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WASHINGTON STATE PASSIVE STACK STUDY

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ABSTRACT

Since 1991, Washington State's Ventilation and Indoor Air Quality Code has had radon-resistive construction requirements specifying installation of prescriptive passive stack systems or "alternate" systems approved by local building departments. In 1993, the Washington State Department of Health initiated a study of passive stack effectiveness in new homes. Forty-two homes in a 1000 square mile area including Spokane, WA and Post Falls, ID have been studied from pre-construction open sites, through completion to the present. In these homes, the passive stack includes an airtight slide-gate valve at the base. Radon testing is being done with stacks alternately open and closed, simulating the presence or absence of a stack. Preliminary results indicate that passive stacks can produce significant reductions in indoor radon under a variety of conditions. A growing number of findings may be contrary to conventional theories of preventative radon mitigation technology. Findings may be useful to local, state and federal jurisdictions attempting to formulate or implement similar regulations.

INTRODUCTION

The Passive Stack Study was contracted in May 1993 to Thomas J. Gerard and Associates, Inc., working in conjunction with Faytek Inc. The intent was to gather data on the effectiveness of code mandated passive stacks as specified in the Washington State Radon Resistive Construction Standards (WAC 51-13-501, 502, 503). The study addresses houses in the Spokane, Washington area.

The original plan for the Passive Stack Study called for a study of houses that met the prescriptive path as described in the code, and conform to normal building practices in the Spokane area. Very early in the study, it was found that virtually none of the residential construction presently in progress in Spokane completely satisfies both of these criteria. For a variety of reasons, home builders in the area feel that the passive stack system described in the code was neither cost-effective nor consistent with accepted building practices in the region.

The prescriptive code requires that "a soil-gas retarder membrane, consisting of at least one layer of virgin polyethylene with a thickness of at least six mil, or equivalent flexible sheet material, shall be placed directly under all concrete slabs so that the slab is in direct contact with the membrane." ... "In no case shall the membrane be installed below the aggregate." Builders in this area are not willing to comply with this portion of the code. Additionally, concrete finishers contacted by the Investigator were unwilling to accept jobs to finish concrete poured directly on plastic. The aggregate and concrete suppliers informed the contractor that they would not warranty their product if used in this way. At the time of this writing, the Investigator has not seen or been told of any houses in Spokane County that are actually built to the prescriptive code specifications.

At the time the Investigator was trying to enlist builders to build code houses, most of the homes were being built with active "alternate" systems installed by a radon mitigation contractor. This system usually consists of a loop of 4 inch flexible slotted drain pipe, often laid in or on native soil, a solid pipe vented through the roof and a fan set to run continuously.

Since none of the builders contacted were willing to build a prescriptive code house, the Investigator obtained permission from the building department for one variation from the code. This variation was to exclude the requirement for the membrane. All of the houses studied in Spokane, WA have slabs poured directly on coarse aggregate known locally as "radon rock."

A group of homes in Post Falls, Idaho were also included in the study. This subset of the homes has one additional modification. Although Idaho code does not address radon, these homes were all designed with passive stacks as part of the builder's normal package. Since "radon rock" is not required in Idaho, these homes are built on a finer aggregate referred to as select fill. In general select fill is an unwashed pea gravel.

ACKNOWLEDGMENTS

Many people have been involved in this study throughout the past year. We would like to thank the following organizations and people: The EPA, BPA and the State of Pennsylvania for supplying monitoring equipment to this project. The EPA for providing assistance in calibration of the continuous radon monitors supplied to this study. RadElec, and particularly Paul Kotrappa for supplying equipment and technical assistance. Battelle, particularly Harley Freeman for aiding in the collection and analysis of supporting information. Our builders for working with us. And last, but definitely not least, our homeowners for all their patience throughout the building and monitoring process.

MATERIALS AND METHODS

All of the houses in the study were studied at specific phases of their construction in order to collect information that may facilitate an understanding of the way passive stacks work. A number of factors were used to select a group of study houses that would represent the most common residential construction. Following are summaries of the data collection processes at the different phases of the project.

<u>Selection Phase</u>

1. Terrain. The terrain at each site was characterized as: flat, moderate - having mild slopes, usually allowing for a daylight basement, or severe - steep slopes, often with one side of the house requiring major excavation.

2. Wind shielding. Description of any wind shielding on the site. Most of the building sites in the study were completely cleared prior to construction. However, in a few cases, stands of trees, or steep slopes close to the house could contribute to wind shielding.

