United States Environmental Protection Agency
Office of Research and Development
Air and Energy Engineering Research Laboratory
Research Triangle Park, NC 27711
EPA/600/9-90/048 Dec. 1990

EPA

# Radon Mitigation Update

## Introduction

This update summarizes the Air and Energy Engineering Research Laboratory's (AEERL's) radon mitigation research program objectives and updates recent Radon Mitigation Branch (RMB) activities. A listing of recent AEERL publications and EPA documents relating to radon mitigation is included as a reference for obtaining additional information.

The technical portions of this update are intended to provide timely and useful information to the radon mitigation industry. It should be noted that this information may be based on regional and/or preliminary findings and should be viewed as such. As research programs progress, AEERL will publish details of its findings as technical reports.

For additional information on specific research activities or programs, you may contact the specific RMB project officer either by phone (see below) or mail at MD-54, U.S. EPA, Research Triangle Park, NC 27711.

Mike Osborne, Branch Chief
(919) 541-4113
- EPA radon mitigation research and development program

Kelly Leovic
(919) 541-7717
- radon mitigation in schools

A.B. "Chick" Craig
(919) 541-2824
- Senior Physical Scientist - Radon

Tim Dyess
(919) 541-2802
- radon resistant new construction

Bruce Harris
(919) 541-7807
- radon diagnostics and measurement technology

John Ruppersberger
(919) 541-2432
- radon barriers and block permeability

Bruce Henschel
(919) 541-4112
- radon mitigation in existing houses

Ron Mosley
(919) 541-7865
- radon data analysis

David Sanchez
(919) 541-2979
- mechanisms of radon entry

## AEERL Radon Mitigation Research Objectives for 1990 and Beyond

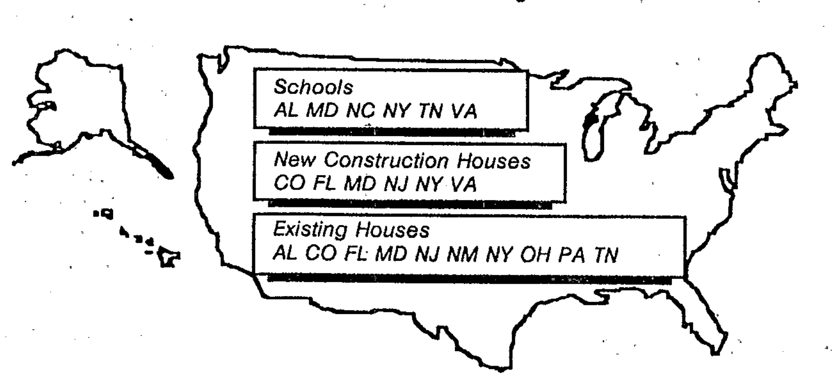
In late 1988, Congress enacted the Indoor Radon Abatement Act (IRAA). The Act sets a long-term goal of reducing indoor radon levels to the point that air within buildings is as free of radon as is the ambient air outdoors (about 0.2-0.7 pCi/L). AEERL will focus its research programs toward developing and demonstrating technologies necessary to reduce indoor radon levels toward this goal.

*Existing House programs* will research the application of subslab depressurization and other radon reduction approaches in different house types, soils, and geographic regions; evaluate the durability and long-term performance of radon reduction techniques and materials; and study the effects of natural ventilation, air cleaners, and block wall coatings.

*Radon Resistant New Construction House programs* will focus on determining the most effective radon resistant construction techniques. Radon resistant features in previously constructed houses will be removed or deactivated to determine their impact on indoor radon levels. Soil and house characteristics for slab-on-grade, basement, and crawl space houses constructed on both sandy and expansive clay soils will be studied to determine interactions. Research will continue on the radon resistant properties of concrete blocks and block wall coatings.

*School programs* will include demonstrating the regional application of subslab depressurization systems, initiating an effort to investigate reduction strategies for difficult to mitigate schools, and quantifying school characteristics throughout the country in order to better focus school research projects.

