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PASSIVE RADON REDUCTION TECHNIQUES FOR EXISTING AND NEW STRUCTURES

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ABSTRACT

Radon reduction field demonstrations to date have primarily emphasized depressurization of subfloor and foundation areas using electrically powered exhaust fans in combination with various configurations of radon collection piping and discharge stacks. This approach to low cost radon reduction has generally proven to be a reliable technique. However, field experience during the 1970's and early 1980's indicates that passive radon reduction techniques can often achieve desired results while eliminating maintenance and operating costs related to the active radon reduction system techniques.

This paper discusses the general concepts related to passive radon reduction techniques, and structure characteristics that lend themselves to passive reduction are identified. Data, including generic passive radon reduction system designs and related field project experience, are presented.

It is concluded that passive radon reduction techniques can play an important role in the national radon problem. The need for expanding the related field demonstration research data base is emphasized. Finally, the author concludes that essentially all elevated radon related to new construction can be addressed through cost effective, passive radon reduction designs.

GENERAL CONCEPTS

THE ROLE OF SEALANTS

Passive radon reduction techniques that are designed to depressurize substructure areas rely on very slight negative pressures and discharge stack flow rates as compared to fan activated systems. To assure the maximum possible depressurization effect of the passive system, sealing of all apparent communication routes between the substructure and inhabited area should be accomplished. Sealing should include floor slab and foundation wall joints, cracks and utility penetrations, along with open drain sumps and bare soil areas within the habitable portion of the structure. In some cases, where basement foundation walls are constructed with concrete masonry units, sealing of the entire interior wall surface and open block cores at the top edge of the foundation wall may be required.

Sealant materials include various caulkings, closed-cell urethane foam, and certain paints and membrane sheets which have proven to be effective radon barriers. There are no unique sealant material requirements related to passive radon reduction since all sealant applications are passive, including those used in conjunction with activated systems.

The effectiveness of sealants as a sole radon reduction technique is highly variable, depending on site specific structural characteristics and the extent of the sealant effort. Generally, an indoor radon concentration reduction ranging from 5% to 30% can be expected; thus, sealants have a very limited use as the sole radon reduction technique.

The concepts of sealant application used in conjunction with other passive radon reduction techniques are discussed below.

Reduction of Radon Influx Rate

By sealing major radon entry routes, the rate at which radon enters the habitable structure is reduced. This in turn will reduce the indoor radon equilibrium concentration by varying degrees, with the net result being a lower radon reduction factor required of the passive depressurization system.

Decoupling of Substructure Pressure Fields

The most important role of sealants related to use in conjunction with other passive radon reduction techniques is to decouple the substructure pressure fields from the habitable portions of the structure.

The habitable structure areas typically have a negative pressure compared to substructure areas. This is a result of using various appliances and the indoor stack effect (heat convection) related to the heating seasons. The goal of decoupling through use of sealants is to reduce or eliminate the differential pressure effect between the substructure and habitable areas. If the decoupling sealant is thorough and effective, changes in the habitable area pressures will not have a significant effect on the performance of the substructure depressurization or venting system.

DILUTION VENTILATION

It can reasonably be stated that the most expedient radon reduction technique available is dilution ventilation. If enough ambient air is introduced into the structure areas, essentially all concentrated radon can be diluted to levels resembling those contained in the ambient air. In the early stages of radon reduction efforts, fan activated dilution systems were demonstrated and used very successfully (1, 2).

Passive radon dilution ventilation has also proved to be an effective technique in reducing the radon related risk in habitable structures. However, the dilution technique is often impractical due to climatic conditions and the related energy/comfort penalty. Additionally, the effectiveness of passive dilution ventilation is related to ambient wind speeds and the stack effect (heat convection) associated to the house; thus, the overall reduction of indoor radon concentrations is unpredictable.

The concepts of dilution ventilation are discussed below.

Habitable Area

This technique consists of opening doors and windows related to the lowest floor level of the structure. Slight breezes will flush ambient air through the house, or the negative indoor pressure caused by heat convection will draw ambient air into the structure. It is important to note that ventilation of the lowest floor level of the house (normally the basement) is recommended. If the second level is ventilated, it is possible that strong winds can pass rapidly through the house causing a venturi effect, or negative pressure, on the bottom level which will result in increasing the indoor radon concentration.

Crawlspace Substructure

This concept is based on allowing ambient air to pass through the crawlspace to dilute and flush the concentrated radon from the crawlspace area. Typical foundation ventilation louvers are used to accommodate ambient air entry into and through the crawlspace. It is important that ventilation louvers be located on all foundation walls, and retrofitting new louvers may be required.

Additionally, louver closure mechanisms should be removed to eliminate the possibility of closing the louvers and negating the crawlspace dilution ventilation system. The concept also includes sealing around all floor penetrations and installing subfloor insulation to reduce the energy penalty related to added air flow through the crawlspace area. Figure 1 shows the details of the crawlspace ventilation concept. As shown in the figure, it is very important to install an appropriate air baffle between subfloor insulation and the foundation ventilation louver; this will eliminate the possibility of sagging insulation obstructing the ventilator.

WIND ASSISTED CONVECTION EXHAUST STACK

The primary component of all passive substructure radon collection systems is the exhaust stack. The concept of the exhaust stack includes maintaining a higher temperature on the stack than the substructure gas temperature to create a convection stack effect. Additionally, the stack is topped with a turbine ventilator which increases the draw on the stack when the wind is blowing.

