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RADON RESISTANCE UNDER PRESSURE

By: William F. McKelvey
Versar, Inc.
2010 Cabot Boulevard West
Langhorne, PA 19047

and: Jay W. Davis
Versar A/E, Inc.
760 Horizon Drive
Grand Junction, CO 81506

ABSTRACT

The radon mitigation field has many products available for the purpose of controlling the influx of radon gas through the cracks and joints which occur in structural components. These products are generally classified as caulkings, paints, membranes or cementitious materials.

Since it is difficult to evaluate the true effectiveness of these products in the field, an air tight laboratory chamber was designed and constructed to evaluate each product. The chamber and test conditions were set up to determine the resistance of each material to radon permeation (Transport) under various pressure differentials that would be similar to field conditions.

Each material was exposed to chamber ambient radon concentrations of several thousand picocuries per liter with an average pressure differential across the test material of 0.5" to 2" H_2O. Each material was tested as the product would be used in the field and compared with a control for QA/QC.

RADON MATERIALS TESTING CHAMBER

BACKGROUND AND PAST METHODOLOGY

The materials testing chamber (patent pending) was designed and constructed to fulfill the need to test various materials for their ability to resist the permeation of radon gas through the material under pressure in a controlled environment, where both the radon gas concentration and the pressure can be controlled.

Prior to the construction of this chamber, one of the most common methods for testing materials for radon resistance was the "bucket test", which entailed the use of two five gallon buckets placed end to end. The opposed ends of the buckets were structured to remain open to each other, save for the material to be tested, which was sealed in place between the two ends. The radon gas generating material, or the gas itself, would be placed or pumped into the "hot" bucket. Under atmospheric conditions, the radon would diffuse across the test material and accumulate in the "cold" bucket. Radon gas samples would be collected from the "hot" and "cold" buckets and compared. The percent reduction was obtained by dividing the "cold" bucket radon concentration by the "hot" bucket radon concentration times 100%.

$$\frac{\text{Hot pCi/l} - \text{cold pCi/l}}{\text{hot pCi/l}} \times 100\% = \text{percent reduction in radon concentration.}$$

With the above described method there were several constraints. They are as follows:

1. No way of controlling the radon concentrations generated by the source material.
2. Could not maintain a constant pressure differential across the material under test.
3. Size of material to be tested had to be at least 13"to 14" in diameter to span the diameter of the buckets, which limited the types of materials that could be tested, due to the large surface area requirement.
4. Difficult to seal and maintain a seal between the test buckets and the material undergoing the test, especially for a 30-day test period.
5. Only one type of material could be tested at a time.

To overcome the above listed problems, Versar designed and constructed a radon materials testing chamber, and filed for a patent (pending). The chamber was constructed primarily for testing materials for radon resistance, however, the application can be used for other gases as well.

DESCRIPTION

The radon material testing chamber has six (6) major components. They are as follows:

1. Radon Test Chamber
2. Radon Source Chamber
3. Test Cells (4)
4. Pump with flow rate calibrator
5. Manometers (2)
6. Radon Gas Monitor

Radon Test Chamber (Reference Figures I & II)

The radon test chamber is constructed of 1/2 inch thick clear acrylic, with an internal volume of 12 cubic feet (339.97 liters). The top of the test chamber is removable for access to the chamber interior. There are 18 brass valves attached to one end of the test chamber. The valves and their functions are as follows:

- Test Cell Supply Valve - There are four valves, numbered 1 through 4. These numbers coincide with the number of the test cells placed inside the chamber. The valves penetrate the wall of the chamber and allow for the connection inside the chamber from the valve to the corresponding test cell with tubing.

- Test Cell Return Valve - There are four valves numbered 1 through 4. These numbers also coincide with the number of the test cells placed inside the chamber. As with the supply valves, tubing connects the valve to the corresponding test cell.

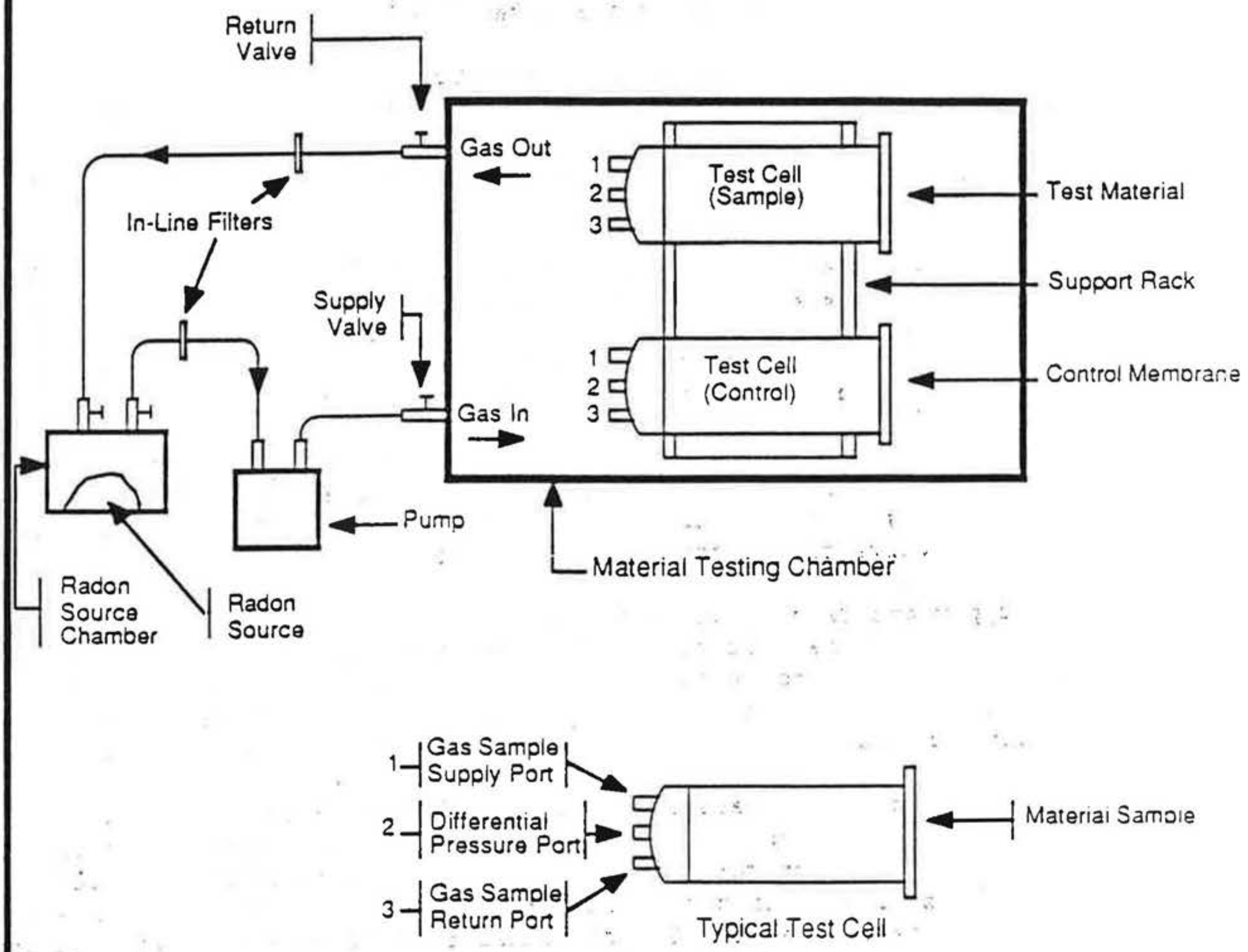
The supply and return valves provide the means to take a radon gas sample from inside each of the test cells. The radon gas is drawn through the supply valve, collected and/or passed through the radon monitor back into the test cell via the return valve. This keeps the pressure inside the test cell in equilibrium and allows for a complete exchange of the air in the cell.

- Test Cell Pressure Valves and Chamber Pressure Valve - There are four valves, numbered 1 through 4, and as with the test cell supply and return valves, each one is connected to a test cell. A manometer is connected to each valve and to the signal-in port of the manometer. The reference port of each manometer is connected to the chamber pressure valve. This provision gives an accurate reading of the pressure differential between the internal pressure of each test cell and the radon chamber.

- Chamber to Atmosphere Pressure Valve - This single valve penetrates the wall of the chamber for the purpose of measuring the pressure differential between the chamber and the atmosphere with a manometer. The reference port of the manometer is open to the atmosphere and the signal-in port is connected to the chamber valve.

