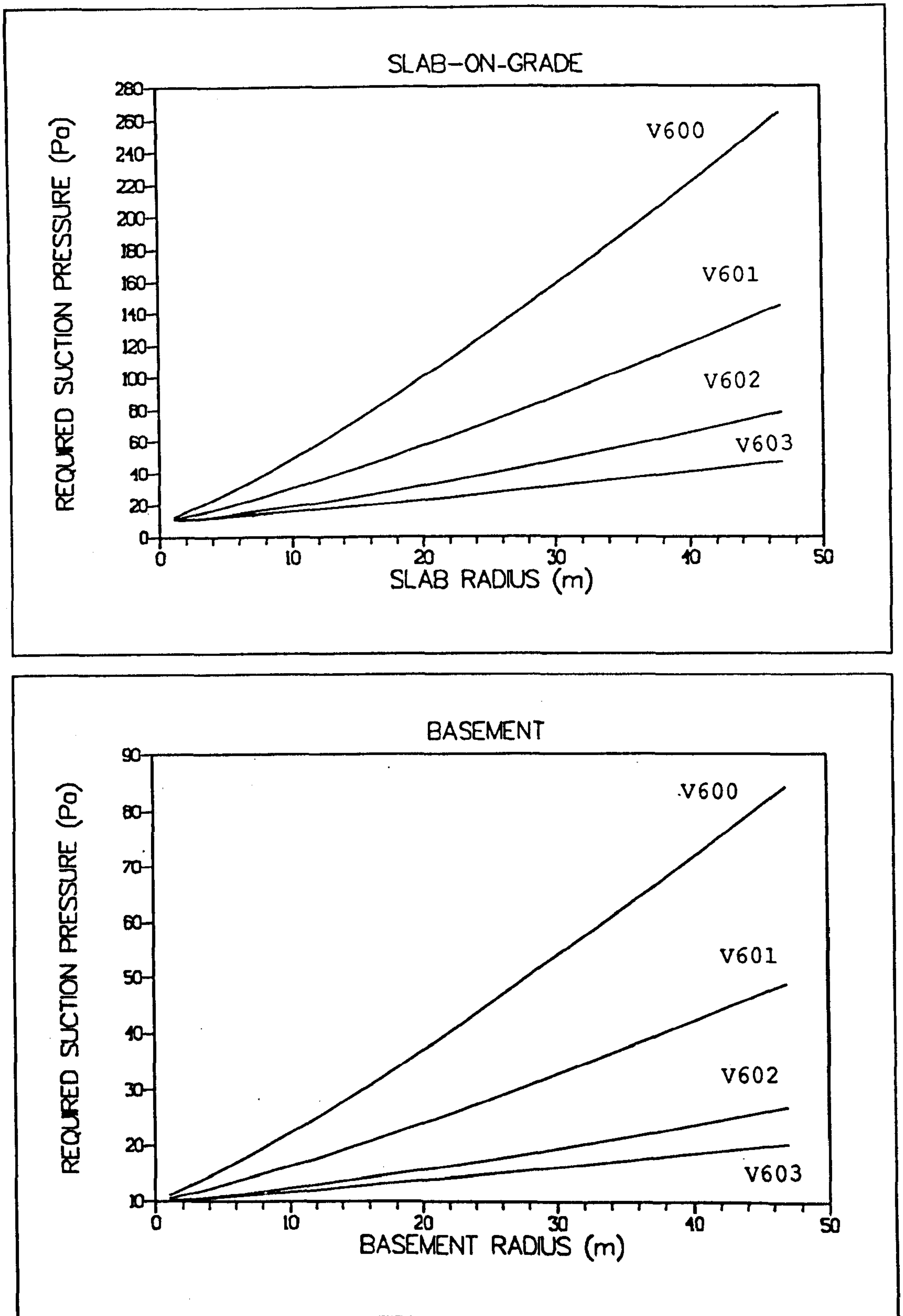

Figure 3. Pressure field extension for case (i): $k_s = 10^{-8}\ m^2$ for the four gravel mixes tested. Soil flow path length is 1 m for slab-on-grade and 3 m for basement houses.

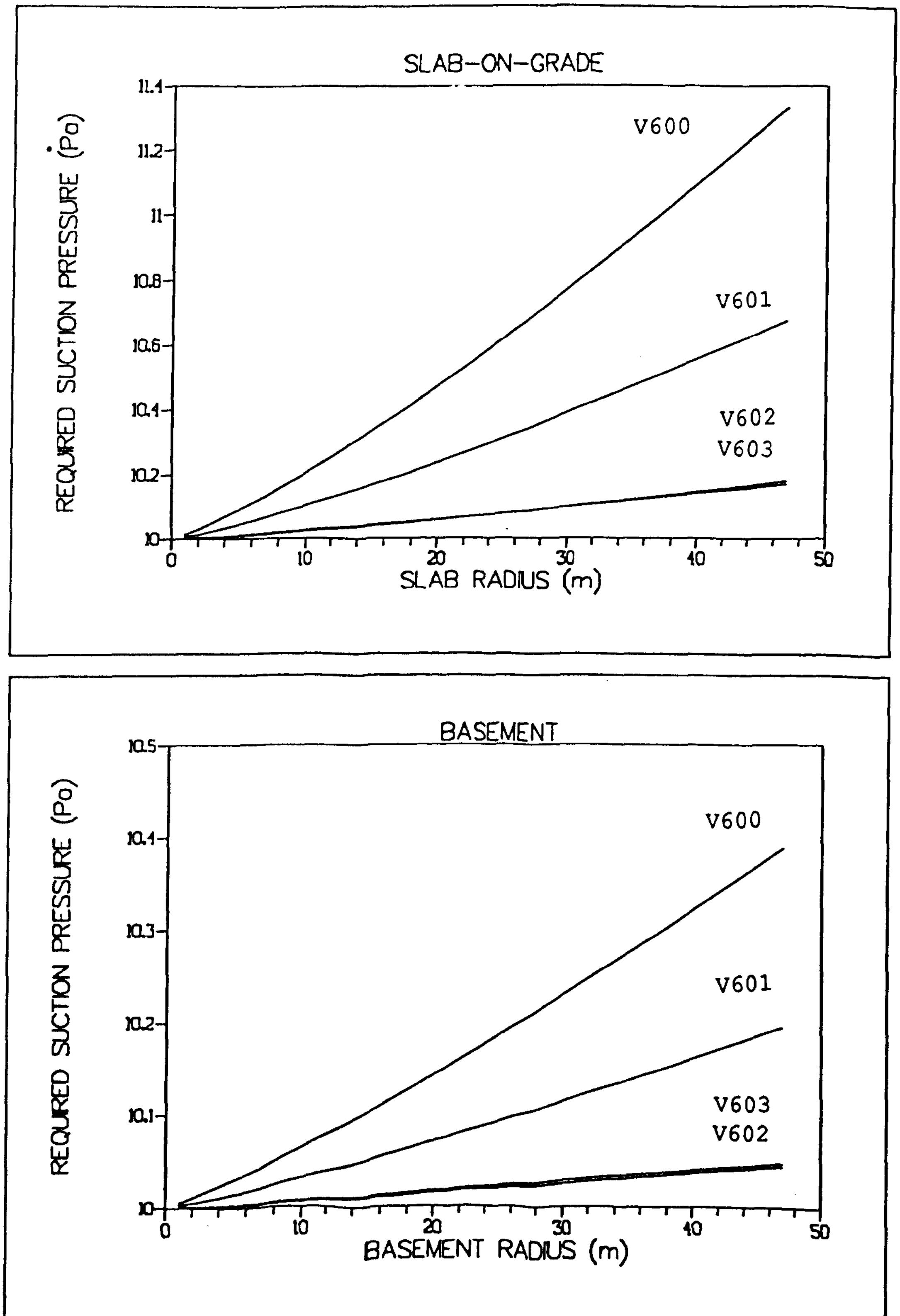

Figure 4. Pressure field extension for case (ii): $k_s = 10^{-10} m^2$ for the four gravel mixes tested. Soil flow path length is 1 m for slab-on-grade and 3 m for basement houses.

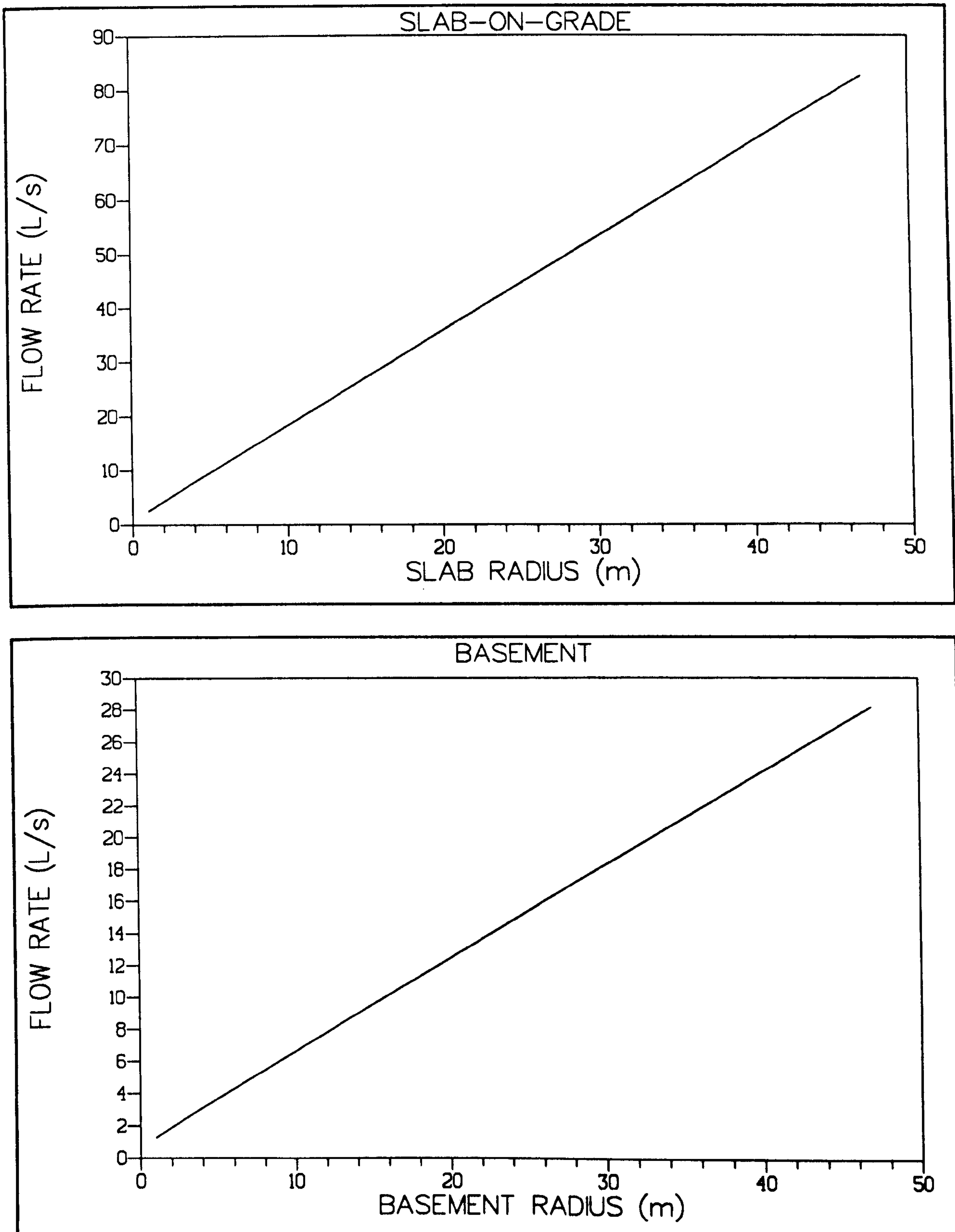

Figure 5. Total air flow rates for case (i): $k_s = 10^{-8}$ m^2, computed from Eq. (2).

Session VIII:

Radon Prevention in New Construction -- POSTERS

RADON PREVENTION IN RESIDENTIAL NEW CONSTRUCTION: PASSIVE DESIGNS THAT WORK

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ABSTRACT

Various approaches and criteria have been developed and promulgated by EPA concerning radon prevention during new construction of private residences. Yet, very little information is available which describes cost effective passive radon reduction techniques for residential new construction. This paper will present two case studies of the evaluation, design, installation, and performance of successful passive radon prevention in new construction. Both case studies make extensive use of EPA recommended new construction techniques which, when utilized synergistically, provide long term average radon concentrations of less than two picocuries per liter of air in the lowest livable areas of each residence.

