MEASURING RADON AND THORON EMANATION FROM CONCRETE AND GRANITE WITH CONTINUOUS RADON MONITORS AND E-PERM's®

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Abstract

The author investigated the use of commercially available continuous radon monitors (CRM's) and S-Chamber E-PERM's® using short term electrets to measure the radon (^{222}Rn) and thoron (^{220}Rn) emanation from concrete and granite counter tops. The performance of CRM's and E-PERM's® placed in 3 to 23 liters metal accumulator chambers sealed to a building material were compared to the total emanation rate of the building material when the material was placed in a sealed 122 liter chamber. Concrete slabs were constructed that had radon only versus radon and thoron and actinon(^{219}Rn) to determine the test equipment response to these isotopes. A thoron chamber was constructed to test the detectors response to thoron and the reduction in response to thoron when the detectors were placed in diffusion barriers. Accumulator and sealed chamber tests on three different granites found significant variation in emanation rates depending on what side of the granite was tested.

Elevated Indoor Radon Levels due to Building Materials

The author investigated a 200 unit seven story tall condominium unit that had elevated radon levels in the hallway and individual units on every floor. This building had two levels of ventilated parking garage under most of the building that precluded ground base soil gas as the source. The building was constructed with post stressed concrete floors and ceilings and concrete support columns. All other walls except those adjacent to stairwells were metal stud and drywall construction. Ventilation measurements indicated the units were typically getting less than 0.1 air changes per hour (ACH). A simple method was used to measure the concrete emanation rate by placing single EPERM's® inside 3 liter stainless mixing bowls that were sealed against exposed concrete floors, ceilings and walls. The total ingrowth inside the bowl was determined by doubling the E-PERM® average after first subtracting the back ground radon when the unit was first sealed. This total ingrowth is then divided by the hours of exposure and multiplied times the volume of the accumulator and divided by the square feet of exposed concrete to obtain the emanation rate of the concrete. The exposures were approximately 24 hours long to minimize the effect of ingrowth decay. These emanation measurements made on every floor of the condominium indicated that the concrete along with the low ventilation rate was the likely source of the elevated radon. The research presented in this paper was conducted to determine if an accumulator method using continuous radon monitors (CRM's) or E-

PERM's® with ingrowth correction factors would provide a simple method with reasonable accuracy to determine the emanation rate of any building material.

Testing Equipment Set Up

The author has two AB5 Pylons® with passive radon detector heads (PRD) and a RAD7® radon monitor. These units were cross compared with two similar AB5 Pylons with newer CPRD heads supplied by Pennsylvania DEP Radon Division. In addition the following CRM's were generously loaned from the manufacturer/suppliers; two Femto-Tech 510's®, Sun Nuclear 1029®, Rad Elec Scout®, RadonAway RS500® , RadonAway RS800® and the RTCA On Guard. Metal test chambers were constructed varying in size from 38 liters to 129 liter size by using commercially available metal trash cans with removable lids. Each of the cans had all interior seems sealed with urethane caulking and then covered with 17 mil aluminum tape. A power cord was installed in each chamber with the cord penetration carefully sealed in a similar manner. Sampling ports were installed in each of the chambers by mechanically attaching 3/8" ball valves through the side of each chamber and carefully sealing the penetration. See picture in Figure 10. The removable lid for each chamber had pliable plumbers putty placed around the edge. A ball valve would be left open and the lid pressed down on the chamber, compressing the putty and forming an air tight chamber when the ball valve was closed. The tightness of the chamber was tested by flowing radon into a chamber with two CRMs and then closing all the valves to allow the radon to decay. The radon decayed with a normal radon decay rate indicating that there was no radon leakage out of the chamber. See the decay rate chart below in Figure 1.