*AEERL Research Programs*




*AEERL has conducted radon mitigation research and demonstration programs in each of the states identified. Locations were chosen to represent diverse geological conditions and building construction practices.*

## Recent Research Findings

### Existing Houses

#### Slab-On-Grade and Basement Houses

Subslab Depressurization (SSD) has been shown to be the most effective mitigation strategy for slab-on-grade (SOG) and basement houses. SSD works best when there is clean coarse aggregate underneath the slab which facilitates air movement (communication) throughout the subslab area. When good communication exists, SSD with only one or two suction pipes has been shown to provide substantial radon reduction even when there are forced air heating or cooling supply ducts under the slab. Large slabs (greater than 1000 sq ft) are more likely to require two suction points.

Excavating pits 1 to 2 ft in diameter underneath the slab/suction pipe interface has proven effective in increasing the area of subslab depressurization.

Research has also shown that suction pipes inserted through the foundation from outdoors are often as effective as interior suction pipes, that houses with poured concrete stem walls generally performed better than those with block stem walls, and that suction fans could generally be slowed to 15-40% of full capacity and still provide adequate reductions (although fans generally provide better reductions when operated at full capacity).

#### Crawl Space Houses

Sub-Membrane Depressurization (SMD) — where suction is applied to the soil underneath a plastic liner — has demonstrated significantly better radon reductions than any crawl space ventilation technique.

By depressurizing the soil underneath a membrane, SMD (like SSD) causes a reversal of pressure differentials and typical air movement patterns. Radon-laden soil gases, along with small quantities of crawl-space air, are drawn from beneath the membrane and vented outdoors.

Research in four crawl space houses in Ohio has shown that 90%+ reductions can sometimes be achieved when perforated drain tile is used in conjunction with 8-10 ft membranes extending from all sides of a crawl space, even when the center of the crawl space is left uncovered. This indicates that it may not always be necessary to cover entire areas when using SMD mitigation strategies.

An alternative to SMD is ventilation of the entire crawl space. SMD is commonly more effective, as shown in the table below, but crawl space ventilation may be sufficient in some cases. Forced exhaust (blowing crawl space air out with a fan) consistently provides better reductions than natural and forced supply ventilation. Even though forced exhaust may increase crawl space radon levels by drawing more radon from the soil, it inhibits crawl space air from entering the living spaces by depressurizing the crawl space. Forced exhaust is less likely to contribute to cold floors and increased indoor humidity than forced supply or natural ventilation.

Percent Radon Reduction

Living Area (Four Dayton, OH, houses)

| House | SMD | Natural Venting | Forced Exhaust | Forced Supply |
|---|---|---|---|---|
| 1 | 92 | 46 | 74 | 73 |
| 2 | 93 | 57 | 70 | 53 |
| 3 | 90 | 46 | 84 | (-16) |
| 4 | 98 | 83 | 92 | N/A |

### New Construction

It is generally less expensive to build radon resistant features into new houses than it is to mitigate existing houses. The average cost of building passive radon resistant features into a new house is about $300 to $400, but this will vary depending on local building practices and availability of materials. To activate the SSD system with an electric fan may cost an additional $220 to $300.

Research in Maryland and Virginia has shown that SSD with passive stacks can sometimes provide considerable radon reduction if properly installed under the following conditions: the stack is routed through the warm part of the house up to the roof line; there is at least 4 in. of clean coarse aggregate under the slab; care is taken to seal openings in the house shell; and activities which depressurize the building are avoided (e.g., use of air-consuming appliances). It should be noted, however, that all 16 SSD systems studied provided better and more reliable reductions when activated by a fan.

### Schools

Important factors contributing to elevated radon levels in schools and influencing the mitigation approach are the design, installation, and operation of the heating, ventilating, and air conditioning (HVAC) system. The complexity of these systems and their potential to depressurize buildings present problems not encountered in house mitigation research.

Experience to date indicates that SSD in schools typically requires greater fan capacities (typically 300 cfm) and suction pipe diameters (4-6 in.) than does mitigation in houses, but can usually overcome negative pressures induced by HVAC operations if there is a layer of clean coarse aggregate under the slab and no subslab return air ducts. In fact, SSD has been applied successfully in a school with only one suction point depressurizing an area of 15,000 sq ft. However, if interior walls extend through the aggregate creating subslab barriers or compartments, a suction point will likely be needed for each subslab area surrounded by walls that penetrate the slab.