RADON PREVENTION IN RESIDENTIAL NEW CONSTRUCTION: PASSIVE DESIGNS THAT WORK

INTRODUCTION

Recent studies of the performance of new construction, passive radon reduction systems have been conducted (1). However, very little information is available about specific approaches taken to install cost effective passive systems that work. By using the EPA's approach to radon resistant new construction (2,3) as a general guide, two residences have been effectively protected from radon entry through the use of completely passive radon mitigation strategies.

The benefits associated with the implementation of passive radon reduction systems during the construction of a structure include:

a. A radon reduction system which is more aesthetically appealing than a similar retrofit system. Many times, during a retrofit operation, portions of the system will be visible to the homeowner, or the system will reduce effective storage space. This is particularly apparant when retrofit systems pass through storage closets in route to the roofline.

b. The ability to install a completely passive system which would require no on-going operating expense and would provide for minimal energy loss.

c. The ability to consistently provide annual average radon concentrations in the lowest liveable floor of the structure below 2.0 pCi/l of air.

d. And, through judicious use of on-site workers and a close relationship with the builder, the ability to provide the most cost effective means to attain the lowest reasonably achievable radon concentrations.

This paper is organized to provide a method of approach to new construction through the description of cost effective new construction techniques implemented in two residences in Connecticut. The approach begins with the site and building plan reviews. Then, a description of the development and implementation of mitigation strategies is provided. The discussion then concludes with an assessment of the performance of each system and the associated costs for each completed project.

SITE EVALUATION

The site evaluation is typically the first step when considering the use of radon resistant new construction techniques. It is during the site evaluation that the actual decision is made whether radon resistant techniques should be used. During the site evaluation various sources of data are reviewed to determine the likelihood of radon occurance. Should the likelihood exist, new construction techniques to reduce radon entry are implemented.

The site evaluations for both projects began with the acquisition of various pieces of data available through federal, state, and local government agencies. Such sources of data included topographical maps, bedrock and surface geology maps, aeroradioactivity maps, and state and local radon testing program results.

After a thorough review of the data available through the above sources the decision to implement radon resistant new construction techniques was made based on the following information:

a. Each residence is located in geologic areas documented to have a high percentage of homes (>15%) with radon levels in excess of the EPA's recommended action level of about 4 picocuries per liter of air (4,5).

b. Radon levels in other homes within the immediate geographic region of each structure have shown the presence of radon in excess of 20 pCi/l of air. This was evidenced by actual test results from homes in the immediate neighborhood.

c. The background gamma radiation at each site is in excess of 600 counts per minute (6).

4. Each home buyer was keenly aware of the potential for radon related health risks due to long-term exposure to radon and wished to decrease family exposure to levels as low as reasonably attainable. In both cases the home buyer wished guarantees of annual average radon levels below 2.0 pCi/l of air.

The use of direct soil gas measurements prior to construction were not considered to be a predictor of post construction indoor radon concentrations. Therefore, soil gas measurements were not conducted prior to construction of the structure.

BUILDING PLAN EVALUATION

Once the site assessments had been conducted and enough evidence was available to support the implementation of radon reduction techniques, a thorough examination of building plans was conducted. Examination of building plans reveals the nature and extent of thermal bypasses, the potential characteristics of the sub-slab area, the availability of verticle chases for locating the vent stack, and details about the foundation and slab which might have an affect radon entry.

HOUSE A BUILDING PLAN

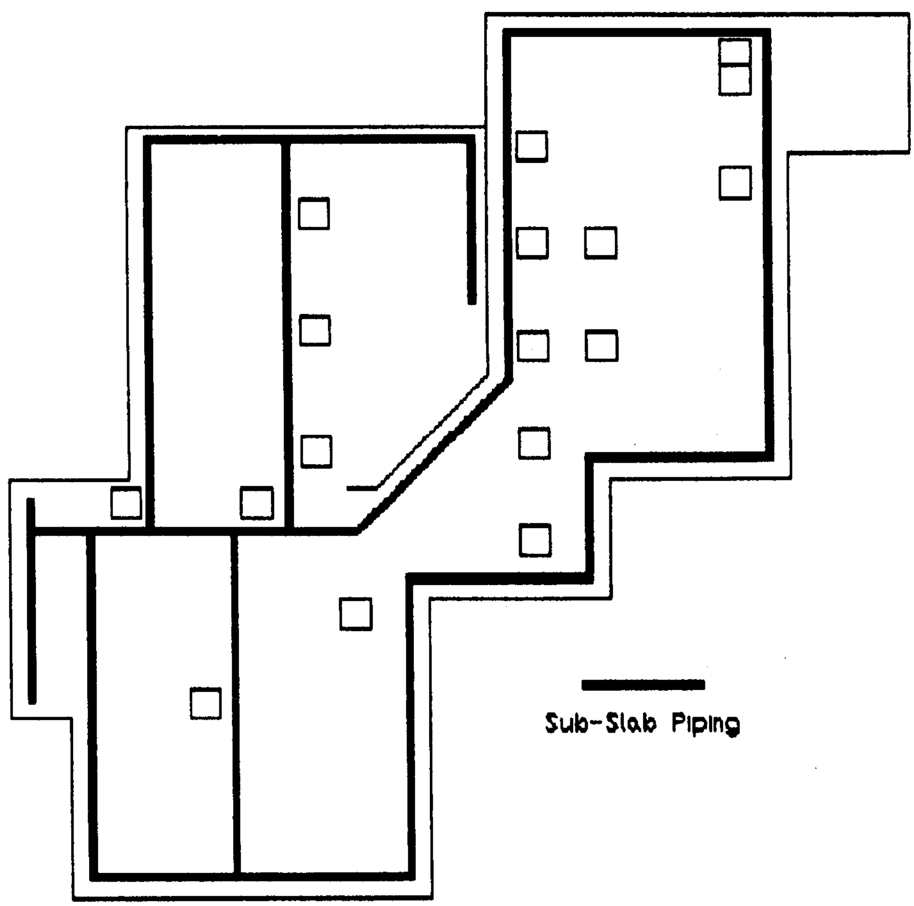

Figure 1. House A Foundation and Sub-Slab Piping Network

As can be seen in Figure 1., House A is an irregular shaped contemporary home with numerous inside corners in the foundation. This indicates a need for more sealing of cracks after the slab cures because typically cracks form from an inside corner and radiate toward the center of the slab. Each small square in the interior of the foundation indicates a concrete "pad" upon which lally columns and other structural supports are placed. The location of each of these pads dictates, to some extent, the placement of sub-slab piping networks.

A careful review of the lighting schedule showed that extensive use of recessed lights was planned. Each of these recessed fixtures is a potential thermal bypass which would allow the movement of air from the room below to the area above the fixture. Because of the extensive use of recessed fixtures, combined with the presence of vaulted ceilings, the decision was made not to address each individual thermal bypass. But instead, more emphasis would be placed on the sub-slab piping network and establishment of a negative pressure field.

The materials schedule for the foundation plan indicated that the use of processed gravel was planned for the sub-slab fill material (95% sand). This indicated that the installation of a sub-slab piping network would be necessary in order to provide adequate sub-slab permeability.

After discussing possible locations of the verticle stack with the builder, a decision was made to locate the stack in a double-wide wall to be used for plumbing. This allowed locating the stack near the center of the house where there would be adequate warmth to induce a stack effect in the pipe.

HOUSE B BUILDING PLAN

As can be seen in Figure 2., House B is basically a rectangle with a minimum of irregularities in the foundation. As with House A, the lighting schedule for House B indicated extensive use of recessed light fixtures, causing numerous thermal bypasses. In addition, there were several large rooms on the first floor which were to have vaulted ceilings, precluding the effective blocking of thermal bypasses. Here again the decision was made to concentrate on the use of pressure manipulation in the verticle stack and sub-slab area to impede radon entry in the structure.

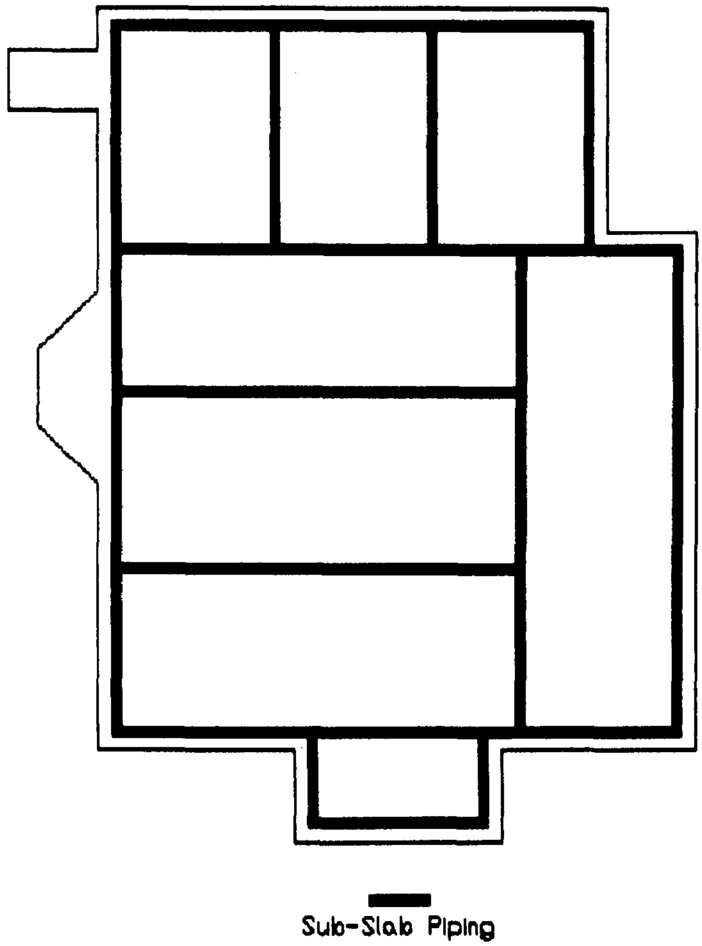

Figure 2. House B Foundation and Sub-Slab Piping Network

The materials list for the foundation plan indicated the use of crushed stone as sub-slab fill material. Due to the intended use of crushed stone fill, no piping network was planned. Only the use of a pipe stub inserted into the fill material would be necessary to ensure the negative pressure developed in the verticle stack would be transmitted to the sub-slab area.

After discussing the placement of the verticle stack with the builder, it was decided that the most appropriate location of the stack would be rising within the chimney chase. Although not a typical location, the local Building Official authorized this location since all flues rising within the chase were "zero clearance" type flues which would prevent excessive heat buildup in the chase.

MITIGATION STRATEGIES

The new construction strategies used included provision of sub-slab permeability during construction, prevention of radon entry through the use of barriers to radon movement from the soil into the structure, and the installation of a passive stack vent to develop differential pressures between the basement of the residence and the sub-slab fill material.

Reduction in the number and amount of thermal bypasses, as recommended by EPA, was not used. In both cases, the residences had too many thermal bypasses to facilitate cost effectively dealing with the treatment of each bypass source. Rather than attempt to treat each thermal bypass, more emphasis was placed on prevention of radon entry through establishment of sub-slab permeability and the miticulous use of sub-slab vapor barriers and entry route sealants.

PROVISION OF SUB-SLAB PERMEABILITY

Provision of sub-slab permeability is perhaps the most influential cost of the overall system. The type of sub-slab fill which is used will determine the necessary actions required to establish adequate permeability in the sub-slab fill material. In Connecticut, it is quite common to use "processed" or "bank-run" gravel as fill material. These are terms which indicate fill material which is approximately 95% sand and 5% stone.

In order to ensure adequate sub-slab permeability, three common techniques are available. The use of crushed stone as a fill material, although very desirable, is not a common practice in Connecticut because of the increase in construction cost. A more common method is the installation of a sub-slab piping network, much like a drainage system, into a bed of crushed stone beneath the slab. The least common method is the use of mat-type material because the expense of such material encourages residential builders to seek less expensive alternatives.

When using the sub-slab piping network to provide permeability, a significant amount of labor can be saved through proper timing. If the piping system can be installed during the installation of the fill material itself, all that may be required is the actual assembly and layout of the network. However, installation of the network at sometime after the fill material has been installed, will not only require that the piping system be assembled, but the fill material must be excavated, the piping network installed, covered with fill material, and then the excess fill material must be removed from the site.