3. Soil Radon Level. These measurements were made utilizing a calibrated Pylon AB-5 continuous monitor with a flow through scintillation cell. A sampling probe was driven into the soil to the approximate depth of the footings. The sampling depth was normally approximately .5 meters. Thirty second "sniffing" samples were taken until the readings stabilized. Two to three readings were taken at each site. An effort was made to take these measurements from the area within the footings or proposed footing area.

4. Photographic Documentation. Photographs were taken of the sites, and houses throughout this study. The primary purpose of photographs in this study was to document conditions under the slabs of the study houses. While we did not endeavor to take pictures of each house at each stage of the process, photographs were taken to record unusual construction details and to document the locations of various sub slab features such as footings and plumbing.

5. Soil Type. On site inspection was made of the soil type(s) at each site. The study called for visual inspection and description of the soil type(s). Additionally, soil samples were collected from each site. Battelle Northwest Labs is presently doing sieve analysis on samples from many of the sites.

6. Soil Permeability. Soil permeability on the site is thought to have a great impact on the movement of radon into a structure built on the site. Each study house was given a general soil permeability designation of low, medium or high. These designations were derived from a number of different sources. These included: 1. An LBL type permeameter was used to measure the permeability in one or more test holes within the footing area on each site. 2. Physical examination of the soil at each site. and 3. Information from the Spokane and Kootenai County Soil Conservation Service maps of the sites. Additionally, Battelle Northwest Labs is working on a model that would produce permeability data from the size analyses of the soils collected from the sites.

Note: It was observed that the results from the LBL style permeameter and probes varied substantially with very minor variations in the placement or adjustment of the probes. The results gathered with this device were not found to be reproducible.

7. Geology. The geologic characteristics of the site were considered, both in the literature (USGS regional maps) and in on site evaluations.

8. Housing Type.

Table 1. House breakdown by Style and Soil Permeability

House Type	Permeability			Total
	Low	Medium	High	
Basement	2	3	6	10
Daylight Basement	6	3	3	12
Slab on Grade			14	14
Other (a)	1	3	2	6

(a) Other constitutes a mix of California Split and Split Level

Total: 42 Houses

Note: Over the course of the project, 5 of these houses were removed from the study due to design or building problems.

Construction Phase

During the construction of the house, observations were made at a number of critical points in the process. It was found that in order to insure that the study houses were constructed according to the code, it was necessary to inspect them frequently throughout the building process. Most of the houses were inspected during the following stages:

1. When the footings were in place, prior to the stack placement. In most cases, this is when the majority of the preliminary site measurements were made.

2. When the stack was positioned in the gravel. This allowed for modification of the stack placement if the positioning was inappropriate and did not meet the code requirements. At this point, the plumbing of gas, water lines, etc. and the placement of any interior footings could be documented. Prior knowledge of utility line placement prevented us from drilling into any of them during later stages in the study. Footing placements were documented

to facilitate interpretation of pressure field extension tests under the slab at a later date. This examination also permitted observation of the material placed under the slab.

3. Following the slab pour. At this point , it was possible to examine the detail of the floor wall perimeter joint. Additionally, the condition of the concrete was evaluated to observe the progression of cracking as it occurred. At this point any sealing that was performed was documented.

Post Construction Phase

Following the completion of the slab and any sealing performed by the builder, the Investigator began evaluation of the sub slab environment and the stack/gravel connection. In the majority of houses, a pressure field extension test was performed. In some houses tests were run before and after additional sealing performed by the Investigator. Following is a description of the standard pressure field extension testing:

Sub slab communications test were run on most of the houses in the study group. A 1-3/4 inch diameter hole was cut in the three inch passive stack between the shut-off valve and the floor. This hole was tapped with a standard 1-1/2 inch taper pipe tap, producing 11-1/2 threads per inch.

A special test instrument was developed for measuring sub slab air flow under a variety of conditions, as well as the static pressure associated with each measured air flow. A pitot tube was inserted into the center of a piece of 1-1/2 inch schedule 80 PVC pipe some 10 pipe diameters downstream from the end which is screwed into the passive stack. At the opposite end of the PVC pipe, a tight closing air valve was installed, along with a connection machined to fit tightly onto a vacuum cleaner hose.