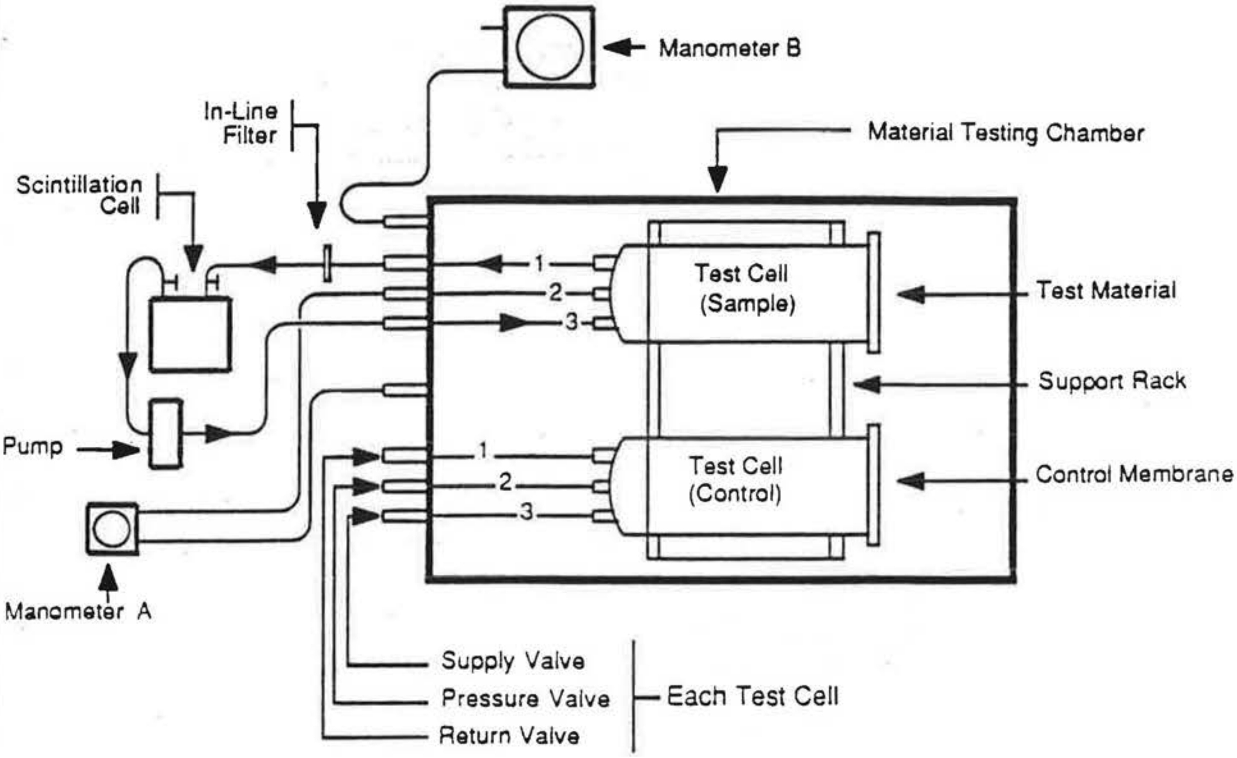
Radon Source Chamber (Reference Figure I)

The radon source chamber is a metal air tight chamber with an internal volume of .245 cubic feet (6.94 liters). This chamber is used to store low level radioactive material that generates the radon gas. The chamber is equipped with two valves; a supply and a return valve. The radon gas is



Charging the Testing Chamber (Patent Pending) Versar, Inc.

Figure I



Material Testing Chamber (Top View)

Manometer A : Measures ΔP between chamber and test cell.

Manometer B : Measures ΔP between chamber and atmosphere.

In-line Filter : Collects radon decay products, allowing only the radon gas to pass.

Scintillation Cell : Collects radon gas that has diffused through test material and accumulated in test ce

Pump: Draws radon gas from test cell through scintillation cell and returns gas back to test ce .

Radon Gas Sampling Diagram (Patent Pending) Versar, Inc.

Figure II

circulated from this chamber into the testing chamber and back again until the testing chamber is charged with a predetermined level of radon gas.

Test Cells (Reference Figure I)

The test cells are constructed of either 4 or 6 inch diameter PVC, Schedule 40 pipe and have internal volumes of 0.102 cubic feet (2.89 liters) for the 4-inch diameter cells and 0.196 cubic feet (5.55 liters) for the 6-inch diameter cells. Each test cell is sealed at one end with end caps of the same material. Each end cap is equipped with three brass nipples which are connected to the appropriate chamber valves via tubing, as described under Radon Test Chamber. The material to be tested for radon permeation characteristics is mounted and sealed to the open end of the cells. The cells are placed on a loading rack inside the test chamber.

Pump (Reference Figure I)

This is a low volume air flow pump, calibrated and set to a flow rate of 2 liters/minute. The pump serves two purposes:

1. To charge the testing chamber with radon gas.

2. To maintain a predetermined pressure within the testing chamber.

Manometer (Reference Figure II)

The manometers used are electronic digital manometers (EDMs) that are capable of measuring one thousandth of an inch of water (1/1000 inch H_2O) pressure. A manometer is connected to the testing chamber, (the valve labeled chamber to atmosphere) to measure the pressure differential between the testing chamber internal air pressure and that of the atmosphere. EDMs are also used to measure the pressure differential between each of the test cells and the testing chamber.

CLASSIFICATIONS OF TESTED MATERIALS

As stated earlier, the materials testing chamber and related components were designed to test all types of materials and to test up to three materials simultaneously. In the radon industry these materials are generally described as sealants. They are manufactured and applied to the building components of a structure in a variety of ways. The five general categories of sealants are as follows:

1. Caulks - generally these are either flowable and self-leveling or of gun grade quality. They are used to seal cracks, control, and expansion joints in floors and walls that are in contact with the soil. Examples include one and two part polyurethanes, silicones, latex, oil based, and butyl rubber caulks.

2. Cementitious materials - generally these are either premixed or in powder form. When applied they are of a consistency suitable to be brushed or trowelled onto floor or wall surfaces. Generally, they are applied from 1/16" to 1/4" in thickness. These materials are

usually used to seal basements against water and moisture infiltrations. The characteristics of these products have appealed to the radon industry.

3. Membranes - generally these are either pliable or semi-rigid. The pliable materials come in rolls 3 to 4 feet wide and 2 to 40 mil. thicknesses. The roll material usually consists of polyethylene or polyurethane based products. The semi-rigid sheet material is generally manufactured in sheets of 3 to 4 feet in width and 8 to 10 feet in length. The sheet material usually consists of plastic or layers of bituminous material laminated with polyethylenes.

4. Paints and epoxies - generally these are manufactured in a liquid state and, when dry, form a water and moisture resistant film. These can be brushed, rolled, or sprayed onto their intended surfaces. Generally paints are applied at 2 to 4 mil. thicknesses and epoxies are applied at heavier rates, up to approximately 1/16 of an inch in thickness. Epoxies, when cured, usually form a hard and impenetrable surface.

5. Foams - are expandable polyurethanes that when exposed to the air, expand volumetrically forming closed air cells. These materials are generally used to seal and insulate large cracks, openings and cavities found in the various components of a building.

The radon industry has used all of the above mentioned types of sealants to prevent or reduce the infiltration of radon into a structure. However, sealing techniques, in general, do not have a high success rate as a sole mitigation method to prevent radon infiltration. Sealing is generally used in conjunction with other mitigation techniques such as subslab and/or wall depressurization for a complete remediation package.

Manufacturers became interested in how their products would perform in radon reduction and contacted Versar for an evaluation of their product(s). Versar's objective was to evaluate each product in a manner that simulated field conditions and to test each material as a separate entity. For example, if testing a paint material, it would have to be bonded to a substrate material which would not bias the test results. The radon gas would have to pass easily through the substrate material in order to evaluate the radon resistance of the paint. The output of the evaluation would be simply expressed in effective percent reduction in radon gas.

OPERATION METHODOLOGY
(Reference Figure I)

The material to be tested is sealed to the open end of a test cell. After the seal has cured, a negative pressure is applied to the test cell to check for leaks. If no leaks are found, the test cell is placed in the testing chamber with the control test cell. Up to three different test cells and the control can be placed in the testing chamber at one time. The testing chamber is then sealed.

A radon source chamber with an in-line filter is connected to the suction side of a pump, and the positive side of the pump is connected to the chamber

A radon source chamber with an in-line filter is connected to the suction side of a pump, and the positive side of the pump is connected to the chamber supply valve. The chamber return valve is connected to the return side of the radon source chamber via tubing with an inline filter. This provides a closed loop system for charging the chamber with radon gas. The in-line filters capture the radon daughters that have accumulated in the radon source chamber. The desired operational concentration of radon in the test chamber is determined by a function of flow rate and time that the radon is pumped from the source chamber.