House A

Since the building plans for House A indicated the use of processed gravel for fill material, the use of a piping network was required to ensure adequate sub-slab permeability. Figure 1. shows the arrangement of the piping system under the slab. In this house the piping network was actually installed by the foundation workers at the same time the fill material was installed. This provided a very cost effective provision of sub-slab permeability.

House B

The building plan specifications for House B indicated the use of crushed stone as the sub-slab fill material. However when the time came to install the fill, the builder used processed gravel (95% sand) due to the lack of available craushed stone. This became apparant after the fill material had been installed and compacted, creating a permeability problem. Modifications to the mitigation strategy had to be made; a piping network was designed and then subsequently installed. Since this house was being constructed during the winter, the fill material quickly froze and required the use of picks and adzes to excavate for the piping system.

CREATING BARRIERS TO RADON ENTRY

The creation of barriers to radon entry for both houses was accomplished in two steps. After the fill material and piping networks were installed, a continuous layer of cross laminated plastic sheeting (Radon Barrier) was installed. The sheeting was layed out on top of the fill material, then sealed around the foundation with a continuous bead of polyurethane caulk. Where layers of the plastic sheeting were overlapped, another continuous bead of caulk was used as glue for the two sections of sheeting.

Once the slabs had been poured and cured all slab-to-foundation, control joints, utility penetrations, and settling/stress cracks appearing in the slab were sealed. The sealing was accomplished by first enlarging the existing cracks, thoroughly cleaning the opened crack, applying a bead of sealant, then tooling the sealant into place. This technique digresses from the EPA recommendations in that no binding agent is applied to the crack prior to application of the sealant. From experience we have found that polyurethane sealant will bond well to clean, fresh concrete as long as all dust and debris is removed prior to application of the sealant.

CONTROL OF DIFFERENTIAL PRESSURE

The control of differential pressures was accomplished primarily by use of the stack effect to induce a negative pressure in the sub-slab fill material. The development and communication of the negative pressures developed by the stack effect was accomplished through the installation of a "vent stack". This stack uses the tendency of warm air rising in order to develop a negative pressure field in the sub-slab material. In order to be most efficient, the verticle vent stack should have the fewest possible restrictions to air flow.

In both structures, the vent stack was able to run vertically for approximately 30 feet with no bends. Two 90 degree bends and two 45 degree bends were required in the basement areas to connect the stack to the sub slab piping network. Through the use of four inch PVC pipe these bends provided minimal resistance to the air flows typical in a passive stack configuration.

SYSTEM INSTALLATION

Unlike retrofit applications where the entire system is typically installed in less than one day, the use of new construction techniques requires periodic involvement over a long period of time. In the case of House A, the construction period lasted over six months. In the case of House B, the construction of the residence took over 14 months. The economical use of time on site, as well as a close communicative relationship with the builder will save countless hours of on-site time and expenses during the construction of the structure. Construction schedules change on a daily, and sometimes hourly, basis.

The actual implementation of the mitigation strategy can be divided into four distinct phases; sub-slab preparation, slab pour, application of sealants, and finally the installation of the vent stack itself. Not every construction project will require these phases to be accomplished at different times. In the case of House A, the slab was poured as the laborers were completing the piping system. Whereas in House B, the slab was poured four months after the installation of the piping system and sub-slab fill material.

SYSTEM PERFORMANCE

The performance of the installed systems was verified through the use of various radon measurements, as well as, periodic differential pressure measurements. The radon measurements included short-term screening measurements and long term measurements. Differential pressure measurements were made once per month after the initial installation of the vent stack.

RADON MEASUREMENTS

Radon measurements began with short term measurements using activated charcoal canisters. Initial radon measurements were not made until the structure was under the interior finishing phases of construction. This ensured that all windows and doors had been installed and sealed, and the heating system was in operation. In the case of House A, where construction was completed in the summer, another short term measurement was conducted during the heating season.

In addition to the short term measurements, long term radon measurements were made using alpha-track devices to determine long term effectiveness of the installed systems. Intentions are to conduct further long term measurements over the next few years to determine the on-going effectiveness of the techniques used.

Table 1. shows the results of the radon measurements made in both structures.

	First Screening Measurement		Second Screening Measurement		Long Term Measurement
	Month	Result	Month	Result	
House A	JUN	< 0.5	FEB	1.9	0.7
House B	DEC	1.2	FEB	1.6	in progress

Table 1. New Construction Radon Measurements (pCi/l air)

DIFFERENTIAL PRESSURE MEASUREMENTS

Due to limitations in the ability to accumulate continuous long term data, the differential pressure measurements were made at periodic times in each structure. Measurement was made of the pressure differences between the basement of the structure and where the piping system penetrates the basement slab. No data was taken regarding the environmental conditions present at the time of the measurements. Although representative of relative operating pressures, the data does not represent average differential pressure maintained by the stack pipe. Table 2 shows the differential pressure measurements made in each structure.

House A		House B	
Month	Press.	Month	Press.
JUN	0.04	OCT	0.12
JUL	0.03	NOV	0.03
SEP	0.01	DEC	0.05
NOV	0.03	JAN	0.04
JAN	0.02	FEB	0.09
FEB	0.04		

Table 2. Differential Pressure Measurements (inches H20)

PROJECT COSTS

The costs associated with each phase of the new construction project for these structure is divided into three categories; sub-slab piping installation, sealing, and stack pipe installation. The total cost for each project is also reported. Although the total cost of each project is in excess of the average cost to provide radon mitigation services in a comparable existing structure, the long-term cost savings due to energy loss/consumption can be substantial. In addition, the new construction systems are virtually "invisible" and become an integrated part of the structure. This is unlike retrofit mitigation systems which are sometimes attached directly to the exterior of the structure.

Table 3 provides a breakdown of the costs associated with both projects.

	Sub-Slab Piping	Preventing Entry	Stack Vent Installation	Total Project Cost
House A	$ 450	$ 520	$ 645	$ 1,615
House B	$ 967	$ 465	$ 450	$ 1,882

Table 3. New Construction Project Cost

CONCLUSION

The ability to implement cost effective radon resistance into residential new construction is certainly attainable as evidenced in the two projects outlined in this paper. Through the use of EPA recommended new construction techniques and judicious use of on-site time, passive radon reduction strategies can be implemented during new construction that provide the home owner with significant long term cost savings.

More research needs to be conducted to quanitify the design parameters involved with the selection and location of the vent stack. In addition, more data needs to be collected concerning the relationship between environmental conditions and the development of sub-slab pressure differentials during the use of passive stack vent systems..

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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PRELIMINARY RESULTS OF HVAC SYSTEM MODIFICATIONS TO CONTROL INDOOR RADON CONCENTRATIONS

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ABSTRACT

Designing and building houses that control radon in the course of their normal operation is a desirable goal. A project was undertaken by the Environmental Protection Agency to assess the feasibility of modifying the heating, ventilating, and air conditioning (HVAC) system in a newly constructed tract house, so that radon entry is prevented, the risk of moisture condensing in the building shell is reduced, and minimum ventilation recommendations are met.

A house has been selected, and the HVAC system has been modified to slightly pressurize the basement while slightly depressurizing the upper floors. Basement and first floor radon concentrations, and first floor and basement to outdoor air pressure differentials have been monitored.

The initial results from one cooling season show that this method can be as effective as active soil depressurization at controlling indoor radon levels, with comparable power consumption.

This paper has been reviewed in accordance with the U. S. EPA's peer and administrative review policies and approved for presentation and publication.

TECHNICAL APPROACH

The purpose of this work was to evaluate whether a typical residential furnace unit (air handler) could be easily modified to pressurize the basement of a tract house to prevent the entry of radon-laden soil gas. In order to accomplish this goal, the air pressure relationships between the upper floors and the basement, and each of those zones and the outdoor air, must be controlled. This is accomplished by using the air handler of the central heating and cooling plant, and the existing conditioned air distribution system, to pressurize the basement and slightly depressurize the upper floors. The basic idea is illustrated in Figure 1.

The house chosen for the study is located in a subdivision in the Allentown, Pennsylvania, area. It is a two story colonial house with a basement under all but the living room. The living room is on a slab, on-grade. The house, when originally constructed, was built with the knowledge that other houses in the area contained high indoor radon concentrations. The builder therefore incorporated several radon resistant techniques during its construction. During construction, attention was paid to building a foundation that prevented soil air from entering. This effort included poured concrete walls and floor, all concrete joints sealed with caulk, and a polyethylene vapor barrier under the slab. In addition, an active soil depressurization system was installed in the building, with a 4 in.* layer of DOT #2 stone, an interior perimeter loop of 4 in. drain pipe, a 4 in. PVC pipe routed through the building and out the roof, and an in-line centrifugal blower.

Air pressure relationships were measured between the inside and outside of the building, and between zones within the building. HVAC system airflows and power consumption were measured for the three HVAC blower operating speeds. These were quite close to the manufacturer's specifications. Investigations of the extent of air leakage, in what appeared to be carefully installed ductwork, revealed that the ductwork was still surprisingly leaky. This was particularly true of the return system. An indication of the effects of this leakage was that, when the air handler was operated on low speed, several pascals negative pressure was produced in the basement relative to outdoor air. Extensive sealing of the return air ductwork was required to bring the basement into neutral pressure with the outdoor air. See the later section on air leakage patterns for details.

The air handler that heats and cools the first floor of the house is located in the basement. All supply and return ductwork is also located in the basement. The basement was pressurized simply by sealing the leaks in the return air ductwork and cutting an opening in the supply ductwork main trunk. This modification resulted in the pressurization of the basement, with respect to outdoors, of 4 Pa. This modification also resulted in greater infiltration in the upstairs living area to make up the air lost through the basement.

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*Readers more familiar with metric units may use the factors at the end of this paper to convert to that system.

AIR HANDLER DESCRIPTION AND OPERATING CHARACTERISTICS

Effects of HVAC system operation on radon levels

The effects of system operation on indoor radon were studied by monitoring radon continuously in the basement and the kitchen with the air handler off, with the air handler on low speed continuously, and with the air handler on high speed only when cooling was called for. The results are summarized in Table 1, and illustrated in Figures 2, 3, and 4. Figure 2 shows that, while the air handler is on, there is about a 4 Pa positive air pressure difference between the basement and outdoor air, and the indoor radon averages 1.2 pCi/L in the basement and kitchen (a sign of good mixing with the air handler on). This level compares well with the active soil depressurization results from the previous year of 1.1 pCi/L[1]. However, with the air handler off, the basement air pressure quickly drops, and there are radon spikes each time the basement goes negative relative to outdoor air. This pattern has been observed in many buildings before[2],[3],[4]. The average radon concentration with the system off is around 14 pCi/L in the basement and 2 pCi/L in the kitchen. Later system off measurements in July (see Table 1) show the same levels in the basement, and a slightly higher kitchen average of 3.3 pCi/L. Figure 3 shows typical data for the system operating continuously, on a scale that allows better detail. The results are the same as the June measurements in Figure 2, and it is clear that radon is being controlled in both the upstairs and basement, with 50% and 90% reductions, respectively. Figure 4 shows a detail of system performance when the air handler runs only in response to cooling demand. While the radon is lowered by a factor of around 3, it is still above the action guideline of 4 pCi/L, averaging 7 pCi/L for the cooling operation test period. It is also clear from the pressure data that the fractional on time of the air handler was large during the test period. The radon levels in this building will be very sensitive to fractional on time.

Description

The house is heated and cooled using a York heat pump with a three-speed air handler. Table 2 lists the design airflows for this unit at low, medium and high speeds for two static pressures.

Airflows through ductwork with the air handler on low speed

Airflows were measured at the supply and return grills, and in the main trunk of the supply ductwork, with the intentional opening used to pressurize the basement open and closed. The results of these measurements are given in Tables 3 and 4. The total measured supply, measured in the supply trunk close to the air handler, was 952 ± 90 cfm. This compares well with the manufacturer's specifications of 1160 to 1185 cfm for the air handler on low speed. From the measurements made, the leakage through the supply ductwork was calculated to be around 230 cfm, and through the return ductwork was around 450 cfm. This means that, with the unit as installed, the basement was under negative pressure of several pascals whenever the air handler was on. The supply ductwork was foil faced ductboard. The return ductwork was made by sealing ductboard to the bottom of floor joists. It is thought that the excessive leakage in the return system, to a great extent, is due to leakage in the floor and wall components that form the return ductwork. In fact, careful sealing of the return system reduced the return air duct leakage to about 200 cfm.

The results of measurements and calculations with the ductwork sealed, and the basement pressurization opening open and closed are presented on Tables 3 and 4.