To maintain the differential temperature between the exhaust and the substructure gas, the stack must be installed through the structure interior and extend above the roof. Additionally, in cases where the substructure collection system includes pipe diameters of less than six inches, an appropriate reducer connection to the stack is used to increase the stack diameter to six inches where practical. A six-inch diameter stack is recommended to increase the heated surface area which enhances the convection effect of the stack. Figure 2 shows a typical design of a passive wind assisted convection stack.

Another convection exhaust stack concept uses existing combustion appliance flues or chimneys, and the substructure radon collection system is simply connected to the existing stack. Most building codes will accommodate this concept if the collection system connection is made with metal pipe, extending a minimum of three feet out from the existing flue or chimney.

The substructure radon gas collection system concepts that are typically used in conjunction with the convection exhaust stack are discussed below.

Subslab Depressurization

This concept includes essentially all techniques currently used in conjunction with fan activated systems. The techniques are generally categorized as interior drain tile suction, drain sump suction, and aggregate/depression suction. Figure 2 also reflects the typical subslab depressurization system.

Crawlspace Collection

This concept is based on intercepting and collecting the radon gas prior to entry through the subfloor, and providing gas collection piping within the area of intercept. The most common application of this technique is referred to as a "subliner ventilation system." Figure 3 shows the concept of this system. As shown, a radon barrier membrane is sealed to the foundation walls, and a collector pipe is placed beneath the membrane. The collector pipe is then connected to an appropriate exhaust stack.

A different application of the radon gas interception and collection concept consists of sealing the entire subfloor area with a closed-cell urethane (including the rim joist and foundation ventilation louvers). This converts the entire crawlspace area into a radon collector while intercepting radon entry directly beneath the subfloor. This system is completed by simply installing a wind assisted convection exhaust stack through the roof and extending it beneath the subfloor, and then sealing the stack/urethane transition.

Plenum Wall Collection

This concept is based on intercepting and collecting the radon gas within a perimeter wall plenum, and use is limited to those cases where basement foundation walls are clearly primary radon contributors. The technique includes retrofitting a metal stud wall around the interior perimeter of the foundation wall with a perforated collection pipe located inside the bottom of the wall. Figure 4 shows the details of this system. As shown, the top and bottom of the plenum wall are sealed in channels, and the exposed wall surfaces are covered with a polyethylene sheet and finished with drywall to assure the plenum is essentially sealed. Radon is collected in the perforated pipe and the collector pipe is connected to an exhaust stack.

PRESSURE RELIEF

Radon reduction concepts previously discussed may simply act as pressure relief systems under certain temperature and wind conditions. However, the pure pressure relief concept is based on simply making an opening in a decoupled substructure to provide a path of least resistance and accommodate radon diffusion through the opening. A familiar technique is to decouple the interior surfaces of a concrete block basement foundation wall, drill holes into the cores of the top block course around the exterior perimeter, and insert nylon or plastic louvered vent tubes into the holes. This technique is not widely used, and further field demonstration should be pursued.

CONSIDERATION OF STRUCTURE CHARACTERISTICS

Considering the relatively low pressures and gas flow-rates produced by the passive exhaust stack, some structure characteristics are not conducive to passive radon reduction techniques. The primary structure characteristics that should be considered as related to passive techniques are discussed below in the order of significance.

AVERAGE INDOOR RADON CONCENTRATION

Although it has been demonstrated that indoor radon concentrations averaging approximately 1,800 pCi/l can be reduced to acceptable levels using retrofit passive techniques, the related costs are unacceptable to most property owners (3).

Experience to date indicates that passive reduction techniques can generally achieve an 80 percent reduction of indoor radon concentrations. This reduction can only be expected in buildings with structural components that are favorable to passive reduction techniques. In short, passive measures should be considered only for structures with favorable component characteristics and average indoor radon concentrations below 20 pCi/l.

SUBSTRUCTURE STRATIFICATION

The basic type of substructure has a direct relationship to the expected cost effectiveness of passive radon reduction measures. The significance of the various basic substructure stratifications is discussed below.

Crawlspace

Buildings with full crawlspace substructures are probably the most conducive to passive measures. In cases where the crawlspace foundation wall extends above exterior grade, louvered dilution ventilation combining subfloor insulation and sealing is appropriate. However, in cases where the foundation wall is at or below exterior grade, or when dealing with a severe winter climate, the subliner ventilation/exhaust stack technique is appropriate. These considerations apply to both existing (retrofit) and new structures.

Buildings with crawlspace combined with other substructure types are generally less desirable for passive radon reduction measures. Such buildings should be considered only if visual inspection indicates reasonable assurance that the crawlspace can be completely decoupled (using sealant techniques) from the other substructure components. Additionally, diagnostics should conclude that the crawlspace portion of the building represents a significant radon source prior to commencing reduction efforts.

Waterlines and furnace ducting located within the crawlspace are also of concern. The decoupling efforts associated with dilution ventilation must include insulation of waterlines and furnace ducting, along with sealing of all duct seams and joints.

Basement

Buildings with unfinished full basements are generally conducive to passive radon reduction methods. The primary considerations related to such buildings are the design and structural conditions of the floor and perimeter foundation walls. If significant structural cracking exists, or if excessive expansion and construction joints are present, the effort related to decoupling of the substructure can be excessive, and passive measures will not be cost effective.