Pressurization through continuous or modified operation of HVAC systems may also provide effective radon reductions in some schools. The use of these techniques in a particular school will depend on HVAC system design, capacity, and potential for modified operation. Long-term feasibility will depend on proper operation and maintenance of the system throughout the life of the building, and the school's ability to afford the additional operational cost.

As with houses, radon resistant features can be cost effectively built into new schools. When 4-6 in. of clean coarse aggregate is placed under slabs and subslab barriers are limited, one SSD suction point should be roughed in for each major area defined by footings and block walls dividing the aggregate. Roughing in roof vents during construction will facilitate post-construction mitigation by avoiding additional roof penetrations.

---

## Radon Reentrainment Into Buildings

Exhaust of high levels of radon-laden soil gas from soil depressurization systems near the walls or below the eave lines of buildings may increase indoor radon levels. Research has shown the potential for radon exhaust to reenter (reentrain into) buildings around the band joist and through other air infiltration points in walls. The potential for reentrainment is increased when down-turn (dryer) vents which push exhausting soil gas toward or parallel to the building are used.

EPA recommends above-eave exhaust to minimize reentrainment. However, studies suggest that exhausting below the eave line may not be a problem when low radon-containing soil gases (less than 1,000 pCi/L) are vented through the band joist or wall, but directly away from the building. The potential for exhausting other soil gas contaminants or pesticides/termiticides should also be considered when selecting exhaust locations. Further research is underway.

## Block Wall Coatings

Laboratory testing indicates that light weight concrete blocks generally allow greater air flow than heavy weight blocks. However, air permeability consistently varies directly with the surface roughness of the block. Both light and heavy weight blocks allow substantial soil gas infiltration if not properly coated and capped with solid materials.

Tests of six paints and coatings demonstrated that all were effective in reducing air movement through block walls. Brushed-on cementitious coatings gave the best reduction per unit cost with single coat applications reducing air flows by up to 99.7%. A two-part water-based epoxy was the best performing paint with reductions of 96.2% after a single coat and 99.9% after a second coat. This indicates that a second coat may not be required in low radon buildings.

Important considerations for selecting and applying coatings include existing water problems, mildew, hairline cracks, and other factors which may affect the life and performance of the coating.

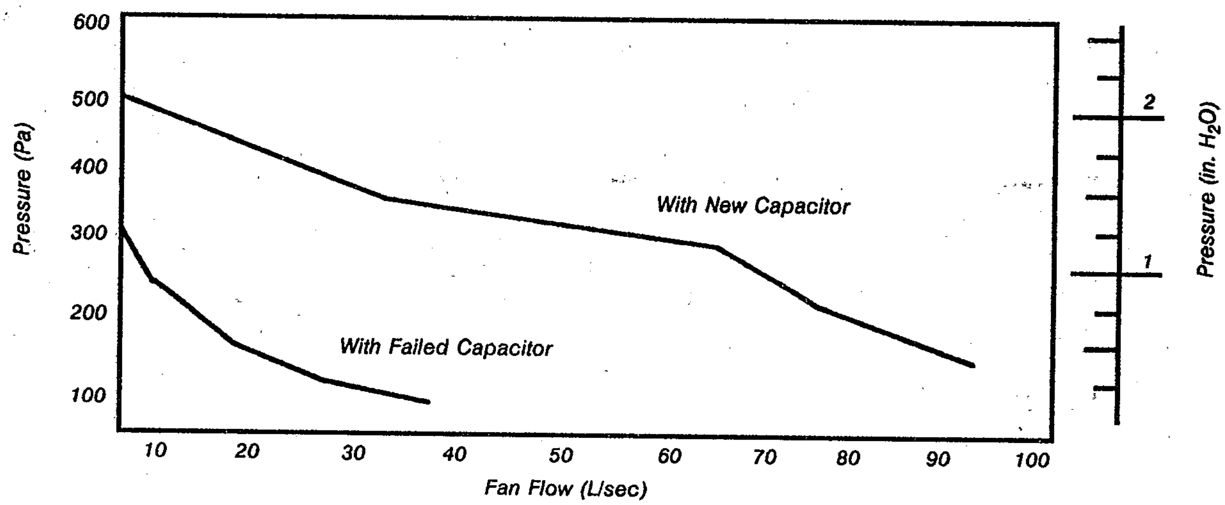
## Mitigation Durability and Long Term Performance

AEERL has evaluated the long-term performance of 34 SSD systems installed 2-4 years ago as part of its Pennsylvania demonstration project. Most but not all of the 34 fans were Kanalflakt models. Five of the fans have lost suction due to capacitor failure in the fan motor. All five were Kanalflakt fans (four T-2 models and one T-1 model).

