RADON MITIGATION FAILURE MODES

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ABSTRACT

An EPA study solicited anecdotal information on failure modes of radon mitigation systems from practicing mitigators, state government agencies which monitor radon mitigation, and EPA radon mitigation project officers and contractors. This study identified three categories of failures: design flaws, component problems, and occupant activities which compromised mitigation systems. This paper reviews several examples of failure modes in each of these categories.

Radon mitigation systems, like other mechanical systems, are subject to failure and should be designed accordingly. Mitigators should design systems to minimize the probability of failure and to readily detect failures that do occur. The system design should include a monitor which occupants can use to determine whether or not the system is operating properly. Occupants must realize that even well-designed and properly installed systems have some chance of failure; they should check the system monitor periodically and measure radon levels annually as long as the structure is occupied.

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INTRODUCTION

BACKGROUND

For several years, the U.S. Environmental Protection Agency (EPA) has been funding radon mitigation demonstration projects in various states. These projects have developed diagnostic measurements and procedures to select the most appropriate mitigation technique for a particular house. A variety of mitigation techniques have been tested in over 170 houses (1). In most houses, post-mitigation measurements have shown that radon concentrations in the living areas were reduced below the EPA's guideline of 4 picocuries per liter (pCi/L).

The EPA has monitored the long-term effectiveness of these mitigation systems with radon measurements during successive heating seasons. Most houses have shown little degradation in the effectiveness of the systems, but in a few, the systems have stopped working altogether. In others, the systems are much less effective than they were initially.

PURPOSE

This project was undertaken to study the failure modes of radon mitigation systems. The study focused on systems which once worked satisfactorily, but stopped working either completely or nearly completely. The study was not intended to deal with "problem houses," where the installed mitigation system never performed satisfactorily, or with systems whose performance has degraded somewhat, but is still generally satisfactory.

Research Triangle Institute (RTI) solicited information on mitigation system failures from practicing mitigators, state government agencies which monitor radon mitigation, and EPA radon mitigation project officers and contractors. During the EPA radon conference in February 1990, RTI convened an impromptu discussion group of approximately 50 attendees to discuss failure modes of radon mitigation systems. Some of them later provided additional details about problems that they had experience or observed. They asked about design flaws, component problems, and resident activities which compromised mitigation systems. This paper discusses the wide variety of radon mitigation system failures noted.

Although the study did not involve any measurements, people who worked for government agencies were asked if they had a data base from long-term follow-up radon measurements or if they knew of anyone who might have one. Unfortunately, the response to this inquiry was uniformly negative. Some data were received on immediate post-mitigation radon measurements from two sources: the New Jersey Department of Environmental Protection (NJDEP) and EPA Region 3 (Philadelphia).

ORGANIZATION

The rest of this paper summarizes the anecdotal information collected during this study. Most of the information refers to subslab depressurization systems, as this is the most common mitigation technique used by commercial mitigators. Sections 2.0 through 4.0 discuss failure modes in the three categories which were established: design flaws, component problems, and resident activities. Section 5.0 draws conclusions and suggests some areas for future work on residential mitigation failure modes.

DESIGN FLAWS

Several people were concerned that conscientious and competent mitigators could not compete with unscrupulous or incompetent ones. If mitigation systems are judged only by radon measurements immediately after installation, poorly designed systems with low quality components may not be distinguishable from better ones. Indeed, cost comparison may favor the poorer systems. The recent listing of mitigators who have passed EPA's Radon Contractor Proficiency (RCP) Program (2) should help homeowners to identify competent mitigators. In addition, several states distribute similar lists of mitigators who have satisfied state requirements.

A major factor in the radon mitigation business is real estate transactions which are contingent upon radon levels below 4 pCi/L. Under these circumstances, there is a strong incentive for a quick and inexpensive solution to the problem, which is seen as a radon measurement > 4 pCi/L, rather than a long-term health risk. Unless the health risk is recognized, the radon level may be viewed merely as a barrier to the transaction which must be surmounted as quickly and inexpensively as possible.

CONDENSATION OF SOIL GAS MOISTURE

Everyone contacted knew that soil gas is very moist and that ducts which exhaust it should be designed with a positive slope so that the inevitable condensation will drain down the duct. Everyone had also seen mitigation systems which failed because of a water trap. Sometimes the trap was part of the design and a drain line had been provided. Such drain lines tend to clog with debris or algae, or to freeze in cold climates. The trap then fills with water, blocking the air flow in the duct. Several mitigators reported rerouting ducts to eliminate such water traps.

Some mitigators reported water accumulating in long horizontal ducts in attics where a slight sag either developed or was not originally noticed. All ducts over a few feet long should have a positive slope.