Buildings with glue-down floor coverings or furred and covered foundation walls should generally be avoided. Such buildings do not accommodate cost effective decoupling of the substructure, and the success of passive reduction methods would be questionable due to unknown floor and foundation conditions.

Buildings where basement is combined with other substructure types should also generally be avoided. Sound judgment must be applied regarding the ability to decouple the different substructures. If decoupling is judged to be achievable, each substructure type can be treated passively with appropriate individual techniques. However, in most cases costs related to passive treatment of combination substructure types are excessive and such efforts should not normally be considered.

Slab-on-Grade

Buildings with full slab-on-grade concrete floors are not generally conducive to retrofit passive radon reduction techniques. This is the result of such buildings being completely finished with numerous partition walls and floor coverings throughout. However, in cases where structural information concluding that the floor slab is a monolithic (continuous pour with thickened edge footing) design is obtainable, passive subslab depressurization techniques are appropriate as discussed later.

Buildings where slab-on-grade is combined with other substructure types should generally be avoided as previously related to other substructure type combinations.

FLOOR SLAB AND FOUNDATION/FOOTING DESIGN

In addition to the structural condition of the existing floor slab and foundation, the basic designs of these components play an important role in passive radon reduction considerations for both existing and new buildings.

In all cases, the design must include a porous subslab fill material which is free from clay and extremely fine soil particles; washed, 3/4-inch stone is ideal. It is important to gain reasonable assurance that the subslab fill will allow radon gas to freely pass through the material, and if this assurance cannot be made, passive radon reduction considerations should be abandoned.

The basic slab and foundation/footing design is also an important consideration. The basic designs that are commonly used and their considerations are discussed below.

Monolithic

This design is a continuous pour concrete slab with thickened edges. The thickened edges typically include steel reinforcement rod, and they are designed as the structural bearing footing. This design eliminates the floor/wall transition joint which is one of the most significant radon entry routes in basement and slab-on-grade substructure types. In the case of basement substructures, a neoprene waterstop is included around the perimeter during pouring; this accommodates a water/gas seal at the cold joint related to the foundation wall that is constructed after the monolithic slab.

The monolithic slab/footing design is normally the most desirable for passive radon reduction measures. This observation is appropriate for both existing (retrofit) and new construction.

Slab over Footing or Stemwall

This design consists of placing a bearing footing (including a stemwall for certain slab-on-grade substructures), and then placing the floor slab perimeter to the point of the planned foundation or perimeter wall exterior; this results in capping over the top of the footing or stemwall with the floor slab. This design also eliminates the floor/ wall transition joint. The primary use of this design is in areas where local building codes require a bearing footing depth that is significantly below the planned concrete floor level, thus rendering the monolithic design inappropriate.

This design is also very conducive to passive radon reduction methods since the floor/wall joint radon entry route is eliminated. This observation is also appropriate for both existing and new construction.

Floating Slab

This design consists of placing the bearing footing and stem or foundation wall prior to placing the floor slab. The basement foundation or slab-on-grade perimeter walls are placed directly on top of the footing or stemwall. The floor slab perimeter is then abutted to the stem or foundation wall, an expansion joint material or "french drain" opening generally separates the wall/floor transition. This design accommodates a separation of the floor slab from the perimeter wall, and it allows vertical movement of the slab without affecting the bearing structure of the building. The design is commonly used throughout the country; however, use is primarily based on habit as opposed to actual engineering needs. Many areas are not prone to soil movement as a result of temperature change or soil moisture conditions. Even in areas with adverse soil conditions, the monolithic or slab over footing/stemwall designs have proved to be appropriate.

This "floating" slab design is the least desirable for passive radon reduction techniques; the finished state of interior perimeter walls reduces the ability to decouple the substructure due to the floor/ wall transition joint. However in the case of unfinished basement substructures, the transition joint can be sealed, and the primary consideration regarding passive radon reduction becomes the cost of joint sealing compared to no joint sealing with a fan activated system.

Basement Foundation Wall Materials

Basement foundation wall material types commonly used vary by geographical area. The material types related to passive radon reduction considerations are as follows:

Poured Concrete -- clearly the most conducive to passive systems.

Concrete Block -- not conducive to passive systems unless diagnostics clearly reveal that the walls are not significant radon entry routes.

Field Stone -- moderately conducive to passive systems based on limited experience indicating insignificant radon entry through the walls.

Pressure Treated Wood - conducive to passive systems when properly constructed with waterproof sheet material surrounding outside; longevity of water/gas-proofing can be questionable, and field experience is extremely limited.

Other Sub-Slab Features

Presently, there is not a significant data base regarding the effect that sub-slab air ducts or floor drains have on passive radon reduction systems. It is logical to assume that these features will adversely affect the limited pressure differential provided by the passive exhaust stack. Unless the ducts and floor drain can reasonably be decoupled from the sub-slab fill materials, buildings with these features should be avoided. However, field demonstrations currently in progress may prove that passive radon reduction techniques can be effective in buildings with these features, thus, the current advice of avoiding the buildings may be unnecessary.

FIELD EXPERIENCE

Prior to general recognition of the naturally occurring radon problem in habitable structures during the winter of 1984/1985, considerable indoor radon reduction work had been accomplished in a production mode. This work commenced in 1973 with the Grand Junction Uranium Mill Tailings Remedial Action Program. It continued through contaminated radium site work in Denver, Colorado and Glen Ridge/Montclair/West Orange, New Jersey; the reclaimed phosphate lands in Florida; the Radiation Reduction Program in Canada; and the naturally occurring radon problem in Butte, Montana and Sweden.