With our radon source, pumping five minutes at 2 liters/minute provides approximately 12,000 pCi/l of radon in the test chamber. A radon sample is collected and analyzed immediately after charging the test chamber to verify the actual concentration. The chamber is then pressurized through the use of an air pump. This places a positive pressure on the chamber side of the material under differential test. Manometers measure the pressure across the tested material. Pressure can be variable, but is usually held at 0.1 to 0.2 inches of water. To maintain this pressure differential, the test chamber is maintained at approximately 6 inches of water relative to atmospheric pressure.

Testing for each product sample is usually conducted at 24-hour intervals for a period of five days. Testing is conducted (reference Figure II) by connecting a radon sampling device (scintillation cells and pumps) via tubing with an inline filter to each of the supply valves for the test chamber and each test cell. The positive discharge side of the pump is connected to each of the return valves of the test chamber and to each test cell. As before, when charging the test chamber, each inline filter captures the radon daughters that have decayed from the radon gas between test periods. Also, sampling is conducted through a closed loop system. This prevents altering the equilibrium of the test chamber or any of the test cells by applying positive or negative pressures to these components. This method allows for the determination of the available radon concentrations in the chamber and each test cell for each test period.

The percent reduction, or the ability of the test material to resist radon infiltration into the test cell, is found by comparing the chamber concentration with that accumulated in each test cell for each test period. The relative overall performance is based on the average of all the five tests.

$$\frac{\text{Chamber pCi/l} - \text{Test Cell pCi/l}}{\text{Chamber pCi/l}} \times 100\% = \%\ \text{reduction in radon concentrations}$$

MATERIAL TESTS AND RESULTS

Because most of our tests were performed under contract to our clients and we have agreed to keep these clients confidential, the following discussion on the products tested refers to these products generically rather than by brand name or manufacturer. The following graphs represent the tests and the results of the many different products that manufacturers thought could be useful in the radon field. The vertical bars represent the radon concentrations measured in the test chamber and the test cell for each product sample. The bottom horizontal axis represents the elapsed time in hours.

between sampling. The tests and the results are both graphically depicted, and above each bar, the actual numerical value is given in pCi/l. Also, the average radon concentration over the testing period for the test chamber and the average percent reduction for each product sample is shown.

For each of the following graphs, sample preparation procedures and the base materials in the product, when known, are discussed. The products were prepared for the tests as they would be used in the field and in accordance with the manufacturer's recommendations. However, as stated earlier, we were interested in evaluating the product only, not the material it may be bonded or applied to. For example, joints were constructed by using two pieces of acrylic, which is dense and not permeable to radon. In the field, caulks used to seal joints may be very effective, but radon could bypass the joint or crack and diffuse through the host material that is being sealed.

CAULKS

Graph #1 represents the results of the tests conducted on a gun grade caulk of 1 part polyurethane. Sample numbers 1, 2, and 3 represent three different size joints. The joint aspect ratios for the samples are as follows:

Sample #1 - 1/2" deep x 1/4" wide
Sample #2 - 1/4" deep x 1/2" wide
Sample #3 - 3/4" deep x 3/4" wide

The joints were constructed by using two pieces of acrylic, the thickness being equal to the depth of the joint. After the joints cured, the samples were sealed to the open end of the test cell. The data indicates that all 3 test samples and the control performed equally.

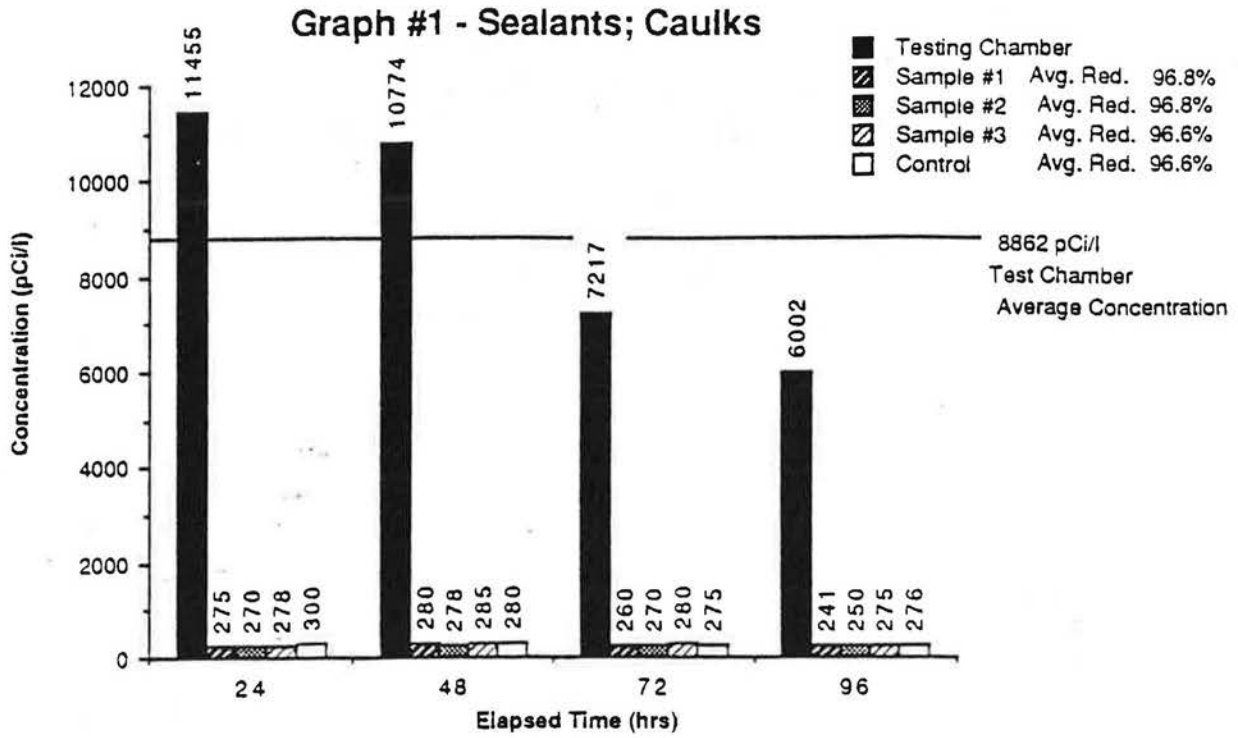
Graph #2 represents the results of the tests conducted on gun grade caulks supplied by a different manufacturer than those of Graph # 1. Sample #1 is a silicone base caulk and sample #2 is a siliconized acrylic latex based caulk. Sample #1 was constructed with a joint aspect ratio of 1/2" deep x 1/4" wide and for sample #2 the joint aspect ratio was 1/4" deep x 1/4" wide. These caulks performed similarly to the polyurethane caulks.