FROZEN PRECIPITATION OR CONDENSATION

Even when ducts maintain a positive slope, they may be subject to condensation problems if they have long runs in unheated or exterior space, particularly if they have low air flows. Condensation may freeze to the inside of the duct rather than draining down, gradually choking the air flow.

If the duct is exposed to alternate heating and cooling, ice may form and then break loose, dropping down the duct into the fan. One mitigator who works for a national company mentioned that they have a guideline which requires that exterior ducts be insulated if the winter season has more than 5,000 heating degree days.

FAN MOUNTING

Improper fan mounting can lead to a variety of problems with mitigation systems. The EPA recommends that fans be vertically oriented so that condensation will drain through without accumulating in the fan housing. The Agency also recommends that fans be located outside the building envelope so that all ducts inside the building are under negative pressure (3). Thus, if any leaks develop in the duct, indoor air will be pulled in rather than radon-laden soil gas being pushed out. The fans used in radon mitigation systems have powerful motors which tend to vibrate and must be securely mounted to a sturdy support. Two mitigators cautioned about securing fan supports to a frame wall because the wall may act as a sounding board, amplifying the fan noise. One mitigator reported a failure where the fan housing was supporting the weight of a vertical duct and warped enough to bind the fan blade.

Mitigators should also consider the environment in which the fan must operate. Florida attics are hot in the summer; Minnesota attics are cold in the winter. It may be difficult to imagine temperatures of -20 or 120 °F (-29 or 49 °C) when working on a roof in April, but a fan which is mounted there will experience a wide range of environments. Even if the fan is rated for the entire range of environmental conditions which it will encounter, extreme temperatures may contribute to premature failure. Insulating the fan housing or shielding it from direct exposure to wind, rain, and sunlight may moderate effects of extreme conditions.

FOREIGN DEBRIS

Several mitigators mentioned unpleasant experiences with small animals which had entered a duct through an unscreened exterior opening. One noted that children put toys and trash into such openings. Systems which use outdoor air to ventilate or pressurize inside space should have a filter as well as a screen. These filters should be cleaned or changed frequently during times of the year when plant debris (seeds, flower parts, leaves, etc.) may be airborne.

HIGH WATER TABLE

During their pre-mitigation inspection, some mitigators look for a dewatering system or for water stains on basement walls as an indicator of a "problem house." A subslab depressurization system which is blocked by water will not be effective. Even when there is no standing water, some soils will expand when wet and will close off subslab communication. If subslab suction is the selected mitigation technique and there is any indication of an occasional high water table, the pit excavated under the duct penetration through the slab should be enlarged and the duct should extend a minimal distance below the slab. This should provide sufficient volume to accommodate some water accumulation without restricting radial air flow.

Homes in areas with a high water table may have an existing sump which can be used as a suction point for a radon mitigation system. A very effective way to extend a pressure field under the slab is by depressurizing a sump which is connected to footing drains. The sump should be sealed with an airtight cover, which must be removable to allow servicing or replacement of the pump. If the existing pump is not submersible, it should be replaced with one that is, since rusting of the pump will accelerate when the sump is sealed. The cover should contain a drain to allow the sump to collect water from above, as well as below, the slab. This drain should have a seal which allows water to pass while maintaining suction in the sump. If this seal fails, suction will be reduced. This could seriously reduce the effectiveness of the mitigation system, particularly if there is a low flow rate of soil gas.

RE-ENTRAINMENT

In spite of the EPA guidelines, some people mount fans inside buildings so that some of the duct is under positive pressure. A few mitigators had seen problems with re-entrainment, either from leaks in ducts which were under positive pressure, or from ducts which terminated immediately outside a building wall. This illustrates the importance of following the EPA guidelines for mounting fans outside the building envelope and terminating ducts where re-entrainment will not be a problem (3). If the exhaust is at or near grade, it should be far enough from the house to prevent re-entrainment and in an area of the yard not utilized by people (e.g., away from patios or gardens). Preferably, the exhaust should extend high enough above the roof to prevent blockage by snow, as well as re-entrainment through windows or chimneys. Some building codes specify that plumbing vents terminate at least 2 ft (0.6 m) vertically and 10 ft (3 m) horizontally from any openings.

One person mentioned the potential for leaks in the vent from an aeration system installed to remove radon from well water. The air vented from such systems may have much higher radon concentrations than soil gas. If the fan which exhausts the vent is located inside the house near the aeration unit, any leak in the duct could introduce large amounts of radon into the house.

COMPONENT PROBLEMS

FANS

A long-term follow-up study of 40 houses in Pennsylvania mitigated by an EPA contractor found that 5 of 36 houses with active soil ventilation systems had experienced fan failures (4). Four were due to capacitor failures in the fans' split-phase motors. When the capacitor fails, the motor continues to run at reduced efficiency, but cannot be restarted after a power interruption. Although the fan's performance is greatly reduced, the failure may not be detected unless there is a monitor of air flow or pressure drop across the fan, or a continuous radon monitor.