Commencing in early 1985, concerted radon reduction efforts were undertaken in the form of both "demonstration" and production work related to the Reading Prong geological area in the eastern United States. This effort has continued to expand, and a significant field demonstration radon reduction data base has been developed. However, fan activated radon reduction techniques have been the primary method used in this data base, and data relative to passive methods are rather limited.

An overview of the various passive radon reduction field projects, for which the author has first-hand knowledge, is presented below.

GRAND JUNCTION URANIUM MILL TAILINGS PROJECT

Commencing in March 1973 and continuing through December 1987, approximately 601 structures underwent remedial action. In essentially all cases the structures were included for remedial action on the basis of elevated annual average indoor radon progeny concentrations. The program remedial action criteria related to indoor radon/radon progeny was 0.01 working level (WL) above normal background, and the normal indoor background was determined to be 0.007 WL; hence, the gross annual average indoor radon progeny criteria was 0.017 WL.

The primary radon reduction method used was source material removal. However, complete source material identification and removal was not achievable in many instances, and further radon reduction was achieved with passive methods as summarized below.

The Sealant Demonstration Program (4)

Through a subcontract with the Colorado State University, a field sealant demonstration was conducted in the Grand Junction area from September 1973 through August 1974. A total of 15 single-family basement type homes, with source material either below the floor slab or contained in the concrete mix of the floor slab and foundation walls were included for demonstration.

The sealant used was a resin base two-part epoxy, and the entire floor slab and interior perimeter foundation wall were generally completely coated with the sealant to the extent possible in a remodel/retrofit situation. There was no attempt made to remove the radon source material related to the demonstration houses.

The pre and post sealant annual average indoor radon progeny concentrations were measured with Radon Progeny Integrated Sampling Units. Results of this demonstration are summarized in Table 1; the measured radon progeny concentrations have been converted to equivalent radon assuming a progeny equilibrium state of 50%.

Costs of the demonstration sealant applications ranged from $1,500.00 to $6,300.00 per house. Considering these costs related to the option of source removal, the sealant technique was deemed appropriate for cases where source material was in the basement foundation walls.

On the basis of the demonstration, 40 additional basement residences underwent floor and foundation sealant. Initial 100-hour post sealant air sampling indicated that indoor radon was successfully reduced to levels below the project criteria (3.4 pCi/l) in all cases. However, long-term annual average sampling revealed that about 40% (22 residences) of the total sealant locations ultimately exceeded the indoor radon criteria. Investigations revealed that structural movement had caused sealant failure in some cases, and in other cases, pressure gradients simply allowed the radon to seek new influx routes in areas where it was not practical to apply sealant.

In summary, it was determined that the epoxy sealant technique is unreliable, and routine use of the technique was abandoned.

Other Passive Radon Reduction Experience

Other passive radon reduction techniques were successfully used in appropriate cases as summarized in Table 2. In most cases, the technique was applied after source removal failed to achieve the desired indoor radon concentration reduction and pre-remedial concentration ranges shown are those remaining just prior to the passive reduction effort.

BUTTE, MONTANA SILVER BOW HOMES PROJECT

In 1981, the Public Housing Authority of Butte, Montana determined that the Silver Bow Homes (a low-income housing project managed by them) had elevated radon concentrations resulting from natural mineralization. The housing consists of 18 two-story buildings with six apartments in each building. The building substructure is a crawlspace with steam heat and water lines located within the crawlspace. The crawlspace of each building is divided into three cells by concrete foundation walls.

The radon reduction technique applied to the 18 buildings was the subliner ventilation system. The entire subfloor area, piping, and ventilation louvers were sealed with spray-on, closed-cell urethane with a minimum 2-inch thickness. Wind assisted convection exhaust stacks were installed through the structure roof and extending into each crawlspace cell. This technique resulted in converting the crawlspaces into radon accumulators with the habitable portion of the structures completely decoupled from the substructure.

The results of this project are summarized in Table 3. The radon concentration range data listed for each building represents the gradient between each of the six apartments contained in the building. Original indoor radon concentrations ranged from 3 to 26 pCi/l and post radon reduction measurements ranged from 0.4 to 2.8 pCi/l (as converted from 160-hour Radon Integrating Progeny Sampling Unit measurements).

It is interesting to note that post remediation radon concentrations within the crawlspace accumulation areas measured up to 450 pCi/l. This condition was not considered significant since forced air ventilation (through access doors) readily reduced the concentrations to acceptable levels on those occasions when maintenance of subfloor utilities was necessary.

In summary, this radon reduction project was very successful. The primary value of the technique used is in areas where winter temperatures are severe and crawlspace dilution is not desirable.

PENNSYLVANIA DISCOVERY HOUSE PROJECT (3)

In the spring of 1985, a passive radon reduction demonstration was conducted at the residence where the initial natural radon problem was discovered in Pennsylvania. The demonstration was funded by the Philadelphia Electric Company, and the intent was to demonstrate that the most severe case of elevated radon could be remediated, thereby assuring that essentially all elevated homes could be dealt with.

The house had several structure characteristics that accommodated excessive radon entry. The concrete block foundation wall had structural cracking and evidence of water seepage, and the basement and on-grade floor slabs were placed directly on bedrock in thicknesses from 1 inch to 3 inches with significant structural cracking evident.