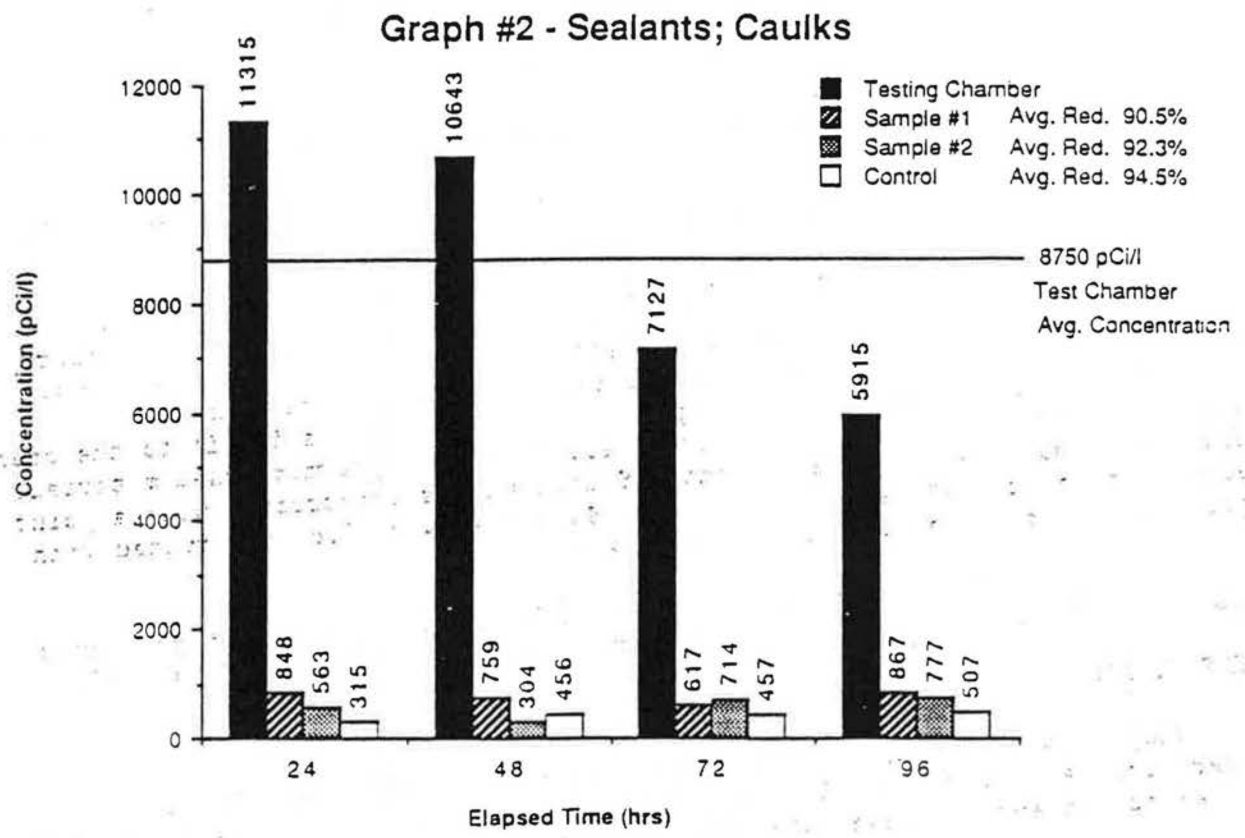
Graph #3 represents the results of the tests conducted on gun grade caulks and a brushable sealant that would be applied to concrete or masonry surfaces. These materials were supplied by the same manufacturer as those represented in graph #2. Sample #1, a brushable sealant of unknown derivation, was prepared by coating a filter paper and sealing it to the open end of the test cell. Sample #2 is an elastomeric copolymer based material, and sample #3 is a metallic sealant. Sample #2 was constructed with a joint aspect ratio of 1/4" deep x 1/4" wide. Sample #3 was also constructed with a joint aspect ratio of 1/4" deep x 1/4" wide.

Overall, regardless of the base material in the caulks, they performed about equally in radon reduction as represented in graphs #1, #2, and #3.

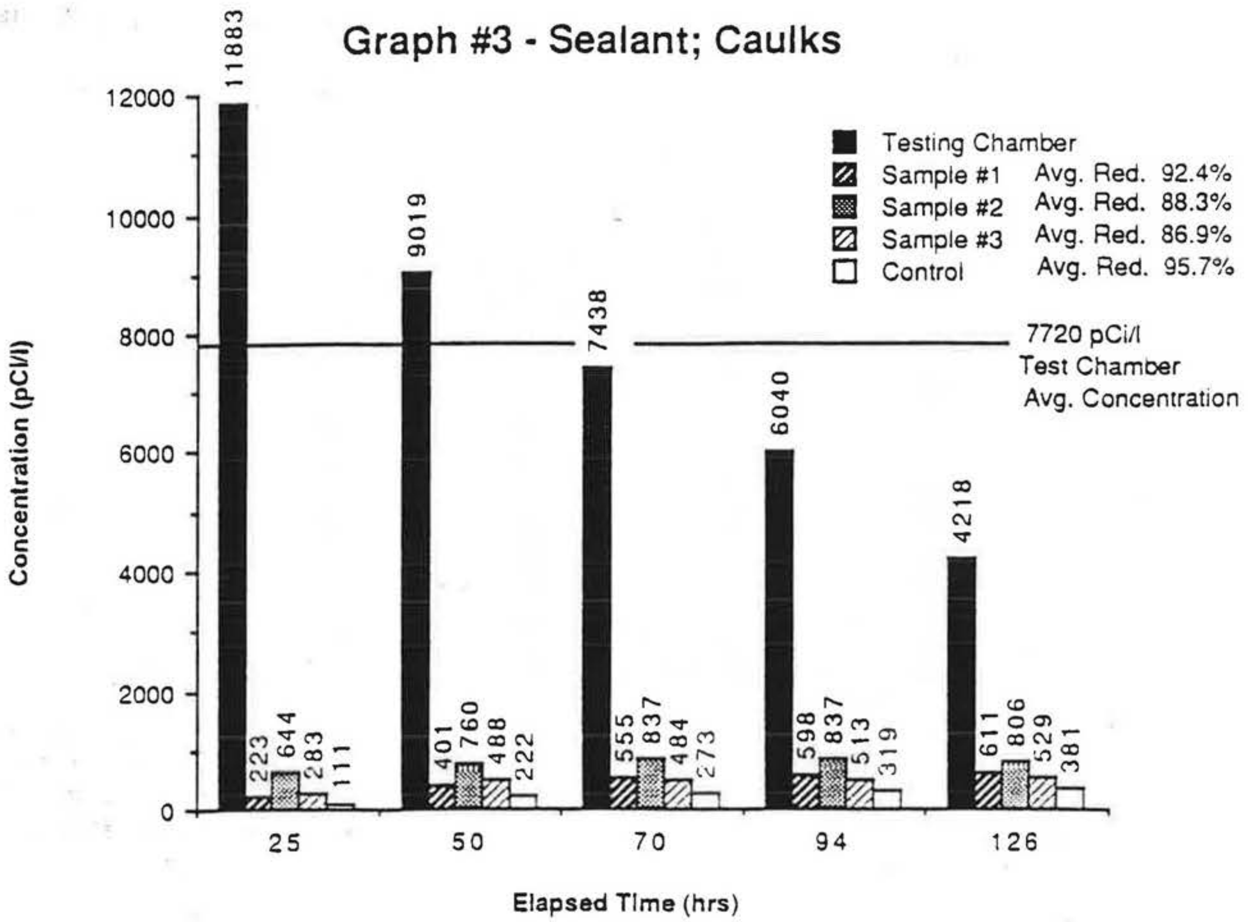
CEMENTITIOUS MATERIALS

Graphs #4, 5, 6, and 7 depict the test results for cement based materials. All of the samples were formulated by the same manufacturer, and the exact content of these materials were not known by Versar. Each sample