If the fan is operating when the capacitor fails, it may continue to operate for up to 1 year, but at greatly reduced suction and flow capacities (see graph).

*System Performance Cannot Be Judged By Fan Noise Alone.* These findings underscore the need for an air flow or pressure sensitive alarm to alert building owners to system failures. A simple test for capacitor failure is to turn the system off, allow the fan to stop, and then turn it back on. Systems with failed capacitors will not restart.

*Effect of capacitor failure on Kanalflakt fans.*




## State Code Development

AEERL is serving as technical managers of the state of Florida's research activities focused on understanding radon generation and movement in soils, entry into buildings, and distribution throughout buildings. Results of this research will be used in the development of Florida's radon codes and standards which are slated for release in February 1992.

Output from this cooperative research will assist both Florida and AEERL in developing recommendations and specifications for fill materials, SSD systems, improved slab/floor radon barriers, slab/superstructure tightness, and mechanical air moving systems.

## Research Notes

Basement pressurization has worked successfully in some houses in Tennessee but has not been applicable in others. The ability to seal the basement from the first floor appears to be the limiting factor. Pressurization is extremely difficult if the house has forced air heating or air conditioning.

Preliminary studies of natural ventilation in one New Jersey house indicate that opening basement windows can reduce the radon levels by a factor of 8 while increasing the air exchange rate by only a factor of 2.

Radon measurements in two areas of Alabama resulted in summer radon levels which were consistently higher than winter radon levels.

Sealing of radon entry routes enhanced the effectiveness of subslab suction depressurization techniques. However, when sealing was used alone, it often failed to reduce radon levels below 4 pCi/L, with typical reductions ranging from 50 to 70%.

In slab-on-grade houses in Florida, it was difficult to create suction under the entire slab area using only one suction hole because tightly packed soil (and lack of aggregate) inhibited the flow of air under the slab. The most effective means of increasing system performance in these geological conditions was the installation of additional suction holes where the air flow was inhibited.

Research in existing Maryland houses shows that passive subslab systems (i.e., systems without fans) were generally not adequate and required activation with fans to lower radon levels below 4 pCi/L.

## Recent Technical Information

### *Journal Articles*

Some Results from the Demonstration of Indoor Radon Reduction Measures in Block Basement Houses. *Environ International,* 15:265-270, 1989, Henschel, D.B. and A. G. Scott.

Radon Mitigation in Schools - Part 1. *American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Journal,* Vol. 32, No. 1, pp. 40-45, January 1990. Leovic, K. W., et al.

Radon Mitigation in Schools - Part 2. *American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Journal,* Vol. 32, No. 2, pp. 20-25, February 1990, Saum, D. W., et al.

### *Symposium Presentations*

New Construction Techniques and HVAC Over-pressurization for Radon Reduction in Schools. In: *Proceedings of the ASHRAE Conference IAQ '88,* Atlanta, 1988. pp. 69-76. Witter (Leovic), K., et al.

Fan Door Testing on Crawl Space Buildings. In: *Proceedings of the ASTM Symposium on Air Change Rate and Air Tightness in Buildings,* Atlanta, April 17-18, 1989, Brennan, T., et al. (M.C. Osborne, Project Officer)

The Influences of HVAC Design and Operation on Radon Mitigation of Existing School Buildings, In: *Proceedings of the IAQ '89. The Human Equation: Health and Comfort.* Leovic, K.W., et al.

Technical Issues Related to Emission Releases from Subslab Radon Mitigation Systems, In: *Proceedings of the 1989 National Conference on Environmental Engineering,* American Society of Civil Engineers, Austin, July 1989, Sanchez, D. C.