The radon reduction techniques used included excavation of the exterior foundation to accommodate installation of a "radon proof" membrane and footing water drainage system; removal of the basement and on-grade floor slabs and excavating bedrock to a depth of about 8 inches to accommodate placing washed stone subslab fill; installing interior perimeter footing perforated pipe loops in the basement level and in the on-grade level subslab fill; connecting each subslab pipe loop to a separate wind assisted convection exhaust stack; placing a "radon proof" membrane over the subslab fill; and placing new 5-1/2-inch thick floor slab in the basement and on-grade areas.

This passive radon reduction demonstration successfully lowered the indoor radon concentration from about 1,800 pCi/l to 1.4 pCi/l. The initial post-remedial indoor radon measurements were taken over a 13-day period with the house closed and unoccupied. After this initial monitoring, and as the heating season commenced, intermittent elevated indoor radon concentrations to about 30 pCi/l were observed which resulted in placing an activated fan in the on-grade area radon exhaust stack. On an annual average basis this fan may not be needed; however, it has proven to be capable of maintaining indoor radon concentrations that are consistently below the 4 pCi/l criteria.

NORTHERN MARYLAND DEMONSTRATION PROJECT

Commencing in the fall of 1987, the U. S. Environmental Protection Agency (EPA) undertook a radon reduction demonstration project in northern Maryland as part of their continuing efforts to develop reliable low-cost techniques. The primary thrust of this project is to perform research related to passive radon reduction methods and their practical application.

To date, passive radon reduction techniques have been applied to 13 residences. Since the project is currently in progress, related data have not previously been reported, it is of a preliminary nature, and changes in both reduction system designs and long-term post mitigation radon concentration/effectiveness evaluations are likely.

Table 4 summarizes the preliminary data related to the passive demonstration portion of this project. The preliminary data certainly support the important role that decoupling of substructure pressure fields and structure characteristics have in successful passive radon reduction techniques. Structure diagnostics currently in progress indicate that decoupling of block basement foundation walls will be required in most cases, and that subslab fill material with low permeability should be avoided.

In the author's opinion, preliminary data related to this demonstration clearly indicate that passive radon reduction techniques can play a role in our national radon reduction work. However, it is important to continue development of a demonstration data base to better understand the underlying reasons for success and failure.

CAREFREE, ARIZONA NEW RESIDENTIAL CONSTRUCTION PROJECT

In January 1988, a project was undertaken to evaluate open land and indoor radon related to a planned major residential development near Carefree, Arizona. Need for this project was indicated by cursory open land gamma surveys, performed with a portable gamma scintillometer, that revealed surface soil measurements about two times "normal" background (20 μR/hr).

The natural soils in the area are decomposed, granular granite with granite outcroppings on some small hills and granite boulders randomly located on surface areas. The planned structures were slab-on-grade with poured concrete footings and stemwalls, and the slab design included perimeter expansion joints (floating slab). The open land and indoor radon studies, along with related radon reduction design techniques are discussed below. The information presented is previously unreported; and it was produced for a private client.

Open Land Evaluation

The elevated gamma was confirmed to be about two times "normal" background on surface areas as well as at three feet deep (the planned footing depth). Soil samples were collected and analyzed for radium-226, thorium-232, and potassium-40. Analytical results from the soil samples are presented in Table 5. The data indicate that radium-226 concentrations are within the range of "normal" background with results ranging from 0.8 to 4.5 pCi/g. However, the potassium-40 concentrations are from two to four times "normal" background with results ranging from 21.9 to 42.2 pCi/g.

The soil sample data strongly suggest that the open land elevated gamma is the result of abnormal potassium-40 concentrations, and that the radium-226 concentrations in the area are of no undue concern with respect to indoor radon. On the basis of these data, it was decided that a model home would be constructed, using planned design, to accommodate further evaluation of the elevated indoor radon potential.

Model Home Evaluation

A finished model home was evaluated to determine if radon reduction design should be considered for future structures. Tracer gas studies revealed excellent subslab communication within the ABC fill material used. Radon "grab" sampling was performed with the house unoccupied, and with the heating and air conditioning systems both off and operating. The data indicated that elevated indoor radon (to 6.5 pCi/l) was present with the house heating system operating for a 14-hour period, and that elevated radon was not present with the heating system off for a 14-hour period (indoor temperature lower than outdoor). Table 6 presents this radon data.

On the basis of the initial model home evaluation, radon reduction floor slab design changes were made. These changes included poured concrete block-outs beneath the bathtub and shower, caulking utility line penetrations, and eliminating the perimeter expansion joint by pouring the slab over the top of the stemwalls. Additionally, perforated 4-inch, flexible pipe was placed in the subslab fill and capped off at the finished floor level as an added "insurance" policy.

A model home was constructed including the floor slab radon reduction design changes. Radon "grab" sampling was performed under identical conditions and from the same locations as those performed at the initial model home. The subslab depressurization system remained inoperable during the evaluation. The resulting data clearly indicated that indoor radon was reduced to acceptable levels (2.3 pCi/l with structure heated). Table 6 presents the radon data related to this home evaluation.

This residential development is continuing with the radon reduction floor slab design changes. However, the subslab perforated pipe "insurance" has been eliminated.

CONCLUSIONS

Available information clearly indicates that passive radon reduction can play an important role in dealing with the national radon problem. Certain structure characteristics are conducive to passive techniques, and it is important to continue expansion of the field demonstration data base to accommodate appropriate understanding and application of passive measures.