Sealing the return ductwork

The return system in the basement was carefully sealed using duct tape and caulk. The indoor-outdoor pressure differential was monitored before and after the sealing. With the air handler running and the pressure opening closed, the basement was several pascals negative before the sealing, and neutral after. Sealing the return air ducts reduced leakage to approximately 200 cfm. At this point supply leakage, excluding the intentional opening used to pressurize the basement, approximately equaled return leakage. It is estimated that the additional cost of sealing ductwork and making wiring modifications to the air handler is $200 to $300.

AIR LEAKAGE PATTERNS CAUSED BY OPERATION OF THE BASEMENT PRESSURIZATION MODE

In order to understand the dynamics of operating the air handler to pressurize the basement and slightly depressurize the upstairs, interzonal and indoor to outdoor pressure differentials, and the leakage areas of interest were measured. From these data, the amount of outdoor air drawn into the building could be estimated. This can then be compared to the ASHRAE ventilation guidelines [5] and the estimated stack effect infiltration that would occur in this house normally.

Operating the air handler induces a 4 Pa pressure differential between the basement air and the outdoor air and a 4.5 Pa pressure differential between the upstairs and the basement. This implies a 0.5 Pa pressure differential between the upstairs air and the outdoors.

By combining this air pressure distribution data with measured building leakage area data, airflows between the two zones and outdoors can be estimated. The leakage areas were measured using a fan door technique, involving the use of two fan doors. Measurements were made on each zone individually, and then simultaneously. Details of the method are presented elsewhere [6]. The results of the measurements and analysis are found on Figure 5.

ENERGY AND VENTILATION ISSUES

Changing the air pressure relationships in a building to control soil gas entry will have an impact on other dynamics in the building. Specifically it is expected that this will impact on the ventilation pattern, the energy costs associated with ventilation, and the risk of moisture condensation in the building shell. No data are available to judge the effects of moisture in the building shell. However, the data collected can be used to estimate the impact on the amount and pattern of infiltrating air. This is accomplished by first estimating the amount of air that would flow through the building as a result of ordinary stack effect and then comparing to the airflows induced by pressurizing the basement

The results of these estimates can be used to calculate the power consumption for controlling radon with basement pressurization and with active soil depressurization.

Impact of basement pressurization on infiltration

A fan door test of the entire building shell revealed that it has 5 air changes per hour (ACH) at a 50 Pa pressure differential. This is two to three times tighter than the average house built between 1945 and 1980, but is more typical of houses built in the northeast United States since 1980. This translates to about 0.25 ACH under natural conditions.

The infiltration due to stack effect alone has been calculated using four air infiltration models: the Lawrence Berkeley Laboratory model, the Kronval model, the Shaw model, and a modified Shaw model [7]. The results of these four models are plotted on Figure 6. Excluding the Shaw model, the mean values range from 0.13 to 0.17 ACH. This corresponds well to the 0.25 ACH combined wind and stack estimate made from dividing the ACH at 50 Pa by 20 [7]. By using the monthly ACH data the average volume of airflow through the building operating under average stack conditions can be calculated. This has been done in Table 5.

The amount of outdoor air drawn through the building by operating the air handler in the basement pressurization mode was estimated to be between 53 and 87 cfm. If any, there should be only a small energy penalty added by operating in this manner, amounting at most to an additional 35 cfm of outdoor air. This would add 3.3×10^6 Btu to the normally operating stack effect load of 4.6×10^6 Btu. This amounts to around $33 of oil at $1.10/gal. or $79 of electric resistance heat at $0.08/kW-hr. It would actually be less than this because of the superior efficiency of the heat pump in the swing seasons [coefficient of performance (COP) of 2.2].

However, it is unlikely that this will be the case because the direction of airflow is opposite that of the stack effect. The power of the fan will be competing with the power of the stack effect. They should just about cancel each other out in the coldest parts of the year resulting in lowered infiltration for the building during the winter months. This, however, is not an accurate model because the system is acting a lot more like two separate zones with the air handler powering the exchange, rather than with the stack effect powering it. A distributed resistance simulation could approximate the final situation.

It is likely that the infiltration due to stack effect will about equal the infiltration due to pressurizing the basement. The difference is that, with basement pressurization, the infiltration will be greatest in the summer and least in the winter, the opposite of stack effect. Either will provide an average of about 40 cfm. This is over half the recommended ASHRAE guideline of 15 cfm/person and the ASHRAE recommended ventilation rate of 0.35 ACH for residential buildings [5].

POWER CONSUMPTION COMPARISON OF NORMAL HVAC OPERATION AND ACTIVE SUB-SLAB SUCTION VS. USING THE HVAC ON LOW SPEED TO PRESSURIZE THE BASEMENT

The total power consumption of radon control and operation of the heat pump air handler for soil depressurization and basement pressurization must be compared.

The amount of electricity used to power the soil depressurization system is 90 W continuously for a year. This amounts to 788 kWh. The power consumption for the normal air handler operation is estimated to be 671 kWh/yr (223.6 W for 3000 hr a year). This gives a total power consumption of 1459 kWh/yr for the active soil depressurization system.

The amount of power needed to pressurize the basement for the year is estimated as follows. The amount of power used to operate the air handler on high speed for normal operation and low speed for the remaining time is 1673 kWh/yr (174 W for 5760 hr on low speed and 249 W for 3000 hr on high speed).

It is estimated that basement pressurization will use 214 kWh/yr more than soil depressurization or about $18 a year for electricity at $0.085/kWh.

CONCLUSIONS

The basic idea of using the interaction of the air handler, conditioned air distribution system, and the building shell to control air pressure relationships has been demonstrated in a newly constructed house. It has also been demonstrated that this control can prevent radon entry with minimal additional power consumption for equal performance when compared to active soil depressurization. There is insufficient data to determine whether or not the minimum ASHRAE guidelines for ventilation have been met or whether the risk of moisture condensation in the building shell has been reduced. Further research will be required to answer these questions.

The effort required to modify the HVAC system was not great. However, the measurements and understanding it took, while involving only trivial physics, are not part of the ordinary experience or training of builders, mechanical contractors, or mechanical engineers. Further complicating this procedure is the fact that the work needed to make the modifications cuts across traditional trade jurisdictions. It is likely that most of the work falls into the jurisdiction of the mechanical contractor. However, general contractors must be able to request the work and judge the performance.

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CONVERSION FACTORS

Readers more familiar with metric units may use the following to convert to that system.

Non-metric	Multiplied by	Yields Metric
Btu	1.055	kJ
cfm	0.00047	m^3/s
gal.	0.0038	m^3
in.	2.54	cm
in. WC	249	Pa
$in.^2$	0.00065	m^2

TABLE 1 EFFECTS OF AIR HANDLER OPERATION ON INDOOR RADON

Date (mm/dd/yy)	Location	Average Rn (pCi/L)	Average ΔP (Pa)	HVAC Status
06/07-15/90	basement	1.2 ± 0.3	4.0 ± 1.3	on
06/07-15/90	1st floor	1.1 ± 0.4		on
06/16/90-07/04/90	basement	14.3 ± 5.1	0.8 ± 1.8	off
06/16/90-07/04/90	1st floor	2.1 ± 1.4		off
07/07-23/90	basement	14.2*	0.5 ± 1.6	off
07/07-23/90	1st floor	3.3 ± 1.7		off
07/25/90-08/05/90	basement	1.4 ± 0.3	4.2 ± 0.8	on
07/25/90-08/05/90	1st floor	1.2 ± 0.4		on
08/14/90-09/11/90	basement	1.4 ± 0.3	4.2 ± 0.8	cooling
08/14/90-09/11/90	1st floor	1.2 ± 0.4		cooling

* This measurement taken with a Honeywell At-ease Monitor.

TABLE 2 MANUFACTURER'S SPECIFICATIONS FOR FAN UNIT

Speed	Airflow @ 0.2 in. WC (cfm)	Airflow @ 0.3 in. WC (cfm)
high	1625	1550
medium	1355	1310
low	1185	1160

TABLE 3 OPERATING CHARACTERISTICS WITH BASEMENT PRESSURIZATION

Total measured supply at diffusers = 567 ± 60 cfm

Total measured supply = 952 ± 90 cfm

Total supply leakage* = 385 ± 40 cfm
(including flow through the intentional opening pressurizing the basement)

Total measured return = 496 ± 50 cfm

Total return ductwork leakage* = 456 ± 46 cfm

* calculated values

TABLE 4 OPERATING CHARACTERISTICS WITHOUT BASEMENT PRESSURIZATION

Total measured supply at diffusers = 719 ±72 cfm

Total supply ductwork leakage* = 232 ± 23 cfm

Intentional opening to pressurize the basement* = 153 ± 15 cfm

* calculated values

TABLE 5 STACK EFFECT AIRFLOWS FOR AVERAGE TEMPERATURES

Month	Stack (cfm)
Jan	73
Feb	71
Mar	64
Apr	51
May	36
Jun	0
Jul	0
Aug	0
Sep	25
Oct	28
Nov	60
Dec	71

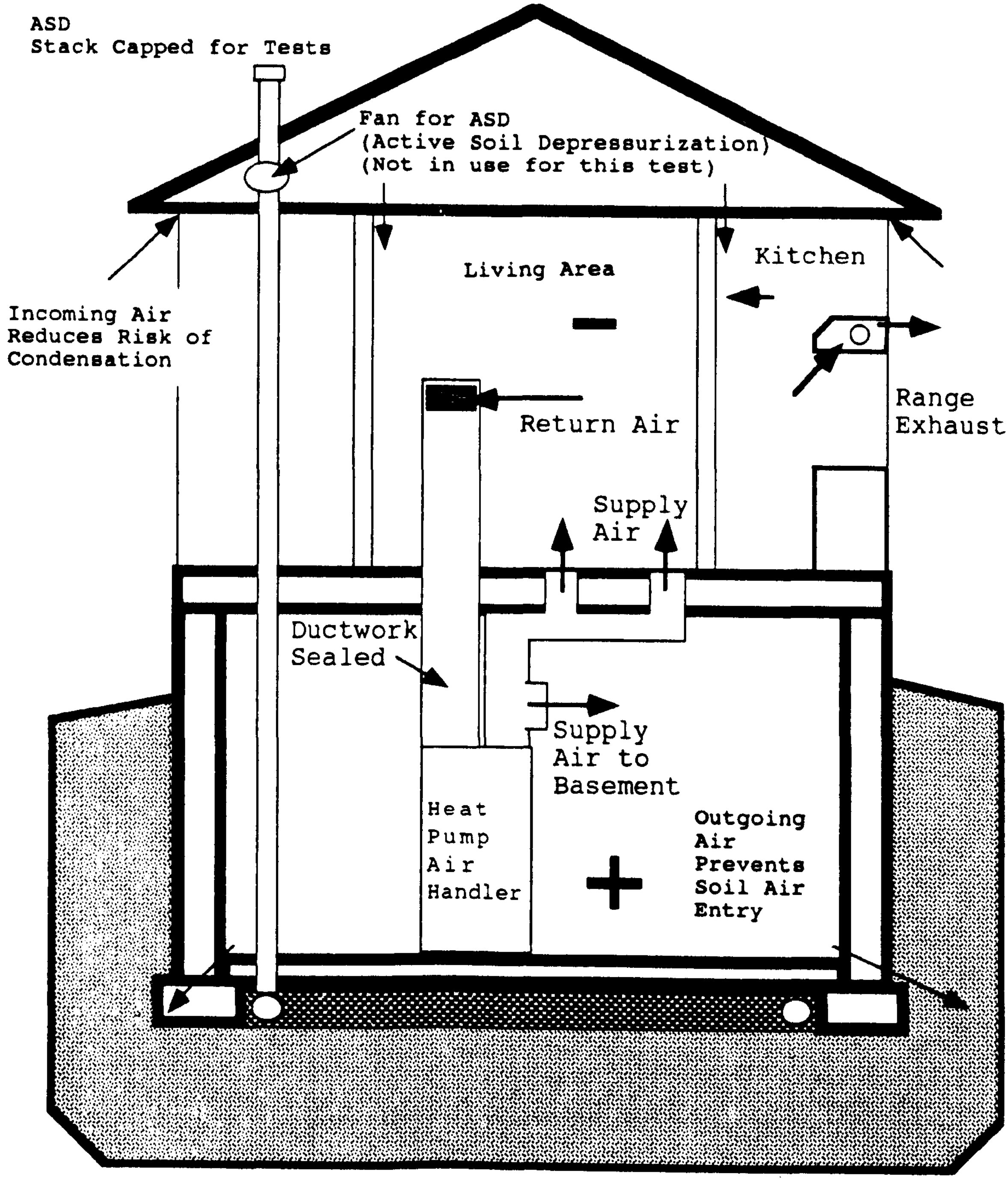


Figure 1. Illustration showing the use of the heating, ventilating and air conditioning system to control radon entry, minimize the risk of condensation in the upper floors, and provide recommended ventilation rates.