A second hole, 7/16 in diameter, was drilled in the passive stack near the floor. It was tapped to receive a 1/4 inch pipe plug. A standard 1/4 inch pipe plug was drilled with a 1/4 diameter bit and a 12 inch length of 1/4 inch O. D. rubber tubing was inserted in the hole. The pipe plug with the tubing installed was screwed into the passive stack as the source of static pressure in the base of the stack.

A series of 1/4 inch holes were drilled at a distance of 3 feet and 7 feet from the stack and around the perimeter of the basement, or the slab on grade in homes with no basement. The number of holes drilled was dependent upon the number of footings or thickened slabs, the configuration of the basement, the location of cracks or other discontinuities in the basement floor and, in some cases, the type of backfill material used. As few as three and as many as eight holes were drilled.

The Pressure Field Extension tests proceeded as follows:

1. The stack valve was closed and the air valve in the 1-1/2 inch diameter test pipe was closed. Using a electronic digital micromonometer, the static pressure in the base of the stack and in each of the test holes was read.

2. With the stack valve closed, a vacuum cleaner was connected to the test pipe. Using a combination of a variable voltage speed controller and the air valve in the test pipe, the air flow in the test pipe was throttled down until the static pressure in the base of the stack read 0.10 inches w.c. The air flow required to produce this static pressure was read from the velocity pressure at the pitot tube installed in the 1-1/2 diameter pipes, and recorded. Communication with the perimeter holes was determined by reading the negative static pressure in all of the perimeter holes.

3. The above tests were normally repeated for static pressures of 0.20, 0.30, 0.40, 0.50, and when the available pressures were high enough, (within the capabilities of the vacuum cleaner) 1.00 and 2.00 inches water column.

On occasion, when there were unusually large cracks in a floor, or when a large area of floor (say, 12 by

30 inches) was left unpoured for installation of a shower drain, the above tests were run with the discontinuities unsealed and then again after they were sealed, in order to learn more about the effect that these discontinuities would have in the operation of a passive stack.

In a few homes, tests were run with the stack open, after the closed stack tests were completed. Some of the test homes had unusually long passive stacks installed, or stacks with a large number of elbows or other fittings. The purpose of these tests was to attempt to quantify the added resistance of a long passive stack.

When the testing phase is completed in these houses, the pressure field extension test data should be useful in evaluating the effectiveness of the passive stack performance under varying sub slab conditions.

Testing Phase

Following completion and occupation of the houses, two series of radon tests were planned in each house. These test series were to be performed during one summer and one winter period. Each series would consist of four tests done for two week periods with the passive stack alternately open and closed.

Fairly early in the progress of the study, it became clear that the majority of the houses would not be completed in time for the test dates that were originally planned. Presently, the summer test rounds are scheduled to start during the second half of July 1994. Any houses still under construction will enter this summer round as they become available. The winter test round of all the study houses will begin in the late fall of 1994.

Testing will be done utilizing E-perm detectors on the lowest floor of each house. Additionally, a subset of the houses will have continuous monitoring utilizing Pylon AB-5's with Passive Radon Monitors or LBL continuous monitors that have been supplied to the project by the Department of Health (through cooperation with the EPA) and by the Bonneville Power Administration. Each of these monitors was calibrated at the EPA's Las Vegas facility by personnel from the EPA and Faytek Incorporated.

Through an add on program with BPA, approximately 15 of the test houses will have additional information collected including temperatures in the house, outside and in the stack, wind speed over the stack, and various pressure measurements (usually outside vs. inside).

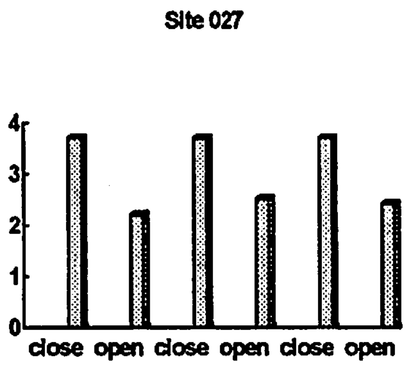
Finally, a subset of four houses will have additional data collection performed in conjunction with Battelle Pacific Northwest Laboratories. This data will include soil testing of material from the site, as well as additional temperature and pressure measurements within the house and passive stack system.