It is the author's opinion that essentially all new construction could be maintained below acceptable indoor radon concentrations through passive reduction designs. The reduction designs primarily consist of quality construction practices with minor related cost increase.

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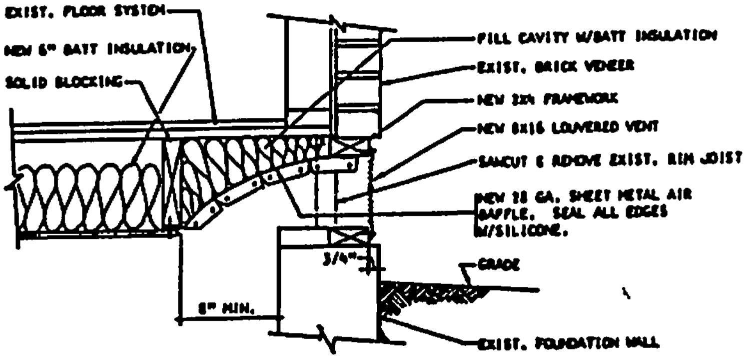

Figure 1. Foundation vent detail

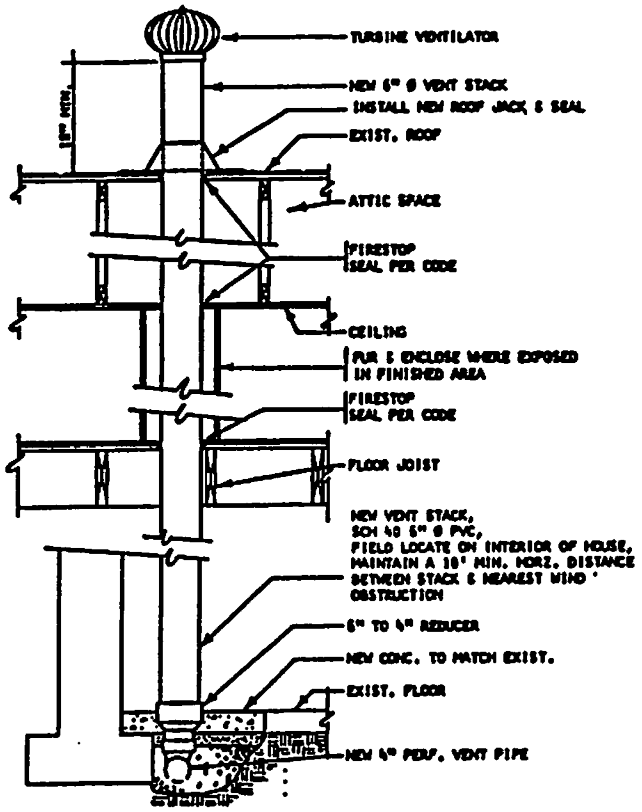

Figure 2. Wind assisted convection stack

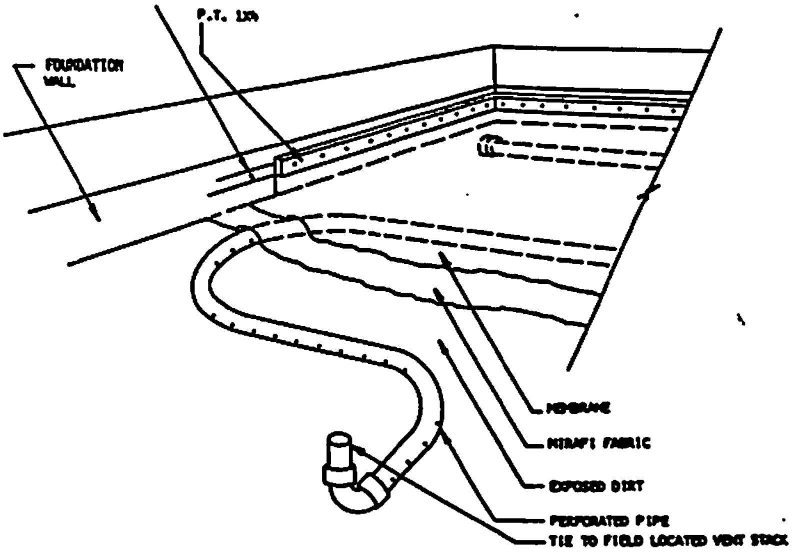

Figure 3. Crawlspace subliner ventilation

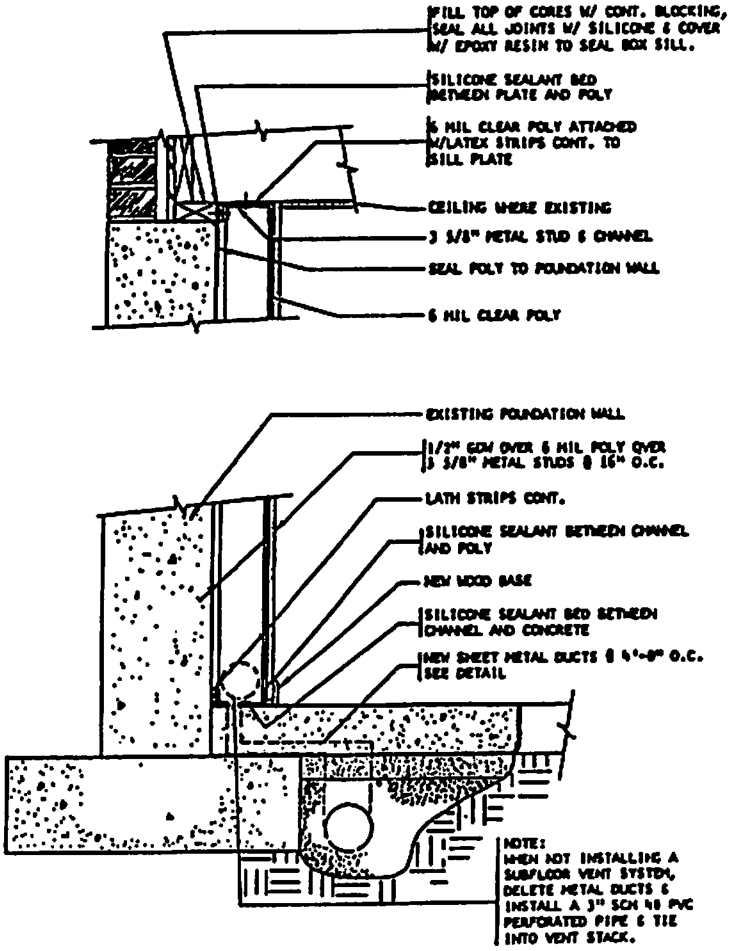

Figure 4. Plenum wall collection system

TABLE 1. SEALANT DEMONSTRATION PROGRAM RESULTS

House I.D.	Source Location			Area(s) Sealed		Radon (pCi/l)	
	Under Slab	In Foundation	In Slab	Floor	Foundation Walls	Pre	Post
1	x			x	x*	10.0	1.0
2		x	x	x	x	14.0	5.8
3	x			x	x*	21.6	0.4
4		x	x	x	x	5.2	2.6
5	x			x	x	5.8	2.6
6		x	x	x	x	8.6	0.6
17†	x			x		6.6	4.2
8		x	x	x	x	18.0	1.0
9		x	x	x	x	5.2	0.4
10		x	x	x	x	4.2	1.6
11			x	x		4.4	1.4
12†		x			x	9.4	10.0
13	x			x		4.8	1.6
14†		x			x	4.2	6.6
15			x	x		6.6	3.0

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* Wall sealed as second work phase when floor sealant alone failed to achieve reduction goal.

† Additional work phase sealing wall or floor that was left unsealed recommended.

TABLE 2. OTHER RADON REDUCTION TECHNIQUE RESULTS

Technique	Number of Structures	Radon Concentration Range (pCi/l)	
		Pre-remedial	Post-remedial
Crawlspace dilution	66	4.8 - 21.0	0.8 - 2.1
Crawlspace subliner vent with retrofitted stack	8	6.3 - 18.1	1.1 - 2.9
Plenum wall with retrofitted stack	10	5.1 - 8.3	1.9 - 3.0