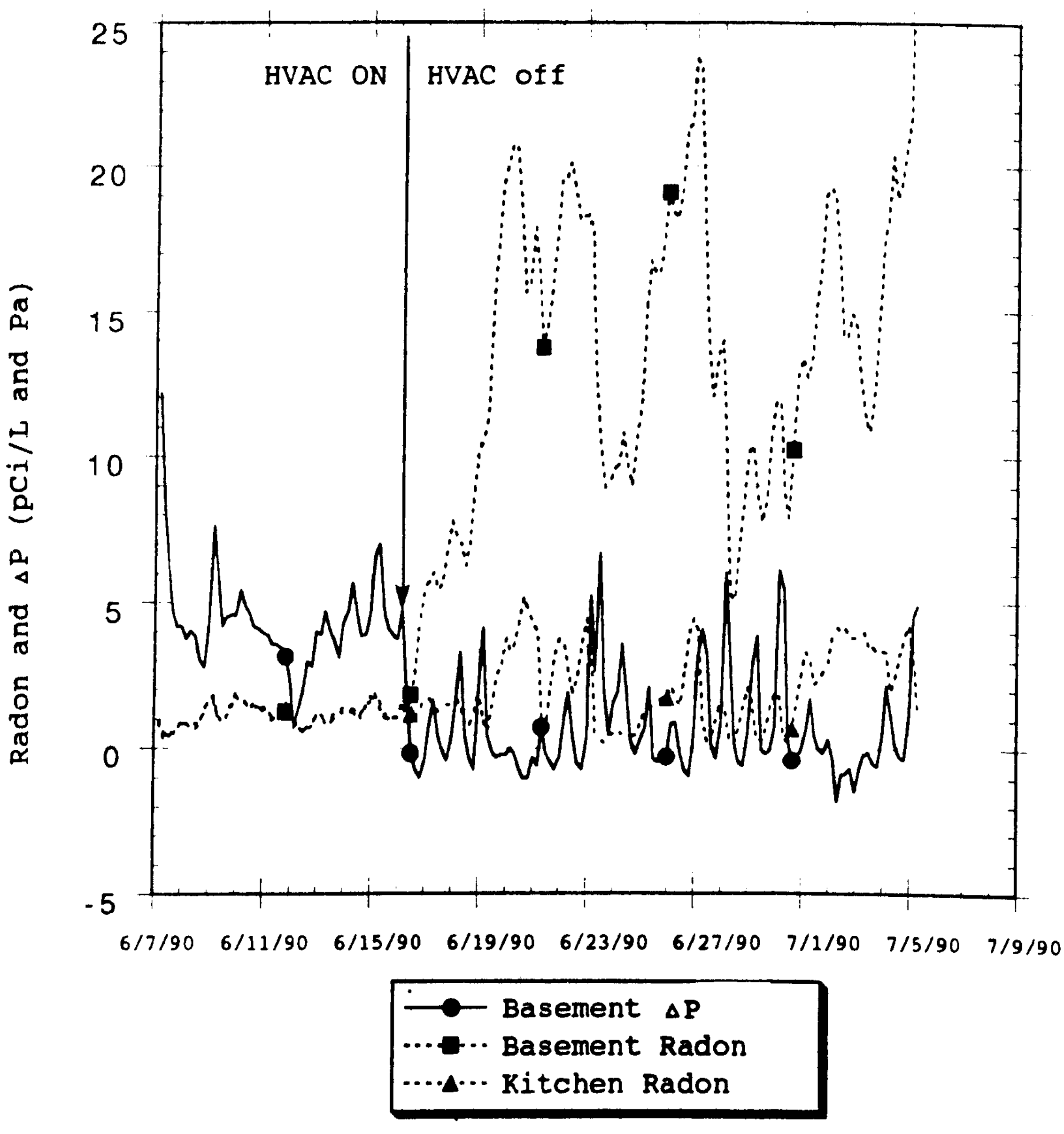


Figure 2. Radon levels and differential pressures with air handler on and off.

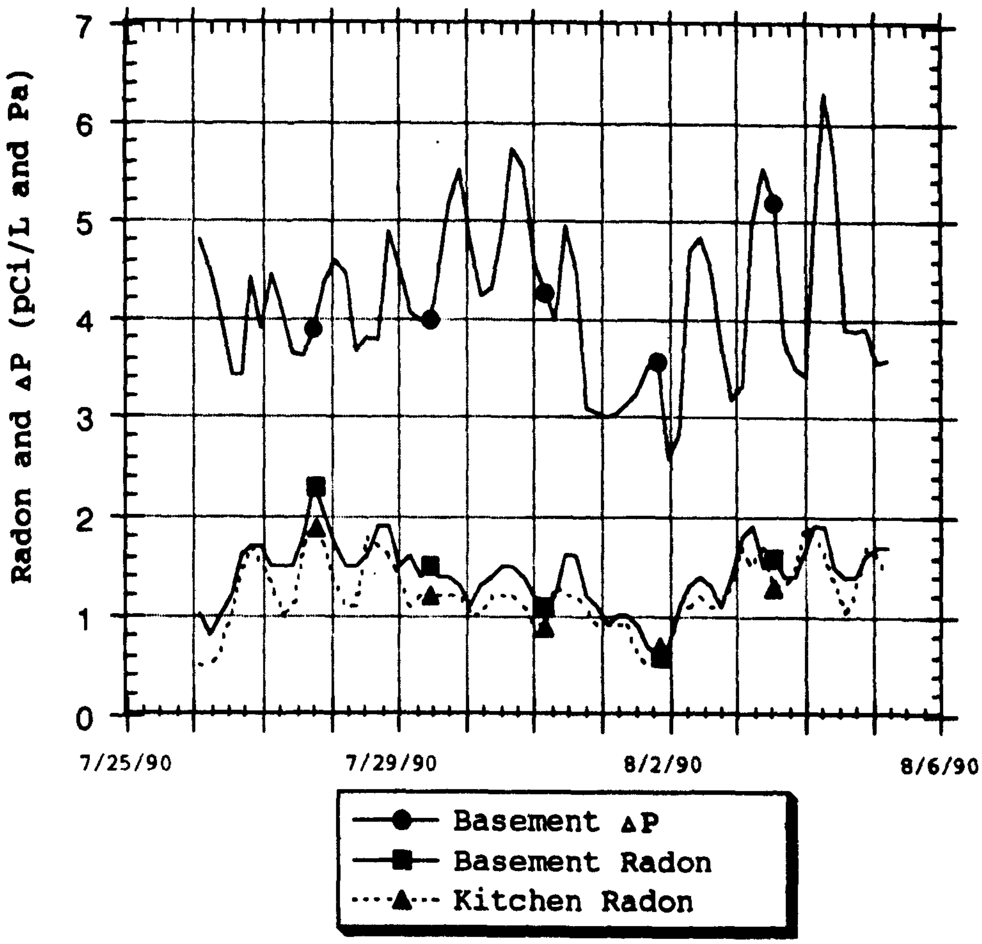


Figure 3. Radon levels and differential pressures with the air handler on continuously

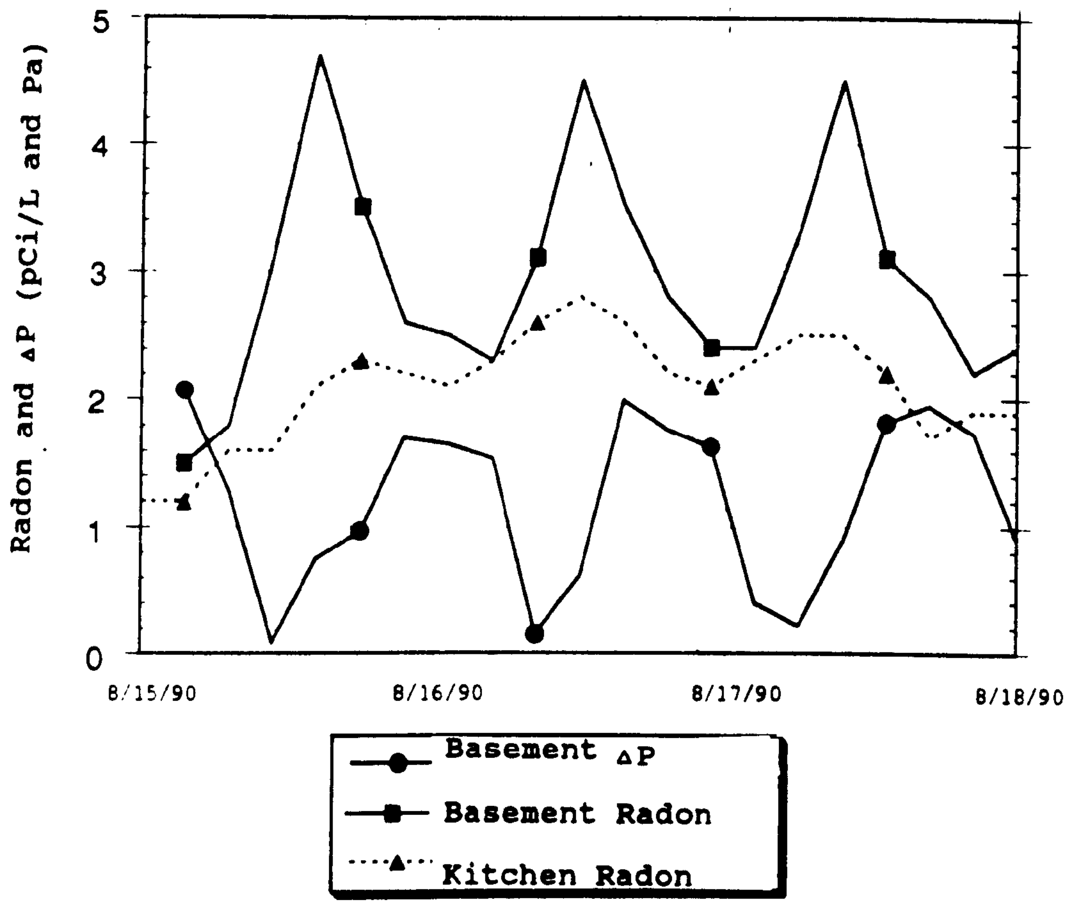
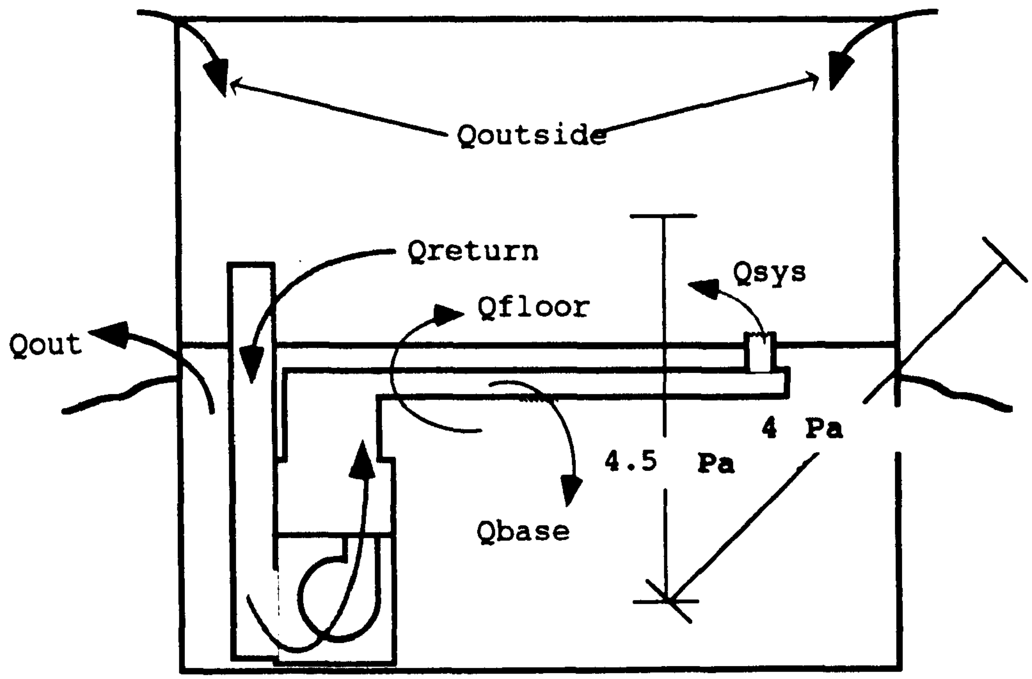


Figure 4. Radon levels and differential pressures with the air handler operating in normal cooling mode



Measured Effective Leakage Area (ELA)

ELA House less floor = 69 sq in.