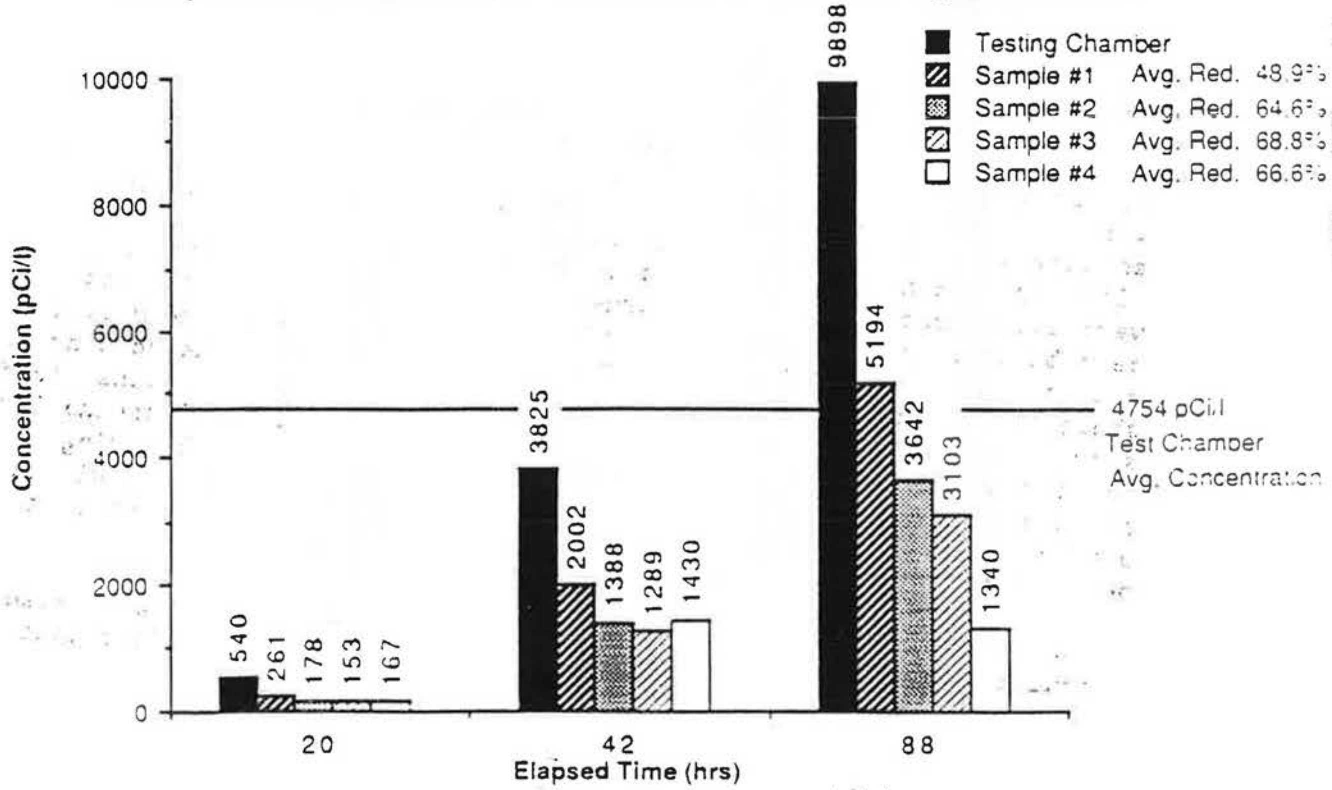

Graph #1 - Sealants; Caulks
Testing Chamber
Sample #1 Avg. Red. 96.8%
Sample #2 Avg. Red. 96.8%
Sample #3 Avg. Red. 96.6%
Control Avg. Red. 96.6%
8862 pCi/l
Test Chamber
Average Concentration
Concentration (pCi/l)
12000
10000
8000
6000
4000
2000
0
11455
275
270
278
300
10774
280
278
285
280
7217
260
270
280
275
6002
241
250
275
276
24
48
72
96
Elapsed Time (hrs)


Graph #2 - Sealants; Caulks
Testing Chamber
Sample #1 Avg. Red. 90.5%
Sample #2 Avg. Red. 92.3%
Control Avg. Red. 94.5%
8750 pCi/l
Test Chamber
Avg. Concentration
Concentration (pCi/l)
12000
10000
8000
6000
4000
2000
0
11315
848
563
315
10643
759
304
456
7127
617
714
457
5915
867
777
507
24
48
72
96
Elapsed Time (hrs)

Graph #3 - Sealant; Caulks



Graph #4 - Sealants; Cementitious Surfacing Materials



was cast to a diameter of 4 1/2" and approximately 3/32" thickness. These samples are surfacing materials to be applied over concrete and/or block substrates. Sample #1 on graph #4 is a premixed material shipped from the manufacturer. Samples #2, 3, and 4 were mixed at the testing site by applying water.

Graph #5 represents the results on the tests of four samples of materials that are also used as surfacing materials over concrete and block substrates. These samples were cast to the same dimensions as stated for Graph #4. The main difference between these materials and those of graph #4 is that plasticizers are used as part of the material matrix.

Graph #6 represents the results of the tests conducted on three samples of materials that are used for patching and sealing around pipes and/or water plugs. As with the samples shown on graphs #4 and #5, these samples were also cast to the same dimensions. Unlike the previous samples that were designed as surfacing materials, these samples are hydraulic cements.

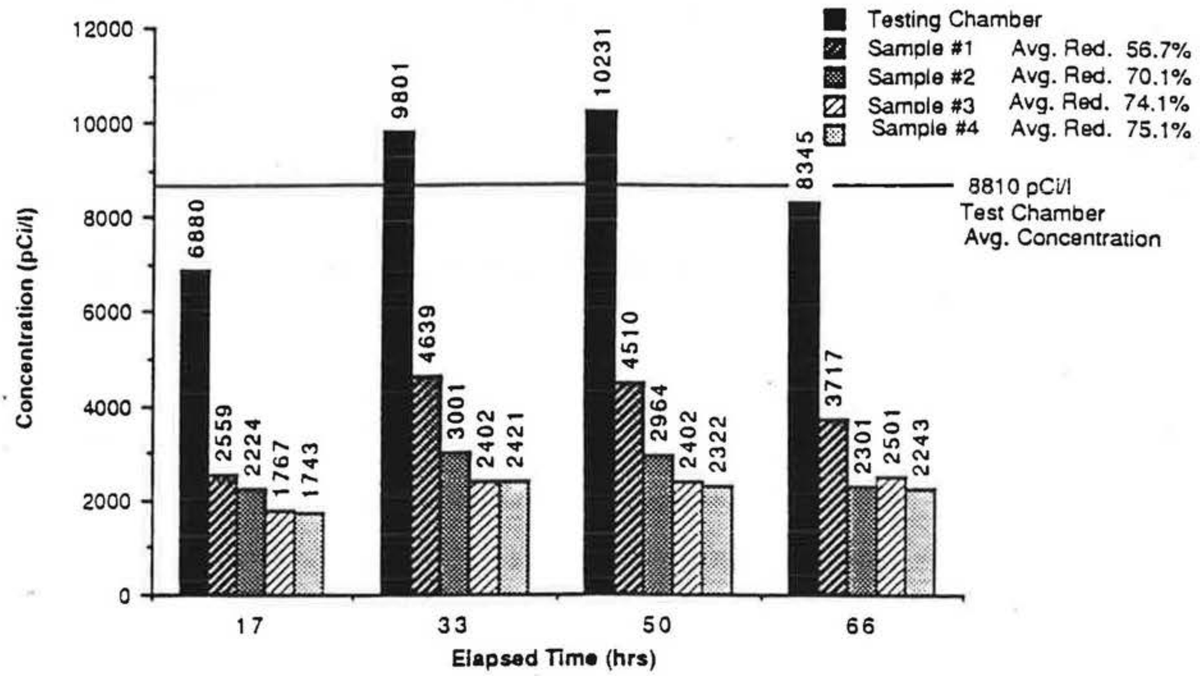
Graph #7 represents the tests and the test results for three samples that are used as surfacing materials over concrete and block substrates. However, there are differences between the materials. Sample #1 is a 50/50 mixture of the products identified as sample #2 from graphs #3 and #4, respectively. There was relatively no increase in performance. Sample #2 is a retest of sample #4 from graph #5, and the results were within 3% for average reduction of radon between the two tests. Sample #3 was a clear coat glazing material to be applied over cement finishing products. This coating was applied over filter paper and allowed to cure before testing. The results were not very impressive, as can be seen from the graph. As a point of interest, the first time this coating was sent to us the manufacturer had applied the coating to a piece of mylar. The sample had a 99% average reduction in radon transferance. At the completion of the test, we found that the sample could not be destroyed because of the mylar. While not specifically tested, it would seem that mylar containing materials may have a potential use in the radon remediation business.

MEMBRANES

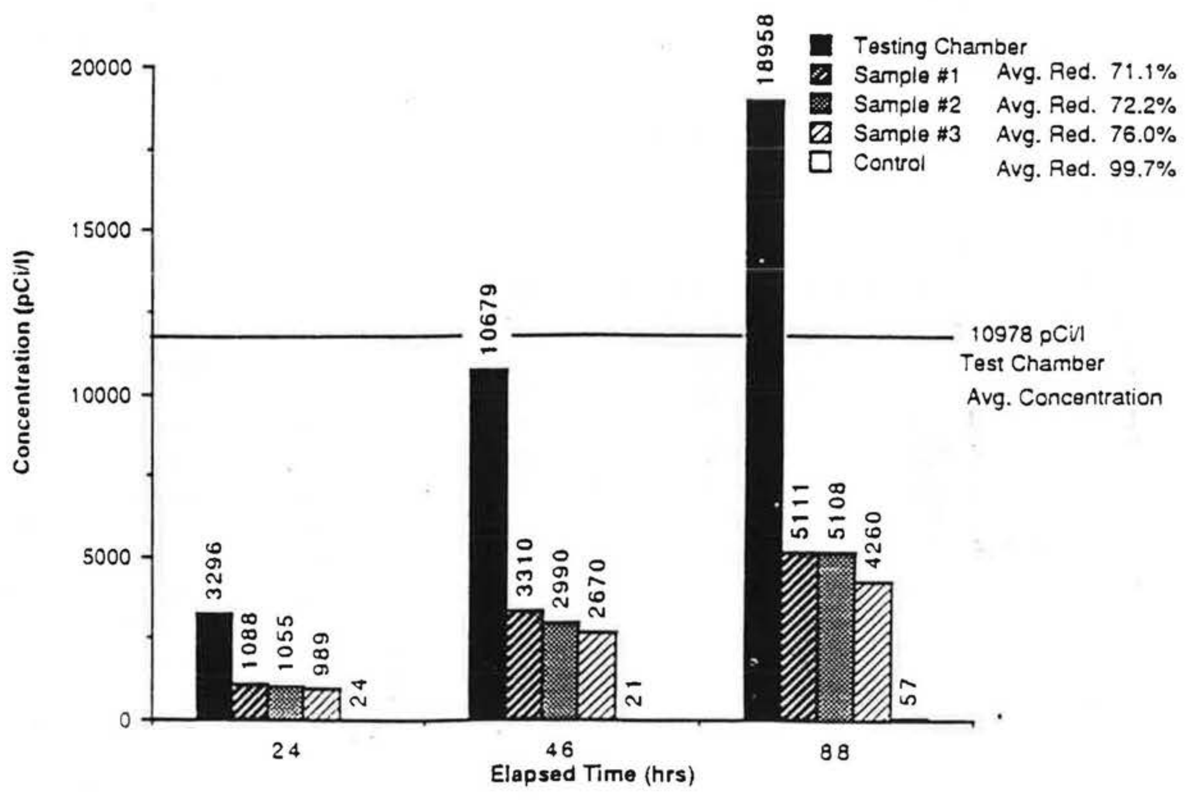
Graph #8 represents the results of the tests conducted on three samples of products used primarily to waterproof foundations. The sheets of materials were supplied by the manufacturer with instructions to laminate the products as they would be applied in the field. All three samples were cut to 7" in diameter, laminated, and sealed to the test cells. The samples when laminated were approximately 1/4" in thickness. The material was rigid and appeared to be a bituminous-like product reinforced with fiberglass-like material. One side of each sheet had adhesive qualities to facilitate the bonding of two sheets. In each of the three samples the bottom sheet was joined to form a seam. Sample #1 had no vapor barrier. Sample #2 had a cellophane like vapor barrier and sample #3 had a 2 mil. thick vapor barrier. Observing the graph, samples #2 and #3 performed similar to the control, but sample #1 did not perform as well. The vapor barriers could have had some effect in the overall performance.