Subslab depressurization with retrofitted stack	83	4.0 - 15.6	1.4 - 2.7

TABLE 3. SILVER BOW HOMES RADON REDUCTION RESULTS*

	Radon Concentration Range (pCi/l)	
Building No.	Pre-remedial	Post-remedial
1	4.9 - 11.6	1.4 - 1.8
2	5.3 - 14.7	0.8 - 2.8
3	6.0 - 13.3	0.9 - 1.5
4	3.8 - 10.4	0.6 - 1.2
5	2.5 - 8.6	0.8 - 1.8
6	2.1 - 7.0	0.4 - 0.9
7	3.5 - 9.6	0.6 - 1.0
8	5.9 - 17.0	1.2 - 2.4
9	4.5 - 16.5	1.1 - 1.8
10	4.0 - 12.1	0.9 - 1.6
11	3.8 - 8.5	0.8 - 1.4
12	5.8 - 16.0	0.9 - 1.8
13	6.0 - 28.5	1.1 - 4.0
14	3.6 - 11.5	0.6 - 0.9
15	6.5 - 14.3	1.2 - 1.9
16	5.4 - 13.0	0.6 - 1.6
17	3.1 - 10.7	0.6 - 0.8
18	3.9 - 12.2	0.4 - 0.8

* These data are unpublished, and related work was of a production nature as opposed to demonstration or research.

TABLE 4. PRELIMINARY PASSIVE RESULTS OF NORTHERN MARYLAND DEMONSTRATION

House			Radon Concentration (pCi/l)	
I.D.	Substructure Type	Reduction Technique	Pre-remedial	Post-remedial
004	Basement, poured foundation	Subslab depressure, 2 suction points, 1 retrofit stack	24-64 (CC) 21-33 (G) 35-44 (P)	9.1 (AT) 4-19 (P)
008	Basement, poured foundation, slab-on-grade extension w/ducts under slab	Subslab depressure, basement only, 1 suction point, 1 retrofit stack	12-65 (CC) 13-18 (G) 5-22 (P)*	2.2 (G)* 3.3 (P)*
010	Basement, block foundation	Seal only; sump, joints, cracks, ducting (walls not treated)	11-17 (CC) 18 (G) 6.8 (P)	7.3 (AT) 10.3 (P) 30 (P) in wall
032	Basement, block foundation	Subslab depressure, 1 suction point, retrofit stack, walls not treated	8-12 (CC) 9-18 (G) 10.2 (P)	8.4 (P) 3-5 (G)

TABLE 4. PRELIMINARY PASSIVE RESULTS OF NORTHERN MARYLAND DEMONSTRATION (cont.)