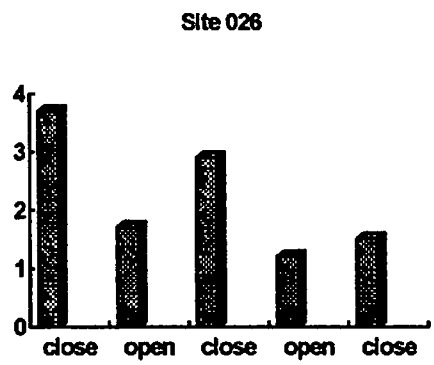
Although the majority of testing has not been performed at this time, some of the houses were completed and occupied in time for testing to be done during the early months of 1994. Most of these houses were in the group of study houses located in Post Falls, Idaho. While these results are preliminary, there are a number of interesting findings that can be reported at this point.

During the early months of occupation of a house, it is very important to check with the occupants as to any unusual occurrences during each test phase. Sometimes non standard events were obvious. The Investigator now possesses an interesting assortment of painted and textured detectors. Other times, occupants reported major modifications that were made during the testing period that would invalidate any effort to compare results from one round with the past or next rounds.

Due to these conditions, a very small sampling of the houses have test rounds that were performed under stabilized conditions. While the sample is small, it appears that in at least some of the houses, under the conditions tested so far, the passive stacks installed in the houses are having a significant effect on the radon levels in the houses. Because the radon levels measured in all of the houses tested so far are relatively low (averaging under 4.0 picoCuries/Liter in the houses tested) houses that had stable occupancy were studied for a longer period than the four test rounds originally planned, to assure that the variations observed were in fact due to the operation of the radon stacks, and not due to random variations in the occupant behavior or uncontrollable conditions such as weather.

Below are two examples of houses where the variations in radon levels under alternating stack conditions appear to be significant. Radon levels are graphed in picoCuries/Liter, and the stack condition (opened or closed) is noted on each measurement.





While lower radon levels under open stack conditions were observed in quite a few of the early test houses, in many of the cases the fluctuations were either so small that they are not conclusive, or the number of test rounds to date is small enough that statements on performance would be premature.

It is interesting to note, that these houses in the first round of testing were in a subset of houses where the material under the slab is a very tight and compactable unwashed pea gravel rather than the coarse "radon rock" of the Spokane houses. As a preliminary observation, this suggests that radon level reduction through the use of a passive stack may not require particularly good communication under the slab. In fact, the pressure field extension tests in the Post Falls houses indicated very poor pressure field extension in the sub slab environment.

Future testing may provide information as to how various types of material under the slab effect the movement of radon in the sub slab environment, particularly under the extremely small pressures and air flows found in passive stack systems.

Observations and Discussion

Through the course of this study, sometimes smooth and sometimes torturous, the Investigator has had many opportunities to make observations on the design and implementation of the Washington State Radon Resistive Construction Standards. The Investigators have spent a tremendous amount of time talking with builders, building code officials and homeowners in an effort to meet the seemingly straight forward goal of the Passive Stack Study; to determine if passive stacks, as they are being installed in the Spokane area, are effective in reducing radon levels. This has lead to the collection of information beyond the scope of the original study.

Although the phase of this study that will demonstrate the effectiveness of the passive stacks installed in the Spokane area is just starting, the preliminary information on the passive stack operation is encouraging. Speculating at this point that passive stacks can be effective in reducing radon levels, it will be important to future code designers to maximize their effectiveness in a manner that is acceptable to the effected parties. Homeowners' concerns are cost, appearance and effectiveness. Builders' concerns are cost and ease of installation. Building officials want a code that is easy to verify and enforce.

With this in mind, the Investigators have compiled some of the observations pertaining to the present handling of radon in the Spokane area, that have surfaced during this study. Hopefully, these observations will be of use to officials formulating the future codes or radon policies to be implemented either locally or nationally.

1. In Spokane County, the radon prescriptive requirements specified in WAC 51-13-501, 502, 503 are considered by most builders to be too expensive, too time consuming and bad building practice.

Our initial contacts with over one hundred builders in the Spokane area indicated that builders were not willing to build houses that met the building code's prescriptive path for radon resistant construction. The various reasons cited for this included: the cost of "radon rock", the difficulty in moving "radon rock", problems with pouring and finishing a good slab on a membrane, and the unwillingness of concrete companies to warranty concrete poured on a membrane.