Graph #9 represents the results of the tests conducted on a special formulation that the manufacturer does not want divulged. This coating was

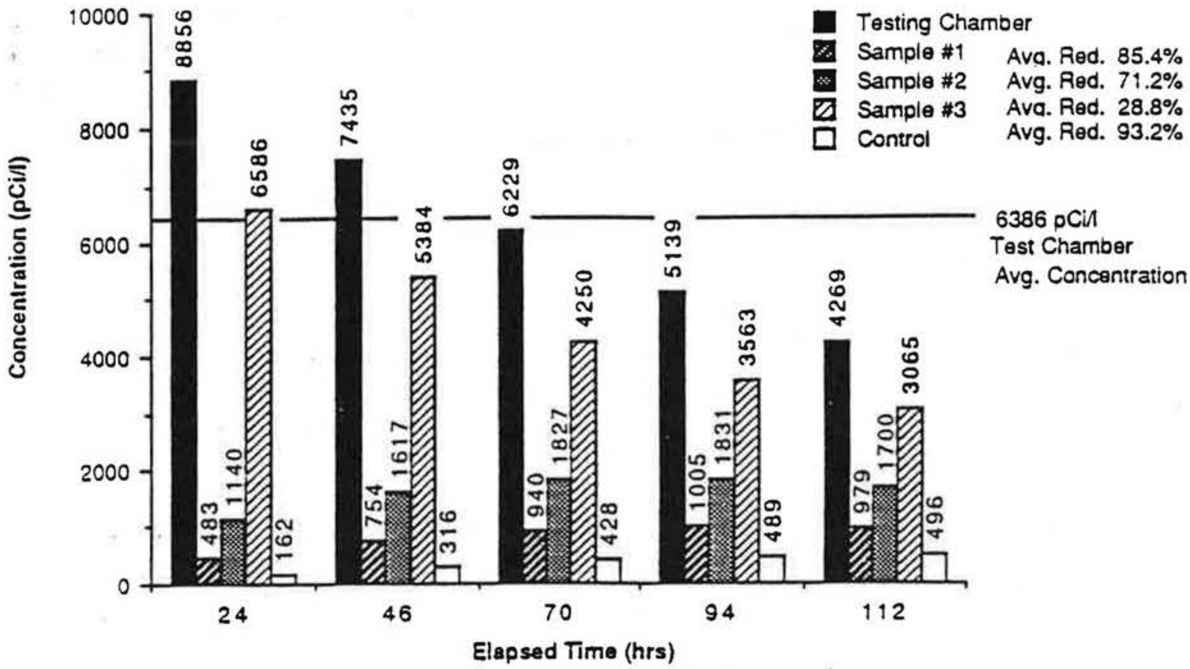
Graph #5 - Sealants; Plasticized Cement Coatings



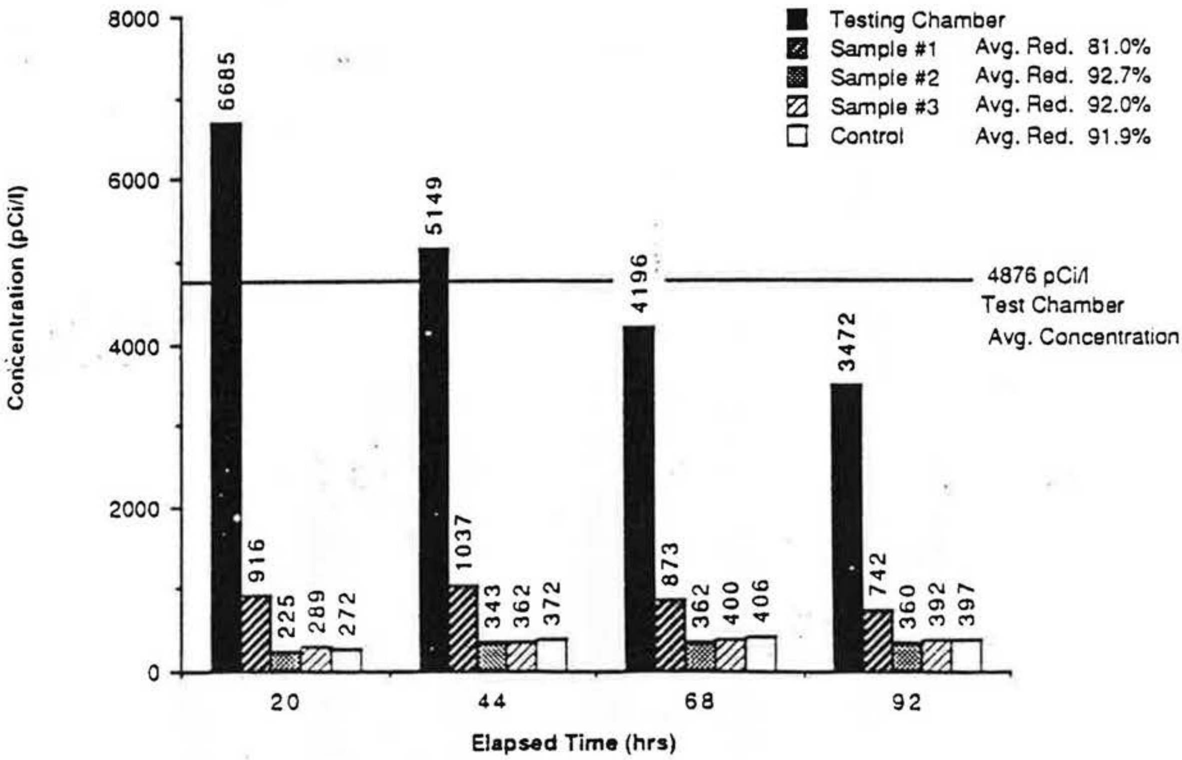
Graph #6 - Sealants; Cementitious Waterplug Material