ELA Basement less floor = 40 sq in.

ELA floor = 35 sq in.

Calculated directly from pressure - ELA data using airflow through a sharp edged orifice

Qoutside should equal Qout. Although 53 does not equal 87 the difference is within the experimental error of the measurements.

Qfloor = 83 cfm ± 25 cfm
Qout = 87 cfm
Qoutside = 53 cfm ± 20 cfm

Assuming that the return leaks equal the supply leaks
Qbase = Qoutside + Qfloor

Resulting in Qbase estimates of

Qbase = 136 - 170 cfm

This compares well with Qbase estimated from the ductwork airflow measurements of 138 cfm.

Figure 5. Airflows and pressure patterns with the air handler on low speed

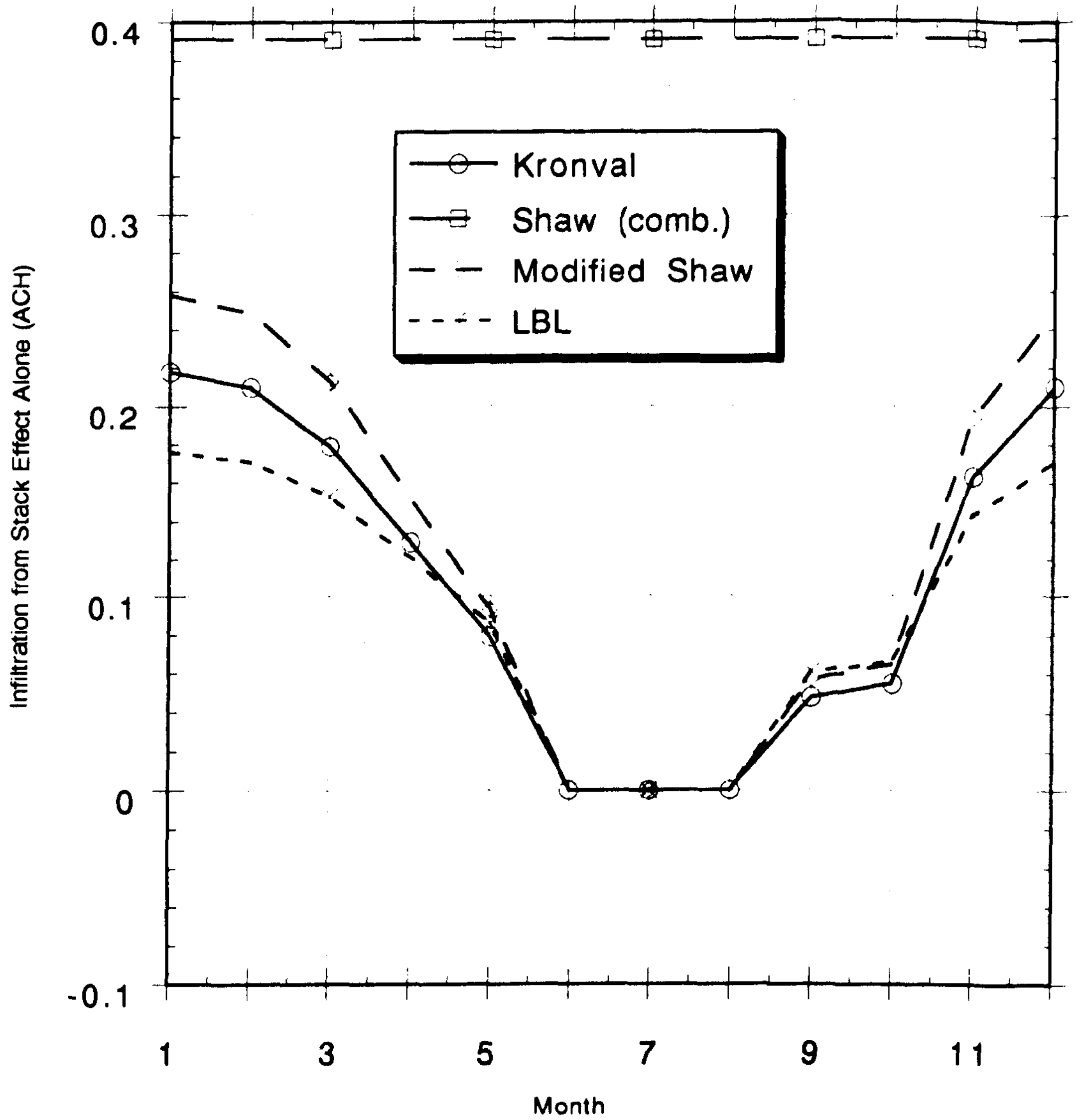


Figure 6. Estimated airflows through the test house resulting from stack effect alone. Four models have been used. The stack effect and the air handler produce countervailing pressure fields, to some extent canceling some of the effect of each.

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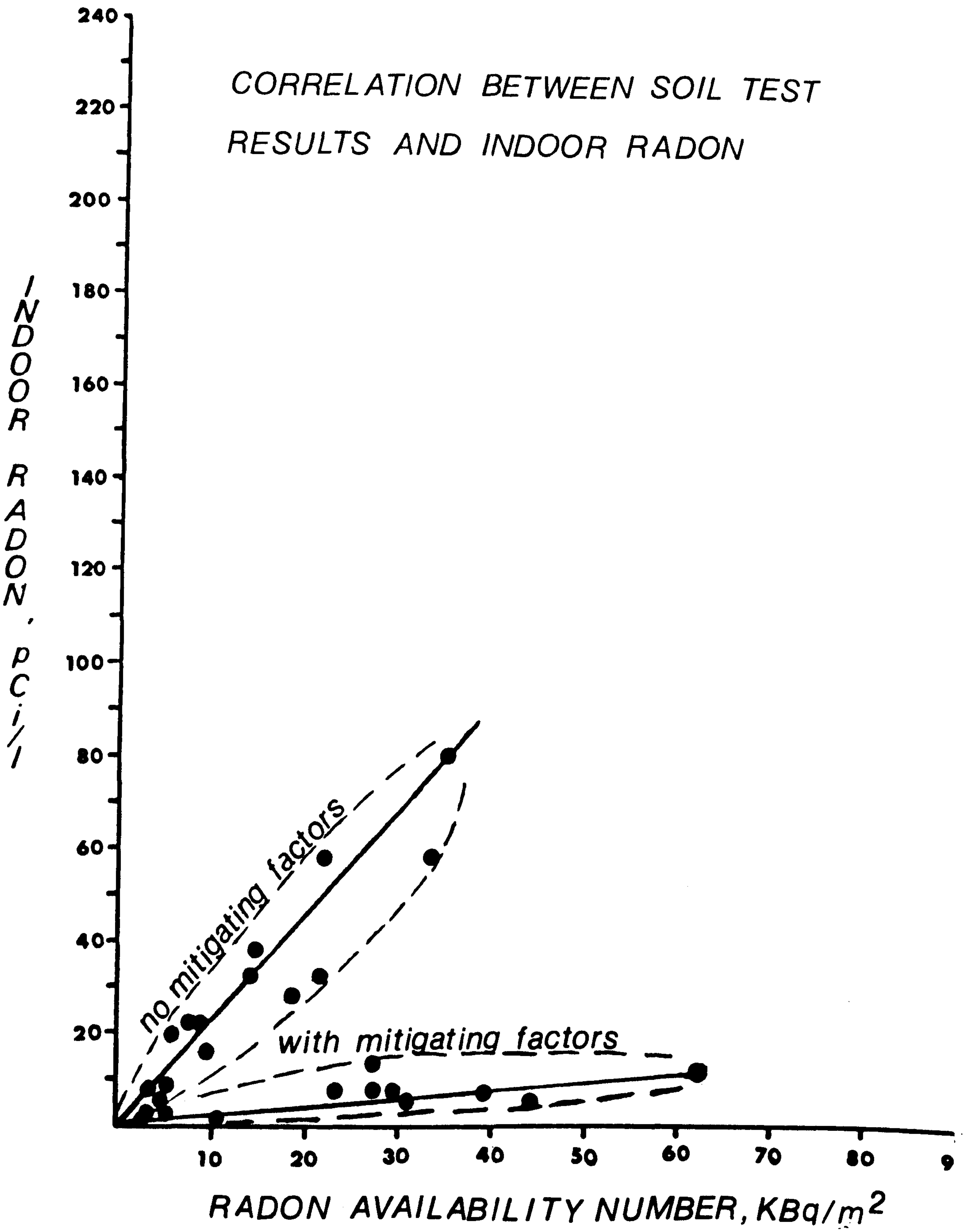
CORRELATION OF SOIL RADON AVAILABILITY NUMBER WITH INDOOR RADON AND GEOLOGY IN VIRGINIA AND MARYLAND

Stephen T. Hall
Radon Control Professionals, Inc.

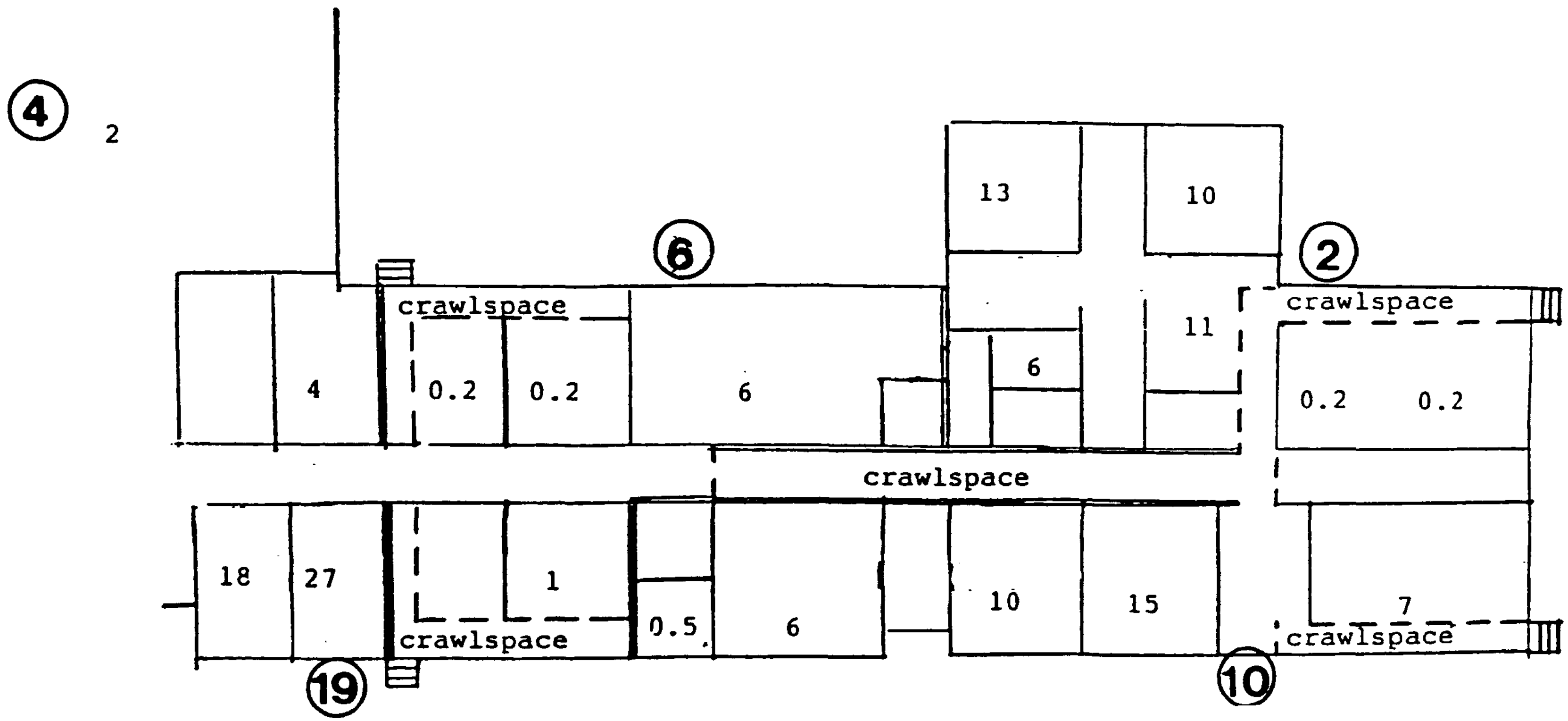
Soil radon availability number measurements by RCP have yielded correlations with both indoor radon levels and various geologic units. Radon availability number is a function of soil radon concentration, permeability, and diffusion rate. The equipment consists of a Pylon radon monitor with attached Lucas cell and RCP-developed soil probe.