2. The contractor found no houses in Spokane County that comply with the radon code's prescriptive requirements.

Because of the problems listed in item 1, and other requirements like the sealing, it is very rare that a builder will attempt to follow the prescriptive code for installation of a passive stack system. During the study, to date, the contractor has not dealt with any builders in Spokane County who would provide evidence of any houses that have met all the prescriptive path requirements.

3. Very few builders in Spokane County even attempt to install passive stacks.

It is very rare that a builder in Spokane County will attempt to install a passive stack. In the occasional house where a passive system was installed, the investigator found that the prescriptive path was not followed. We were unable to locate any builder that would pour concrete on a membrane in residential construction.

4. Aggregate companies do not like selling "radon rock"

"Radon rock" is a local trade term for a coarse aggregate similar to WSDOT grade #5 or AASHTO Grading No. 67. It is a limited commodity. Aggregate companies would prefer to supply another material for use under the slab. The present material being supplied is of more value as a concrete aggregate. In many areas in the state, and also many areas of the country, the material specified in the Washington State Code is rare and would add a significant cost to house construction. There is a great deal of interest in determining if it is necessary to have such a coarse grained aggregate under the slab.

An additional concern by the concrete suppliers is that an uncompacted coarse aggregate may promote cracking in the slab. While this determination was not within the scope of this study, it was observed that the slabs poured on a coarse substrate are cracking more than those poured on a finer and more compacted material. While the reason for this was not determined, it is worth noting that the integrity of the slab is very important to the radon entry into houses. It may be important to study the trade off between good communication in the event that a house requires active mitigation, and construction that is more radon resistive.

5. As of the time of this study, most builders in Spokane County contract with a radon mitigation firm to install an "alternate" active system.

The building department personnel, builders, and radon mitigation contractors in Spokane were contacted during the course of this study. All of them indicated that most of the new residential construction in Spokane County is being done with "alternate" active systems. Some estimates were as high as 96% of the homes. The most commonly described active system consists of a loop of 4 inch flexible slotted drain tube, laid on native soil, hard piped through the roof with a permanently wired radon fan.

While this situation does tend to assure that most new houses will initially have acceptably low radon levels, it does pose some questions. Even in the Spokane area where most studies indicate that more than half of the houses without radon systems have radon levels in excess of 4.0 picoCuries/Liter, a large number of houses are now being built with active systems that would not have needed any system at all. These homeowners are paying for unnecessary active system installations as well as long term energy costs. Additionally, in the future, if these systems fail, the houses may have higher radon levels than if nothing was done at all, since the standard method for active system installation is not designed to be radon resistive.

6. The Spokane County Building Department does not enforce the radon resistive construction standards.

The contractor was told by Building Department officials that if homes are built without the sub slab barrier, the builder would be forced to tear out the slab and install the barrier. At a meeting at the Spokane County Building Department, a Building Department official informed the investigator that the inspectors do enforce the code and that the plastic is always under the slab. This was not the case in the houses that we observed during our solicitation of builders to take part in this study.

On site, builders as well as some of the building code inspectors joke about the same roll of plastic that has been in the truck since July 1, 1991. We were informed of and observed numerous ways that builders pretend to comply with this requirement in the event that an inspector does inquire about the membrane.

During the course of the study we observed multiple examples of systems that were either approved or "red tagged" without a proper inspection. Two examples follow:

While giving a tour of one of the study houses, the Investigator observed a Spokane County Building Department inspector "red tag" the radon system on one of the study houses across the street. This was done without any actual inspection of the system. When the system installer was informed of this, he contacted the building department, and the "red tag" was removed and replaced by an approval. If the inspector had looked in the foundation at any point during this process, he would have seen that the radon system had been displaced by the plumber and was not properly installed at the time of the inspection.

When the contractor went to initiate the radon testing program in one of the study houses, the homeowner mentioned that the radon system was different than she had expected. We found a short stack in the family room, extending out of the slab approximately 18 inches. A Building Department approval tag was taped to it. Unfortunately the portion of the stack that would take any radon up through the roof was missing. (We corrected this omission.)

If there is a radon code, then education of the enforcement officials is very important to make the code effective.

7. To do this study, it was necessary to have a modification of the prescriptive path. No local builder would agree to pour concrete directly on a vapor barrier.

Codes that are not universally liked are sometimes enforced for the well-being of the population. However, in this case the requirement in the code for a membrane seems to have effectively undermined the intention of the code. As long as the membrane is required and active alternate systems without the membrane are accepted, most systems that are installed will be active systems.