This failure mode was discussed at the EPA Radon Symposium in February 1990: mitigators were specifically asked about their experience with fan failures. Most mitigators have experienced some failures, but this EPA project had a failure rate far higher than that experience by these mitigators. A distributor who sells over 700 fans per month for radon mitigation reported that less than 1% fail within the 3-year warranty period. Failures may be due to either bearings or capacitors, but bearing failures are more noticeable because the fan begins to produce more noise. Several mitigators reported that fan failures seem to occur within a few months rather than after a year or more.

SYSTEM MONITORS

As mentioned above, drain lines from water traps may freeze in unheated spaces. A similar failure mode exists when condensation accumulates and freezes in the tubes which connect a pressure monitor or switch to the duct. If either tube is blocked, the switch or monitor will not function properly. System monitors which are electronic or which trigger an electrically powered alarm should be wired to a different circuit than the system itself.

SEALANTS

Most mitigation systems involve some sealing of floor/wall joints as well as of cracks in a slab or wall. Unless the surface is properly prepared, the sealant will not adhere to it. Even with proper preparation, an appropriate sealant must be used. For example, silicone caulk will not stick to concrete, but urethane will. Any sealant used for radon mitigation should last as long as the house. While not technically a sealant failure, it is not uncommon for new cracks to develop in a slab or wall after mitigation. It may be that the drying of soil by a mitigation system stimulates cracks.

Ducts are usually constructed from sections of polyvinyl chloride (PVC) or acrylonitrile-butadiene-styrene (ABS) pipe. PVC pipe can be glued, but ABS pipe must be caulked. It is important that joints fit snugly and be thoroughly cleaned, and that an appropriate adhesive be used to ensure a permanent seal. Metal ducts are a special problem. The joints which are near a fan may be subjected to considerable vibration. The fan should be connected to the duct with rubber couplings to reduce vibration and provide a better seal between the fan and the duct.

PIPES

Since plastic pipe is readily available and easy to work with, it is probably the most common duct material. Some plastic, however, is affected by sunlight; it becomes brittle and more susceptible to impact damage. Only plastic pipe stamped "DWV" (drain, waste, vent) should be used outdoors unless it will be insulated or otherwise protected from sunlight.

RESIDENT ACTIVITIES

INTENTIONAL ACTIONS

Surprisingly, after paying hundreds of dollars for mitigation systems, some people turn them off. Probably the most common reasons are to save energy or to eliminate noise. If a resident thinks that radon is only a problem during the heating season, he or she may turn off the mitigation system during the warmer months, especially if windows are left open (5). Often people do not realize that a typical mitigation system fan uses less electricity than a 100-W light bulb. One mitigator felt that renters had a much lower perception of risk from radon than homeowners and were more likely to be concerned about a mitigation system's operating cost.

Several mitigators reported systems which were turned off by new owners who did not understand their purpose. One new owner had been told that the system was intended to control odors of sewer gas. Another had been advised by the realtor that the system was unnecessary.

UNINTENTIONAL ACTIONS

Several mitigators reported that residents had temporarily turned off systems and forgotten to turn them back on. Acoustic or electrical noise seemed to be the most common reason. One mitigator reported that a system was turned off during a party because the fan noise interfered with conversation. There were several reports of interference with radios and television. Some of these were due to faulty wiring or electrical components of the mitigation system. Often residents did not realize that the system could be fixed or adjusted to reduce or eliminate the noise. Rather than call the mitigator, they turned the systems off when the noise was particularly offensive (6).

Like any other appliance, mitigation systems which are plugged into an electrical outlet can be accidentally unplugged. If the system does not make much noise and has no alarm, it may take some time for a resident to realize that it is not running. This is probably a design failure, stimulated by the desire to avoid the cost of an electrician and possibly an inspection. Radon mitigation systems should be wired so that they cannot be accidentally unplugged. Opinions differed among mitigators as to whether it is better to use a dedicated circuit or an existing circuit. Some felt that a separate circuit would minimize electrical interference with a radio or television. Others felt that tapping into an existing circuit used for lights or appliances would make it more noticeable if the power to the mitigation system were interrupted.

HOME RENOVATION OR REMODELING

Many of the mitigators contacted warned homeowners that a mitigation system may be adversely affected by some typical home renovation or remodeling projects. These include replacing the heating/cooling system, making an addition to the house, or finishing the basement. One EPA contractor reported that a submembrane depressurization system in a crawlspace had been severely damaged by workmen replacing a furnace. Although the contractor had provided a walkway to the furnace, apparently the workmen had dragged the old unit out across the membrane, damaging it.