Determined radon availability numbers plotted against indoor radon levels revealed two distinct populations separating buildings with basements from those without basements or with other construction factors.

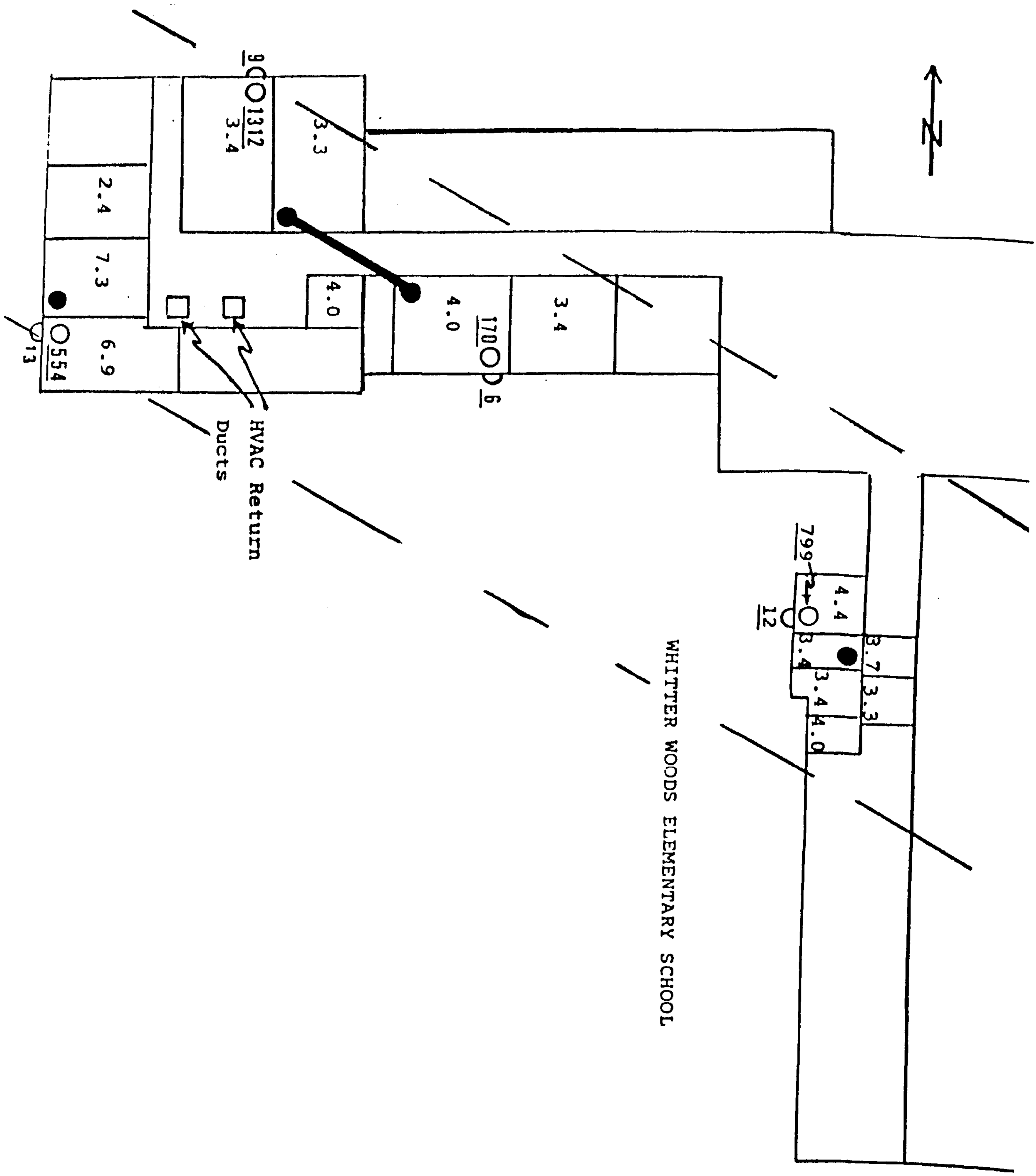
Thus, soil tests are being used with favorable success to predict the potential for elevated indoor radon levels and enable the design of pre-construction mitigation systems with the correct magnitude and location of ventilation points.



CORRELATION BETWEEN SOIL TEST RESULTS AND INDOOR RADON
INDOOR RADON, pCi/l
240
220
200
180
160
140
120
100
80
60
40
20
no mitigating factors
with mitigating factors
10
20
30
40
50
60
70
80
9
RADON AVAILABILITY NUMBER, KBq/m2

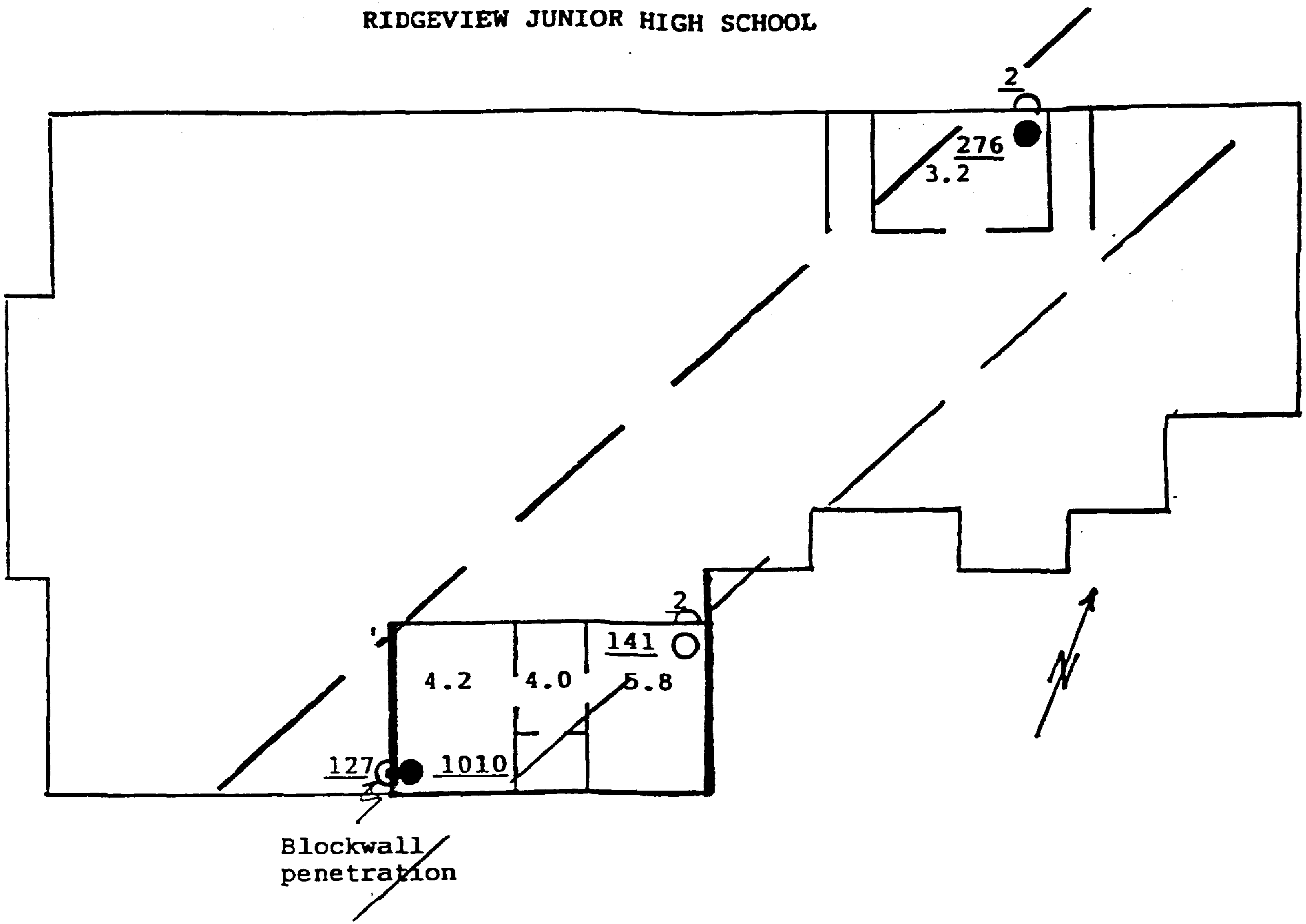


Completed school. Inside numbers = indoor radon, pCi/1.
Encircled numbers = radon availability number, KBq/m^2

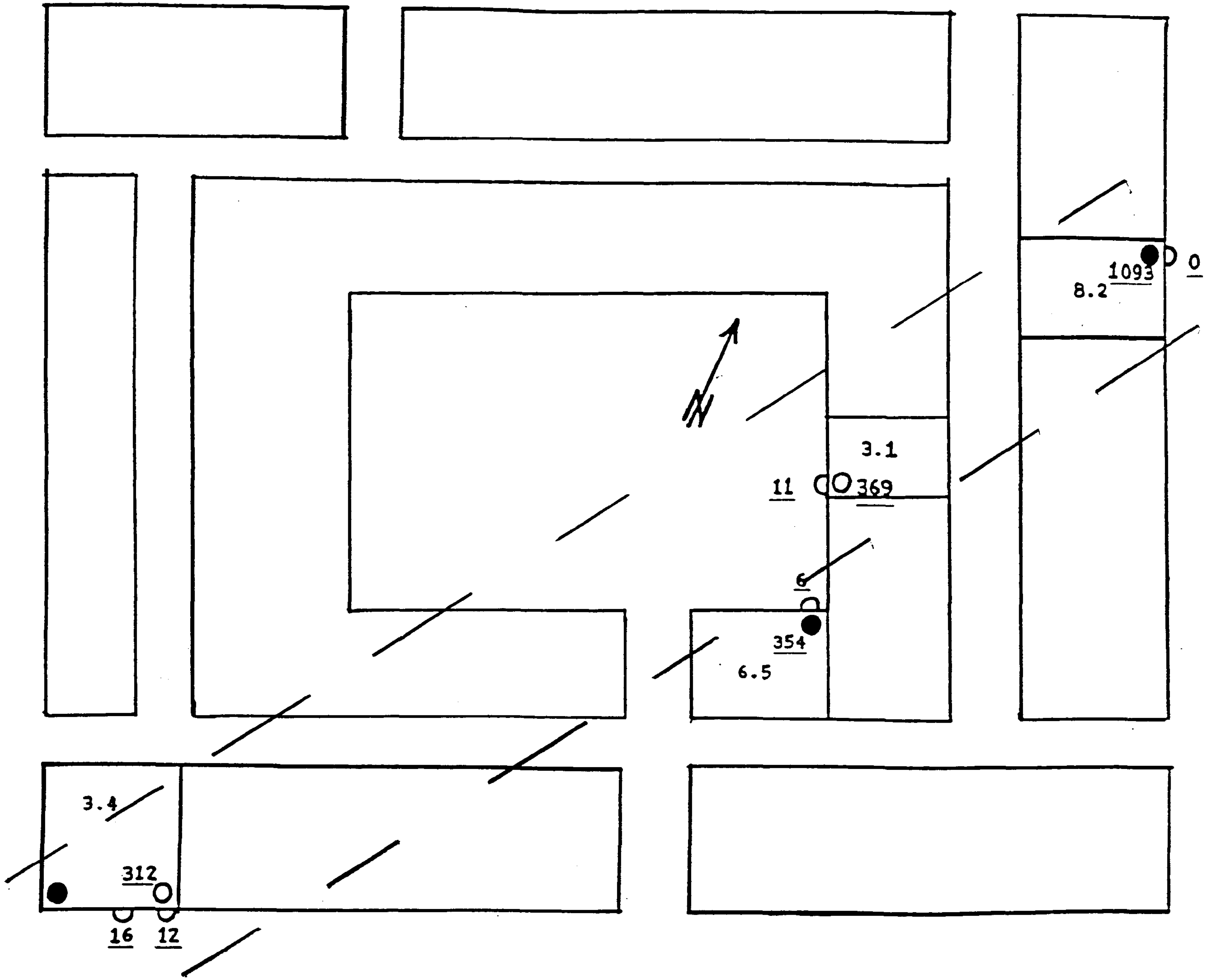


Whitter Woods Elementary School - Sub-slab radon levels delineating a N60°W fracture trend.