Graph # 7 - Sealants; Cementitious Coating



Graph #8 - Sealants; Membranes



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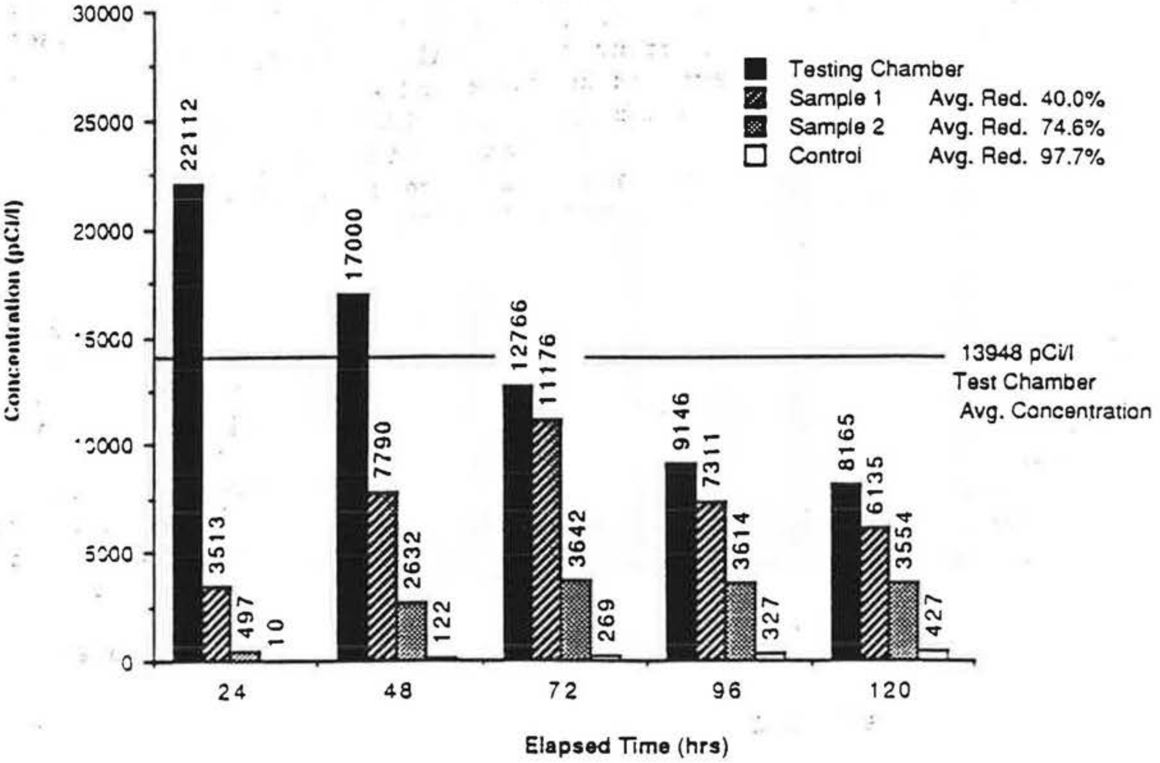
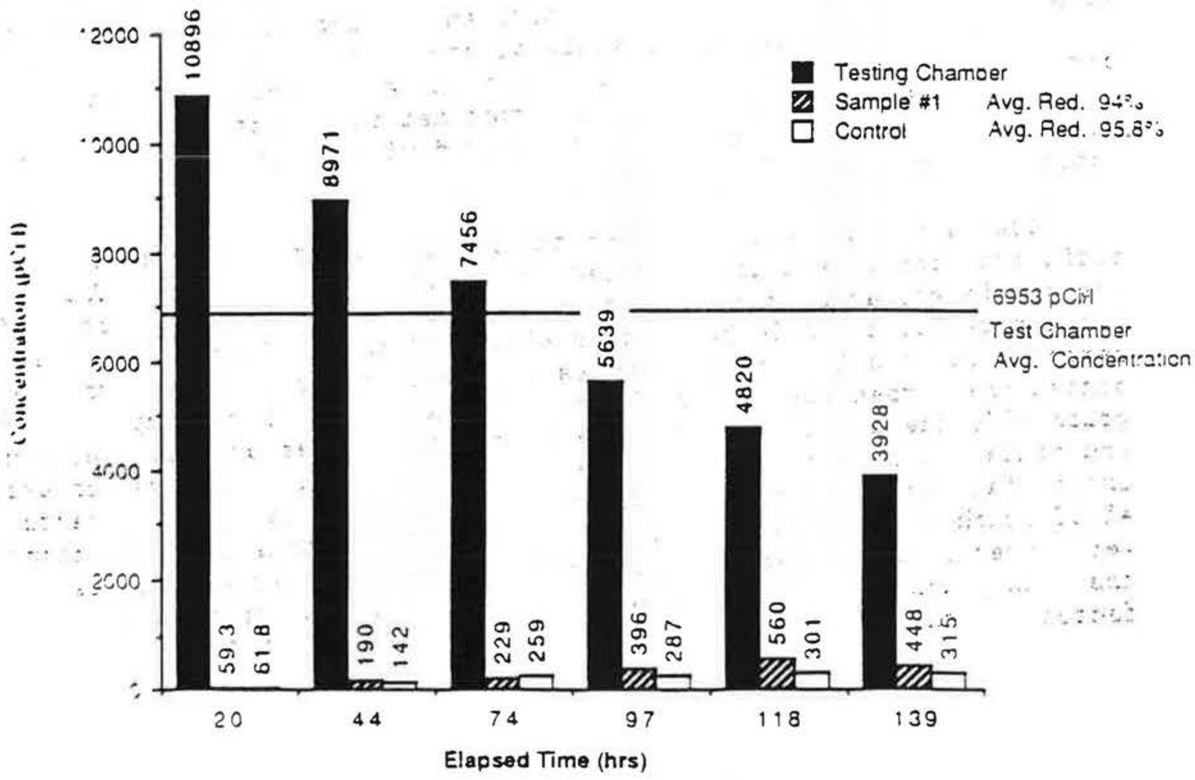
Graph #9 - Sealant; Paints



Graph #10 - Sealants; Foam (expandable)



prepared specifically for the purpose of sealing block (concrete masonry units) surfaces and is to be applied with a spray gun. These samples were prepared by cutting the face shell from a standard block. The face shells were cut in half and each mounted and sealed to a test cell. Sample #1 is the treated block with all exposed surfaces and edges coated with the special formulation. Sample #2 is the untreated block. The overall performance of this coating was not up to expectations. Limited space prevents the showing of two additional follow-up tests that were conducted. However, the results were similar, with only the control showing consistent results in percent reduction of radon.

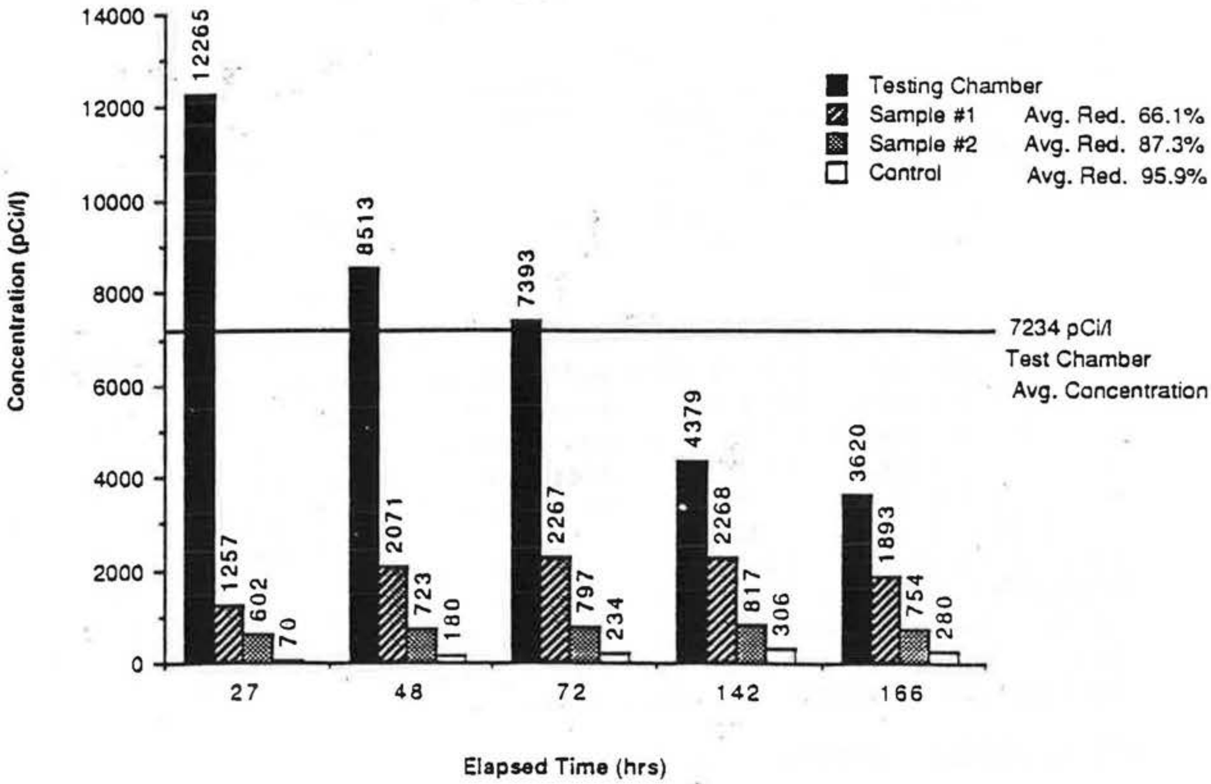
Graph #10 represents the results of tests conducted on expandable polyurethane foam. A screening material was molded to fit over the open end of the test cell. The screen was used as a porous backing material and the foam was sprayed onto it. The foam expanded to a range of 1/2" to 1" thickness. After a seven day curing time, the test was conducted. Additionally, the test chamber was pressurized to induce a negative pressure of 2.5 inches of water inside the test cell. This would equal or exceed the negative pressures this material would be subjected to in a hollow core foundation wall that was being evacuated with a wall depressurization system. The material performed remarkably well, and it is expected that the skin coating that forms over the surfaces exposed to air may have been a contributing factor to its performance.