CONCLUSIONS AND RECOMMENDATIONS

The experiences related in this report show that residential radon mitigation systems do fail for a variety of reasons and that such failures may not be immediately recognized. Mitigators should design systems to minimize the probability of failures. The system design should include a monitor which residents can use to determine whether the system is operating properly. Homeowners must realize that even systems with good design and components have some chance of failure; they should check the system monitor periodically and measure radon levels annually as long as the house is occupied.

SYSTEM MONITOR FOR THE HOMEOWNER

Only a few mitigators reported using system monitors with which they were satisfied; one had personally designed and built the monitor. Some research and development of a suitable monitor for residential radon mitigation systems is needed. The monitor need not have high resolution as it will not be used to monitor minor variations in system performance. It need only be capable of detecting change by a factor of 2 or more. An ideal monitor would have the following characteristics:

- The monitor should be inexpensive so that there is little incentive for mitigators to omit it to cut costs. It could monitor the system operating parameters (e.g., pressure drop) rather than radon concentrations. Such monitors are 2 orders of magnitude less expensive than the least expensive continuous radon monitors.

- The monitor should be adjustable so that the mitigator can set it for the system installed in that house. Mitigators may want to check the settings after a break-in period; two mitigators mentioned that flow rates tend to increase and pressure drops decrease over the first few weeks after system start-up.

- The monitor should be simple enough to be useful to the vast majority of residents. Several mitigators reported that most people do not check monitors when they are provided. Some of those who do check their monitors call the mitigator about minor fluctuations.

- The monitor should be durable. It should not require any adjustment by the resident, who should be able to test whether it is functioning properly. Several mitigators said that many of the reports of mitigation system failure to which they responded were actually failures of the system monitor.

SYSTEM DOCUMENTATION FOR THE HOMEOWNER

It is essential that residents understand the basic principles of the mitigation system and how to interpret the system monitor. If residents are to avoid activities which could compromise mitigation systems and to recognize problems when they occur, they should receive verbal explanation and instruction when the system is installed, as well as written documentation which they may refer to in future years or pass on to a new owner if the house is sold. Such documentation should include:

- Radon concentrations before and after mitigation. The measurement method, duration, and time of year should be documented.
- A description of the principles and specifications of the mitigation system. The basic principle of operation could be taken from EPA's homeowner's guide to radon reduction methods (7). The location of ducts, wires, fans, switches, and the system monitor should be sketched or described. System operating parameters (e.g., pressure drop and air flow) after a break-in period of at least 24 hours should be available.
- An explanation of the system monitor. This would include whether the monitor indicated air flow or pressure drop, and the nominal range for the indicated parameter. If there is an audible or visual alarm, conditions that trigger it and what to do if the alarm goes off.
- A schedule and procedure for periodic inspections. This might simply be to check the monitor monthly.
- A description of any preventive maintenance and of the warranty on any components (e.g., the fan) or on the system as a whole. Homeowner or resident activities that might void the warranty should be listed. Who should be called if there is a problem should be identified.
- The appropriate state or local health department to contact in case of a problem that cannot be resolved by the original mitigator.
- A discussion of the sensitivity of the system to typical home remodeling or renovation projects.
- The importance of measuring radon concentrations annually as long as the house is occupied, even when the mitigation system appears to be operating normally.
- A short, simple summary of all of the above.

This may seem like a tremendous burden for a commercial mitigator, but most of them are already providing such documentation. An EPA survey of commercial mitigators (8) found that over 80% prepare a written mitigation plan and give a copy to their clients; over 60% provide clients with written instructions on how to maintain the systems.

The EPA might develop model documentation which could be copied or modified by commercial mitigators. Most of this documentation could be "boilerplate" which should be easy to assemble for each mitigation technique, with blanks to fill in specifics like radon concentrations and operating parameters. It is essential that the documentation be written so that most residents can understand it; otherwise the mitigation system will remain a "black box." The homeowner or resident will not feel competent to monitor its operation and may not appreciate the need for long-term follow-up radon measurements.

In addition to the documentation described above, the mitigation system should be clearly and permanently labeled with a warning that it is a radon mitigation system, that it protects the residents' health, and that residents should measure radon annually. The label should also identify whom to contact if a problem is identified or suspected.

LONG-TERM FOLLOW-UP

Based on the experiences of the mitigators contacted, few homeowners or residents recognize the potential for failure of their radon mitigation system. When a system monitor is provided, they do not check it regularly. When radon detectors are provided during subsequent heating seasons, they do not expose them. Like any mechanical system, radon mitigation systems are subject to failure. Some way to communicate this fact to current and future residents must be found.

A study involving long-term follow-up radon measurements in a national sample of mitigated houses could show the rate of mitigation system failures. Publicity about such a study might inspire many people to check the performance of their mitigation systems.

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