Occupational and Environmental Exposures to Radon: A Perspective for Mitigators, In: *Proceedings of the 1989 National Conference on Environmental Engineering,* Austin, July 10-12, Sanchez, D.C. et al.

### *Reports*

Testing of Indoor Radon Reduction Techniques in Central Ohio Houses: Phase 1 (Winter 1987-1988). EPA-600/8-89-071, (NTIS PB 89-219984), 1989, Findlay, W.O., et al. (D. B. Henschel, Project Officer).

Testing of Indoor Radon Reduction Techniques in Central Ohio Houses: Phase 2 (Winter 1988-1989). EPA-600/8-90-050, (NTIS PB 90-222704), 1990, Findlay, W.O., et al. (D. B. Henschel, Project Officer).

## 1990 International Symposium on Radon and Radon Reduction Technology, Atlanta, February 1990

Approximately 600 federal, state, and private sector personnel met February 19th-23rd in Atlanta, Georgia, to discuss radon and radon reduction technology. Some of the major findings of the symposium included:

- Less than 5% of homeowners are measuring for radon and most of those measurements are motivated by real estate or relocation activities.
- Most people who test do not follow up with mitigation, and sometimes those who do mitigate receive substandard work from mitigators.
- Many SSD systems are stable after 2-4 years. A SSD system with a passive stack is a judicious first step for new construction in radon prone areas.
- A majority of participants favored testing schools during the school year with the HVAC systems turned off.
- Many schools are proceeding with testing and mitigation.

The next symposium is planned for April 2-5, 1991, in Philadelphia, PA.

## AEERL Research Presented at the 1990 International Symposium

"Evaluation of Radon Resistant New Construction Techniques." Brennan, T., et al.

"Energy Penalties Associated with the Use of Sub-slab Depressurization System." Clarkin, M., et al.

"Radon Diagnostics and Mitigation in Two Public Schools in Nashville, Tennessee." Craig, A. B., et al.

"Engineering Design Criteria for Sub-slab Depressurization Systems in Low Permeability Soils." Fowler, C. S., et al.

"Evaluation of Sub-slab Ventilation for Indoor Radon Reduction in Slab-on-Grade Houses." Henschel, D. B., et al.

"Radon Mitigation Experience in Difficult-to-Mitigate Schools." Leovic, K. W., et al.

"Radon Mitigation Experience in Houses with Basements and Adjoining Crawl Spaces." Messing, M. and B. Henschel.

"Radon Mitigation Techniques for Basement Houses with Poor Sub-slab Communication." Pyle, B. E. and M. Osborne.

"The Florida Radon Research Program: Systematic Development of a Basis for Statewide Standards." Sanchez, D. C., et al.

"Radon Mitigation Performance of Passive Stacks in Residential New Construction." Saum, D. W. and M. Osborne.

"The Effects of HVAC System Design and Operation on Radon Entry Into School Buildings." Turner, W. et al.

"Electret Ion Chambers for Radon Measurements in Schools During Occupied and Unoccupied Periods." Wiggers, K., et al.

"Sub-slab Suction System for Low Permeability Soils." Hintenlang, D. and R. Furman.

"Temporal Patterns of Indoor Radon in North Central Florida and Comparison of Short-term Monitoring to Long-term Averages." Roessler, C., et al.

"A Simplified Modeling Approach and Field Verification of Airflow Dynamics in SSD Radon Mitigation Systems." Gadsby, K., et al.

"Benchmark and Application of the RAETRAD Model." Rogers, V. and K. Nielson.

"Long Term Durability and Performance of Radon Mitigation Subslab Depressurization Systems." Harrje, D., et al.

*(Continued on p. 5)*

"The Use of Coatings and Block Specification to Reduce Radon Inflow Through Block Basement Walls." Ruppersberger, J.

"Study on the Reliability of Short-term Measurements to Predict Long-term Basement Levels in a Residence. Hull, D. and T. Reddy.

"Time Series Linear Regression of Half-hourly Radon Levels in a Residence." Hull, D.

"One-year Follow-up Study of Performance of Radon Mitigation Systems Installed in Tennessee Valley Houses." Dudney, C., et al.