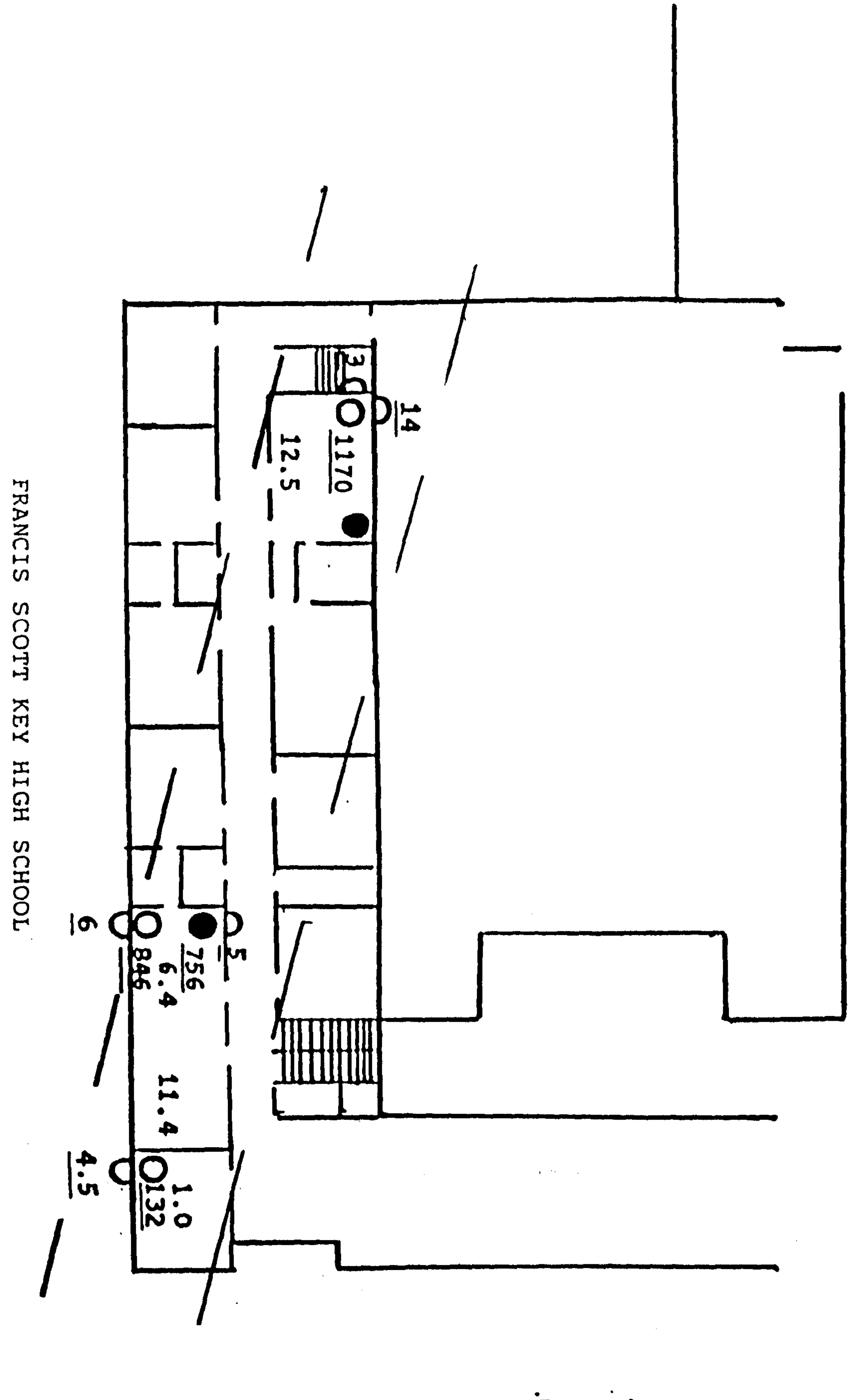
RIDGEVIEW JUNIOR HIGH SCHOOL



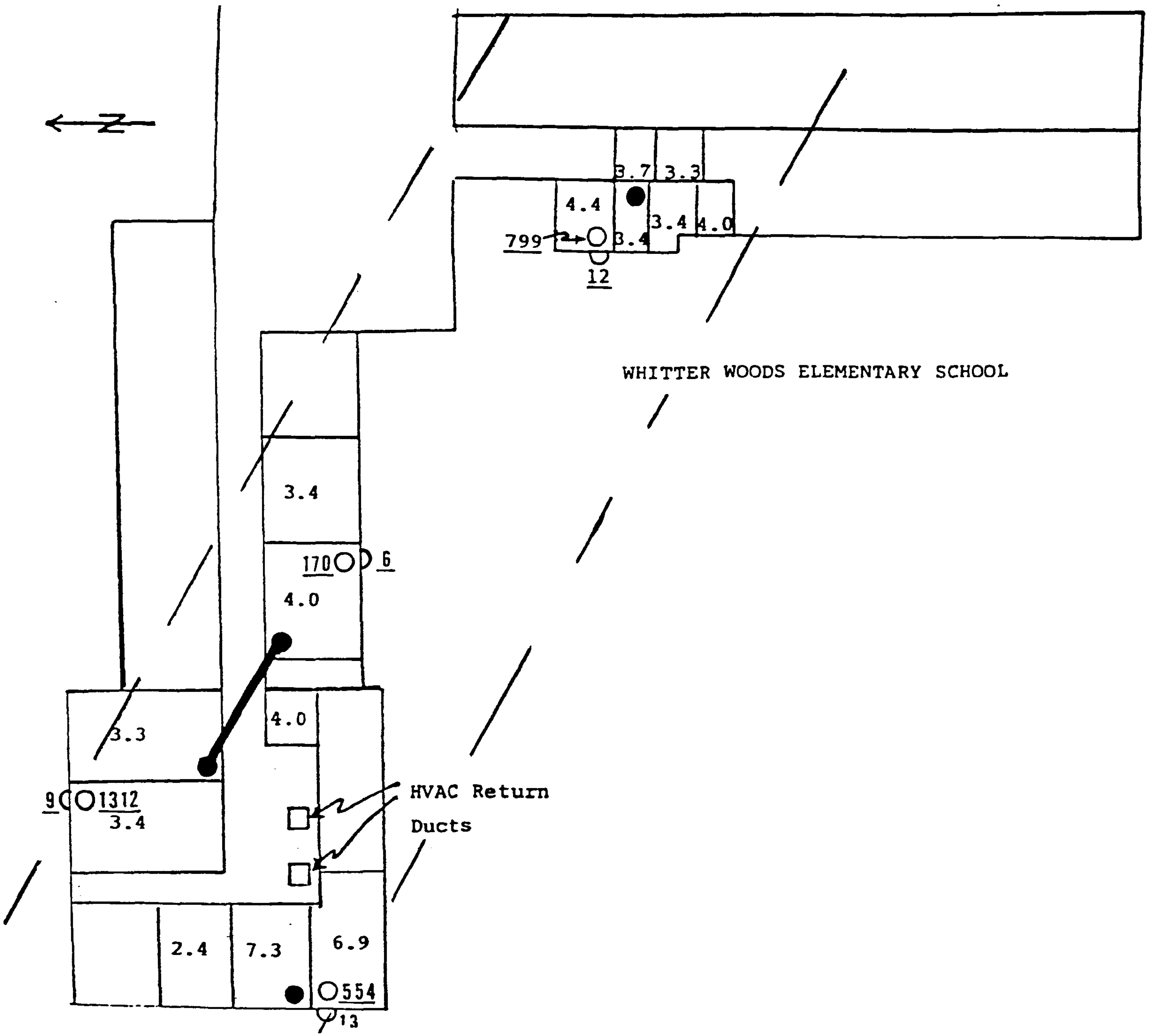
Ridgeview Junior High School - Sub-slab radon levels delineating a N30°E rock layer trend.



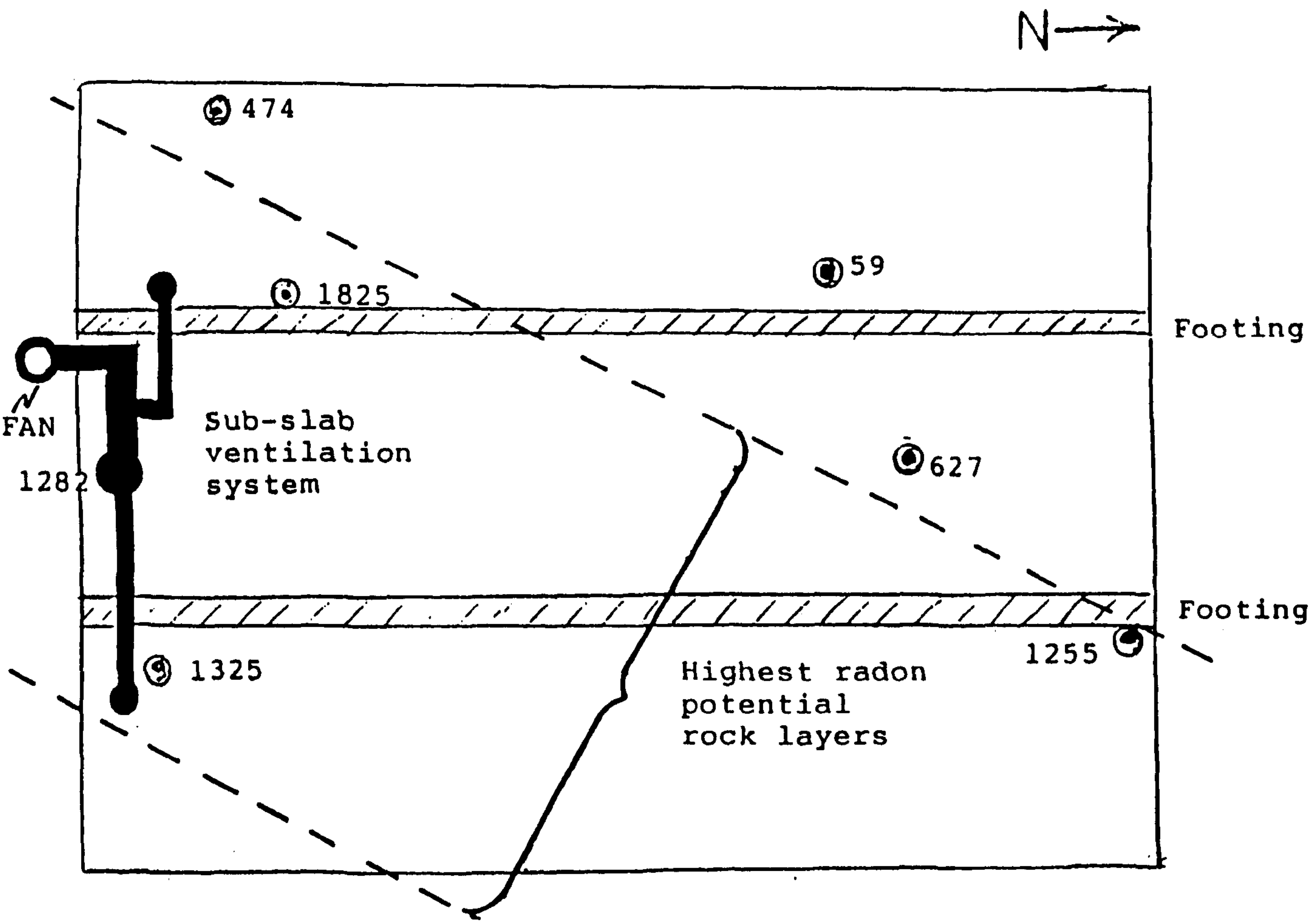
Cannon Road Elementary School - Sub-slab radon levels delineating a N30°E rock layer trend.



Francis Scott Key High School - Sub-slab radon levels delineating a N60°W fracture trend.



Whitter Woods Elementary School - Sub-slab radon levels delineating a N60°W fracture trend.



Footprint plan of a home showing numerical values of sub-slab and blockwall radon concentrations that indicate that the radon source is following N30°E rock layers, delineated by dash lines. Sub-slab ventilation systems penetrations are shown as darkened circles.

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