8. In general very little sealing of either the floor wall perimeter joint or any penetrations in the slab is being performed by the builders.

The houses in the study where the builder made the greatest effort to seal slab penetrations were in Post Falls, Idaho, where the sealing is not required, but the builder felt it was good practice. The Post Falls houses were fairly small houses where the sealing could be accomplished in a short time. Even these houses did not have the floor wall perimeter joint caulked. In the Spokane houses we rarely encountered any sealing of the slab performed by the builder.

9. The preferred design for floor wall perimeter joints that is presently being supplied to builders is very difficult to seal.

There can be conflicts between different codes. In this case, the conflict is between the Washington State Energy Code (WAC Chapter 51-11) and the Washington State Ventilation and Indoor Air Quality Code (WAC Chapter 51-13). Interestingly both codes went into effect on the same day, July 1, 1991 and there was substantial overlap in authors.

The information that builders in the study received from the Washington State Energy Office suggested that the floor wall perimeter joint be addressed with a thermal break next to the footing, such as a foam board, a 2x2 wood strip on top of the foam board and the interior concrete poured up against the 2x2. While this should provide a good thermal break, it also leaves an opening between the foam board and the footing that is very difficult to seal. Sometimes the gap along this joint was found to exceed 1/2 inch. The contractor sealed these joints in a number of the houses. It was found to be very expensive both in man hours and caulk. One typical house required approximately 8 man hours and 17 tubes of a polyurethane caulk just to seal the floor wall perimeter joint. Even with this attention to detail, the joint sealing may not age well due to the varying expansion characteristics of the three different materials involved in the joint and the large crack spans.

10. Penetrations in the slab that are much larger than the cracks on the perimeter or the standard pipe penetrations are being ignored on a routine basis.

In one house, the Contractor sealed a total of approximately 7.5 square feet of openings in the slab, not including the floor wall perimeter joint. In general, neither the builders or the building inspectors seem to realize the importance of the slab as an effective barrier to radon entry. Tub and shower knockouts can become very large by the time the plumber is finished with his work.

11. The conventional wisdom on the material that should be placed under a slab may be biased by industry experience in post construction mitigation.

The houses in the study located in Post Falls, Idaho have slabs poured on a material that is much more compactible than the "radon rock" used in the Spokane houses. As a result, the communication under the slab in the Post Falls houses is substantially lower than in most of the Spokane houses. The Contractor expected that a fair number of the Post Falls houses would have radon levels in excess of 4.0 pCi/L. This projection was based on soil characteristics at the site including high radon soil gas levels and high permeability of the soils. Additionally, the subdivision where the houses are located is surrounded by a residential area where existing houses frequently have radon levels greater than 20.0 pCi/L.

At the present time (with preliminary winter testing done in the Post Falls houses), none of the Post Falls houses are expected to have radon levels exceeding 4.0 pCi/L on a year round average. One possible reason is that the material being placed under the slab has significantly less permeability than the native soil and is acting as a barrier itself. It may be doing this in several ways. First, the finer grained, compactible material seems to yield a better slab with visibly less cracking than slabs poured on "radon rock". Second, a zone of lower permeability material, relative to native soil, directly beneath the slab, reduces calculated radon entry rates. Conversely, having a layer of ultra high permeability material like "radon rock" directly beneath the slab enhances radon entry at any point in the slab.

While communication under the slab in these houses is not nearly as good as in "radon rock", it was still possible to extend a pressure field under these houses with pressures that would be normal for a standard mitigation system. Possibly the perceived benefits of a coarse aggregate under the slab have been exaggerated due to a body of knowledge in the mitigation industry that has most of its experience in fixing existing buildings rather than designing radon resistive buildings.

12. It is interesting that in Spokane County, WA, with radon prescriptive requirements specifying passive stack installations (since July 1, 1991), almost no passive stacks are installed. Adjacent Kootenai County, ID shares; over 40 miles of common border along the state line, similar geology, drinking water from the same aquifer, and high potential for elevated indoor radon levels, with its neighbor to the west. However, in Kootenai County and the State of Idaho, there are no radon resistive construction standards. Yet in Kootenai County, there is a moderate and increasing percentage of new construction with a variety of passive stack designs included. There are also more other radon resistant features built in (such as sealing and plastic tub knockout liners). The only motivation for these builders is marketing.

Perhaps legislated codes are not the only means towards more radon resistive construction practices.