"Long-term Performance and Durability of Active Radon Mitigation Systems in Eastern Pennsylvania Homes." Scott, A. and A. Robertson.

Copies of the 1990 Symposium Proceedings are expected to be available in the fall of 1990 by contacting the National Technical Information Service (NTIS), at 5285 Port Royal Road, Springfield, Virginia 22161, or by calling (800) 336-4700. (Virginia residents call (703) 487-4650.)

## Recent EPA Publications/Manuals on Radon and Radon Reduction Technology

These publications/manuals were developed to provide technical information to individuals and radon industry professionals. *Radon Reduction Methods - A Homeowner's Guide* contains an overview of the basic radon reduction strategies. The other materials contain more specific and detailed technical information. As ongoing research provides new information, these materials will be updated and new manuals published. When requesting information or copies of these materials, individuals should ask if these materials have been updated or superseded.

*Radon Reduction Techniques for Detached Houses, Technical Guidance,* (2nd edition) EPA/625/5-87/019 (NTIS PB 88-184908) 1988

*Application of Radon Reduction Methods,* EPA/625/5-88/024 (NTIS PB 89-122162) 1988

*Radon-resistant Residential New Construction,* EPA/600/8-88/087, 1988

*Radon Reduction Techniques in Schools - Interim Technical Guidance,* EPA-520/1-89/020 (NTIS PB 90-160086) 1989

*Radon Reduction Methods - A Homeowner's Guide* (third edition) 1989

*Application of Radon Reduction Methods (Revised),* EPA/625/5-88-024 (NTIS PB 89-205975) 1989

Copies of these materials may be obtained by writing to NTIS or by contacting your EPA Regional Office.

## Other Sources of Information

If you would like further information on these publications or explanations concerning information contained in them, you should contact your state radiation protection office or homebuilders association.

If you have difficulty locating these offices, you may call your EPA Regional Office listed below. They will be happy to provide you with the names, addresses, and phone numbers of these contacts.

## EPA Regional Offices

Region 1
JFK Federal Building
Boston, MA 02203
(617) 565-4502

Region 2
26 Federal Plaza
New York, NY 10278
(212) 264-4418

Region 3
841 Chestnut Street
Philadelphia, PA 19107
(215) 597-8320

Region 4
345 Courtland St. N.E.
Atlanta, GA 30365
(404) 347-8257

Region 5
230 South Dearborn St.
Chicago, IL 60604
From IN, MI, OH, and WI
(800) 621-8431

Region 6
1445 Ross Avenue
Dallas, TX 75202
(214) 655-7223

Region 7
726 Minnesota Avenue
Kansas City, KS 66101
(913) 551-7020

Region 8
999 18th Street
Denver Place, Suite 500
Denver, CO 80202
(303) 293-1709

Region 9
1235 Mission Street
San Francisco, CA 94103
(415) 556-5285

Region 10
1200 Sixth Avenue
Seattle, WA 98101
(206) 442-7660

EPA Headquarters
401 M Street S.W.
Washington, D.C. 20460
(202) 475-9605

## State - EPA Region

Alabama-4
Alaska-10
Arizona-9
Arkansas-6
California-9
Colorado-8
Connecticut-1
Delaware-3
District of Columbia-3
Florida-4
Georgia-4
Hawaii-9
Idaho-10
Illinois-5
Indiana-5
Iowa-7
Kansas-7
Kentucky-4
Louisiana-6
Maine-1
Maryland-3
Massachusetts-1
Michigan-5
Minnesota-5
Mississippi-4
Missouri-7
Montana-8
Nebraska-7
Nevada-9
New Hampshire-1
New Jersey-2
New Mexico-6
New York-2
North Carolina-4
North Dakota-8
Ohio-5
Oklahoma-6
Oregon-10
Pennsylvania-3
Rhode Island-1
South Carolina-4
South Dakota-8
Tennessee-4
Texas-6
Utah-8
Vermont-1
Virginia-3
Washington-10
West Virginia-3
Wisconsin-5
Wyoming-8



☆U.S. GOVERNMENT PRINTING OFFICE: 1991 - 548-187/20532

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati, OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA PERMIT NO. G-35

Official Business
Penalty for Private Use $300
EPA/600/9-90/048