House I.D.	Substructure Type	Reduction Technique	Radon Concentration (pCi/l)	
			Pre-remedial	Post-remedial
047	Basement, poured foundation, crawlspace extension (no foundation vents)	Crawlspace subliner vent, existing furnace flue stack, basement sump and cracks sealed	11-14 (CC) 8-18 (G) 5-12 (P) 19-41 (P) in crawlspace	3.2 (AT) 4.2 (G) 1-4 (P) 2.1 (AT) in crawlspace
054	Basement, block foundation, crawlspace extension with 1 foundation vent	Subslab depressure, 1 suction point, 1 retrofit stack; added 1 crawlspace vent	10-23 (CC) 7-10 (G) 8-25 (P) 3-21 (P) in crawlspace	14 (G) 3-26 (P) 6-42 (P) in crawlspace
061	Bsmt., block fdn., sump w/drain tiles, completely finished w/wall and floor coverings	Sump depressure, 1 retrofit 4" stack, essentially no sealant	11-14 (CC) 11-23 (G) 4-20 (P)*	6-11 (G)* 1-11 (P)*
069	Basement, block foundation, crawlspace extension with 2 vents	Subslab depressure, 1 retrofit stack, walls not treated; added 2 crawlspace vents	9-20 (CC) 6 (G) 13.7 (P) 1.3 (P) in crawlspace	5.5 (AT) 9-10 (G) 4.5 (P) 7 (P) in crawlspace 50 (P) in wall
074	Basement, block foundation, crawlspace extension with no vents	Subslab depressure, 1 suction point, exist. wood stove for stack; walls not treated; crawlspace subliner vent, 1 retrofit stack routed outdoors	8-28 (CC) 9-13 (G) 11-21 (P) in crawlspace 17 (G) in crawlspace	7-16 (P) 12 (G) 7-16 (P) in crawlspace
076	Basement, poured foundation, crawlspace extension, basement floor covered	Subslab depressure, 1 suction point, exist. furnace flue stack, no slab sealant, F/W joint sealed by owner, no crawlsp. mitigation	4-17 (CC) 3-9 (G) 9.5 (P)* 3.3 (G) in crawlspace	1.1 (G)* 3.1 (P)*
079	Basement, poured foundation, sump w/no drain tiles, totally unfinished	Sump depressure, 1 retrofit stack, good floor sealant	12-20 (CC) 11-49 (G) 2.7 (P)	1-2 (G) 0.8 (P)
096	Basement, block foundation, sump with drain tiles, slab-on-grade extension with subfloor heat ducts	Sump depressure, 1 retrofit stack, no wall treatment; S-O-G depressure, 2 suction points thru basement wall under slab, existing furnace flue stack	16-17 (CC) 7-34 (G) 17-31 (P) 4-11 (G) in S-O-G 1-9 (P) in S-O-G	7-8 (AT) 4.4 (P) 7.5 (G) in S-O-G 1-4 (P) in SOG 4.8 (AT) S-O-G 77 (P) in wall

TABLE 4. PRELIMINARY PASSIVE RESULTS OF NORTHERN MARYLAND DEMONSTRATION (cont.)

House I.D.	Substructure Type	Reduction Technique	Radon Concentration (pCi/l)	
			Pre-remedial	Post-remedial
106	Basement, block foundation, sump w/no drain tiles, unfinished basement, S-O-G extension, excellent quality floor slabs	Subslab depressure, 1 suction point, existing unused stove flue stack, sump filled, no wall or S-O-G treatment	14-19 (CC) 46-50 (G) 13-36 (P) 12-27 (P) in S-O-G*	 6.5 (G) 7-14 (P) 4-14 (P) in S-O-G* 181 (P) in wall

* Pre-mitigation concentrations were measured during cold weather (December 1987-January 1988); post-mitigation measurements were made during mild weather (April-May 1988). Thus, comparison of pre- and post-mitigation results may not fairly reflect performance of passive system.

Notes:

1. Reported concentrations are in basement unless otherwise noted.
2. Where concentrations are reported as ranges, ranges represent two or more measurements of the measurement type noted. For Pylon measurements, ranges reflect at least 48 hours of hourly readings. Where Pylon measurements are reported as a single number, that number is the arithmetic mean of at least 48 hours of readings.
3. Legend for type of measurement:
   (CC) - charcoal canister (48-96 hour exposure)
   (G) - grab sample (5 minutes)
   (P) - Pylon continuous radon monitor (48-98 hour period)
   (AT) - alpha track detector (3-month exposure)

TABLE 5. CAREFREE, ARIZONA SOIL SAMPLE RESULTS

Description	Radium-226 (pCi/g)	Thorium-232 (pCi/g)	Potassium-40 (pCi/g)
ABC subslab fill	0.8 ± 0.2	0.6 ± 0.2	21.9 ± 3.8
Soil at footing level (3 ft.)	1.5 ± 0.3	1.8 ± 0.3	32.3 ± 6.2
Granite rock outcrop	4.5 ± 0.9	5.4 ± 0.9	42.4 ± 6.9

TABLE 6. CAREFREE, ARIZONA INDOOR RADON RESULTS

	Average Radon Concentration (pCi/l)*	
Description	House unheated	House heated
Initial model home	2.4	6.5
Home with radon reduction floor slab design changes	0.9	2.3

* Average of three 5-minute grab samples collected from master bathroom, master bedroom closet, and living room.