MISCELLANEOUS MATERIALS

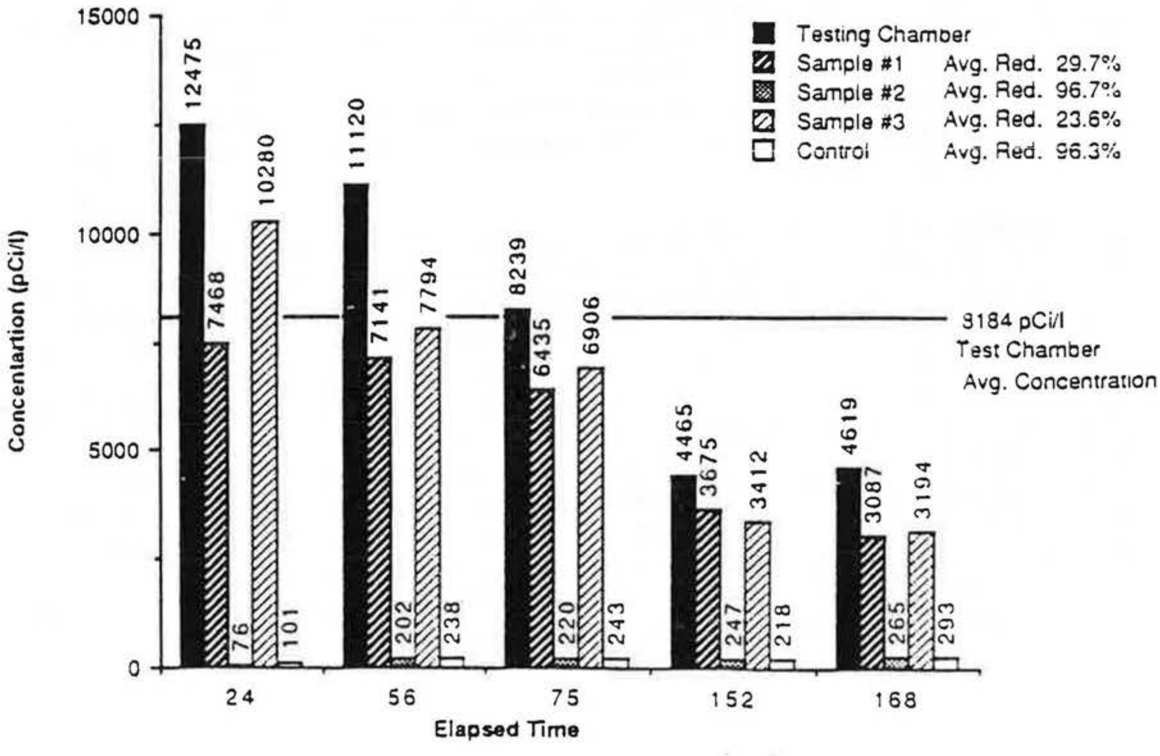
Graphs #11, 12, and 13 represent the results of the tests conducted on a variety of floor coverings. These are not classified as one of the five categories under sealants. The manufacturer requested these materials be tested, as they thought that under certain circumstances these materials, when bonded properly to cracked concrete substrates, may have a favorable impact on reducing radon infiltration. The manufacturer supplied the floor covering samples. Each sample was cut, fitted, and sealed to the open end of the test cells. Graph #11 shows the results of one at three individual tests for carpet samples #1 and #2. The second test was a duplicate test, and the third test was conducted using the same carpet material, but with a seamed joint. All three tests were within a 2% maximum deviation in radon reduction for each sample and the control.

Graphs #12 and #13 represent the results of the tests conducted on additional carpet samples supplied by the same manufacturer. The exception was sample #2, as represented on graph #13. This sample consisted of a sheet vinyl material as would be used on kitchen floors. In general, the performance of all of these samples appear to be based on how the manufacturer bonded the carpet threads to the backing material. For example, sample #1 on graph #12, the carpet threads were very dense (piles or loops per square inch) and bonded in a dense polyurethane backing material. This was an expensive industrial grade carpet and performed surprisingly well in the tests. Sample #1 of graph #13 was an inexpensive carpet with no backing. The carpet threads were woven into a separately constructed backing material. It is suspected that the glues and resins may have been the biggest contributing performance factor, or there would have been none at all.

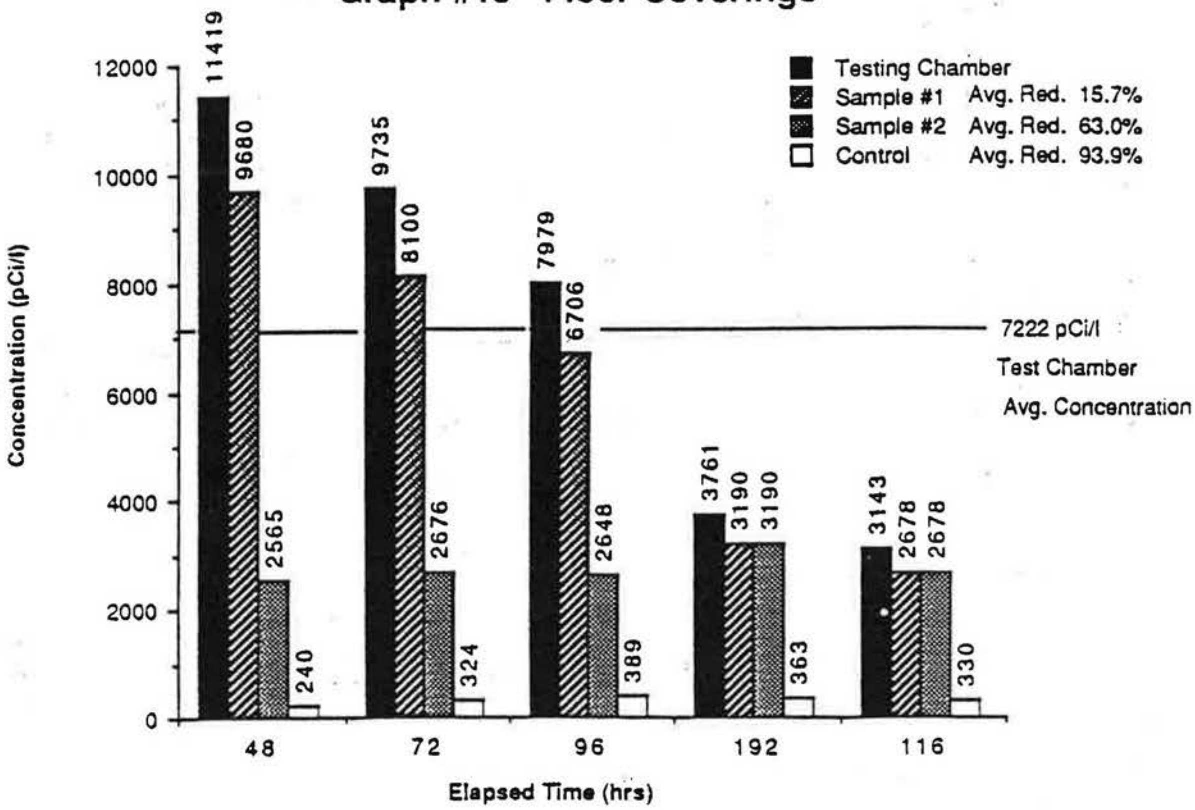
Graph #11 - Floor Coverings



Graph #12 - Floor Coverings



Graph #13 - Floor Coverings



SUMMATION

Many commercial products are available and are being used for the purpose of controlling radon gas infiltration into buildings. Recently, a number of manufacturers have begun developing and marketing materials specifically for radon entry control. These materials have been developed, marketed, and used without real data regarding the radon resistant properties of the product. The radon mitigators have selected these products based on physical or chemical characteristics, or simply availability.

Obviously the physical and chemical properties of the products are important considerations, however, these properties are clearly secondary to the intended function (i.e., as a radon barrier). In the past, the success of a product was based on the comparison of pre- and post-remediation test results of the ambient air in the structure. However, it was impossible to determine if the success or failure of the product was due to the product, workmanship, or the application of the product.

This paper presents a testing methodology that has over come many of the constraints associated with the previously used testing methodologies. The equipment and testing techniques described provide mitigators with quantitative radon permeation data on a specific product to assist them in making material selection decisions. The methods are also useful to manufacturers in evaluating the effectiveness of existing products for radon mitigation applications, and in developing new products designed for such applications.

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