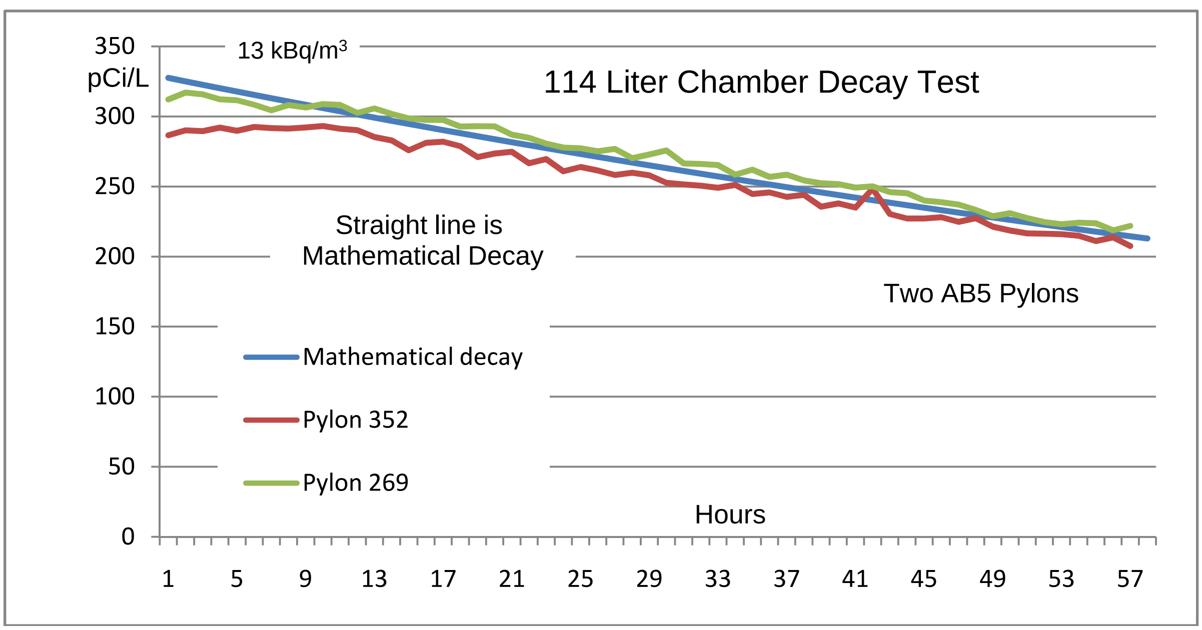

Figure 1 Chamber Tightness test

The author has several radon, thoron and actinon sources that were used to test the performance of the different CRM's and E-PERMs®. One of the sources is soil. During an investigation of a home in need of a radon mitigation system, a suction point was located where a 300 υR/hr gamma reading was obtained at the slab. The soil excavated from this home produces 0.75 pCi/oz/minute (1.6 Bq/gm/hour). This soil was dried and placed in three 6" by 60" long metal ducts that were carefully sealed and constructed with sampling ports on either end. Initial sniff measurements made of the soil indicated it had a low thoron content. Some of this soil was mixed into a concrete test slab to increase its emanation rate. A more careful grab sample of the soil source was then made with a Pylon AB5® and scintillation cell with the counter set to 20 second count interval. The tubing length from the soil source to the cell was less than a foot long and the air flow was set at 4 lpm flow with a 0.8 μm filter. See the graph in Figure 2 below. The last 20 second cell count while sampling was 661 counts. As soon as the pump was turned off the next 20 second count fell to 328. The next 20 second count dropped to 117. The counts then fell off more gradually, dropping to 91 and then a minute latter to 70 and then a minute or two later to around 55. The sample was aged and counted latter indicating about 140 pCi/l (5,180 Bq/m^3) of radon at 4 lpm flow rate. This extreme drop in counts indicates the soil is producing significantly more actinon which has a 4 second half life than radon. The decay also indicates there is some thoron in the soil but it is difficult to measure because of the very high level of actinon in the soil.

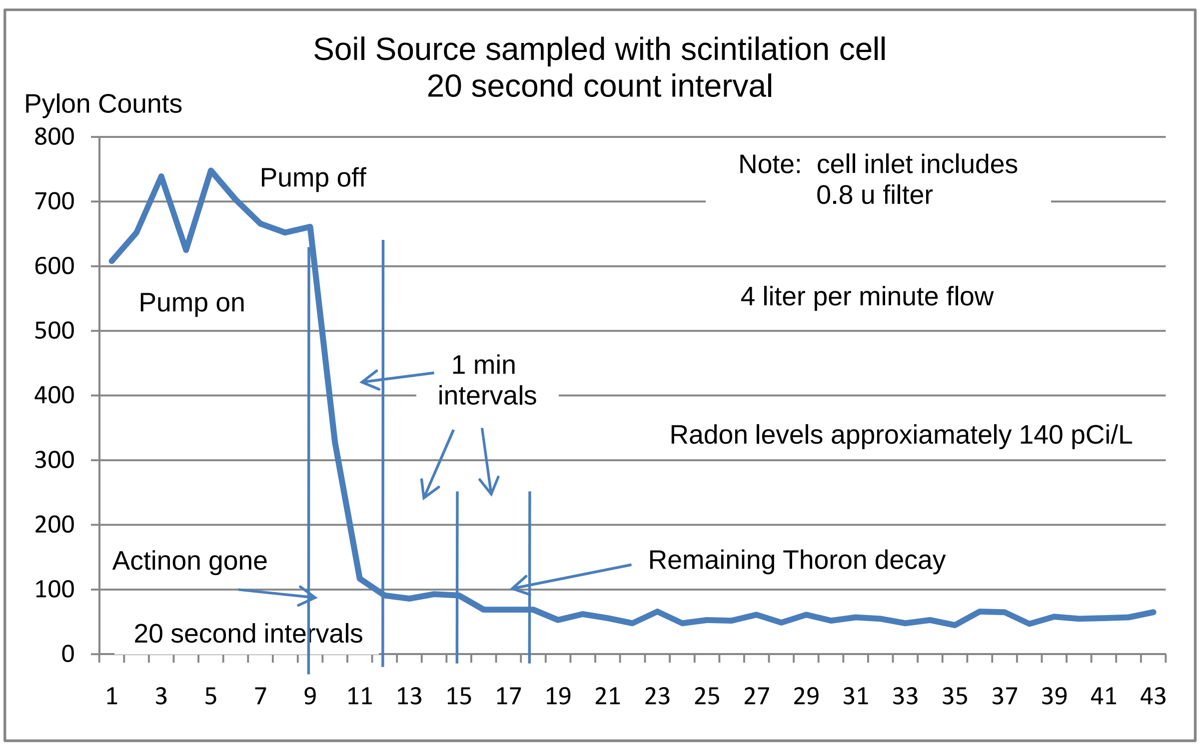

Figure 2 Soil Source Checked for Thoron & Actinon

Once it was determined that there was significant thoron and actinon being produced by the soil source, a 75 liter decay chamber was constructed that delayed the airflow into the final test chamber by 15 minutes (75 liters / 5 lpm flow) to ensure that both thoron and actinon were decayed out. A 47 millimeter 1 μm filter was installed inline before the final test chamber to collect most decay products produced by the actinon, thoron or radon. 1 to 5 lpm of air was pushed through the soil sources using a small aquarium pump. Dwyer flow gauges were installed before and after the test chamber to monitor the flow rate and ensure there was no leakage out of the chamber. The chamber exhaust air is vented to the outside. A typical flow through chamber set up is illustrated in Figure 3 below. Note that the test chamber had internal power outlets and a small mixing fan to create uniform levels inside the chamber.

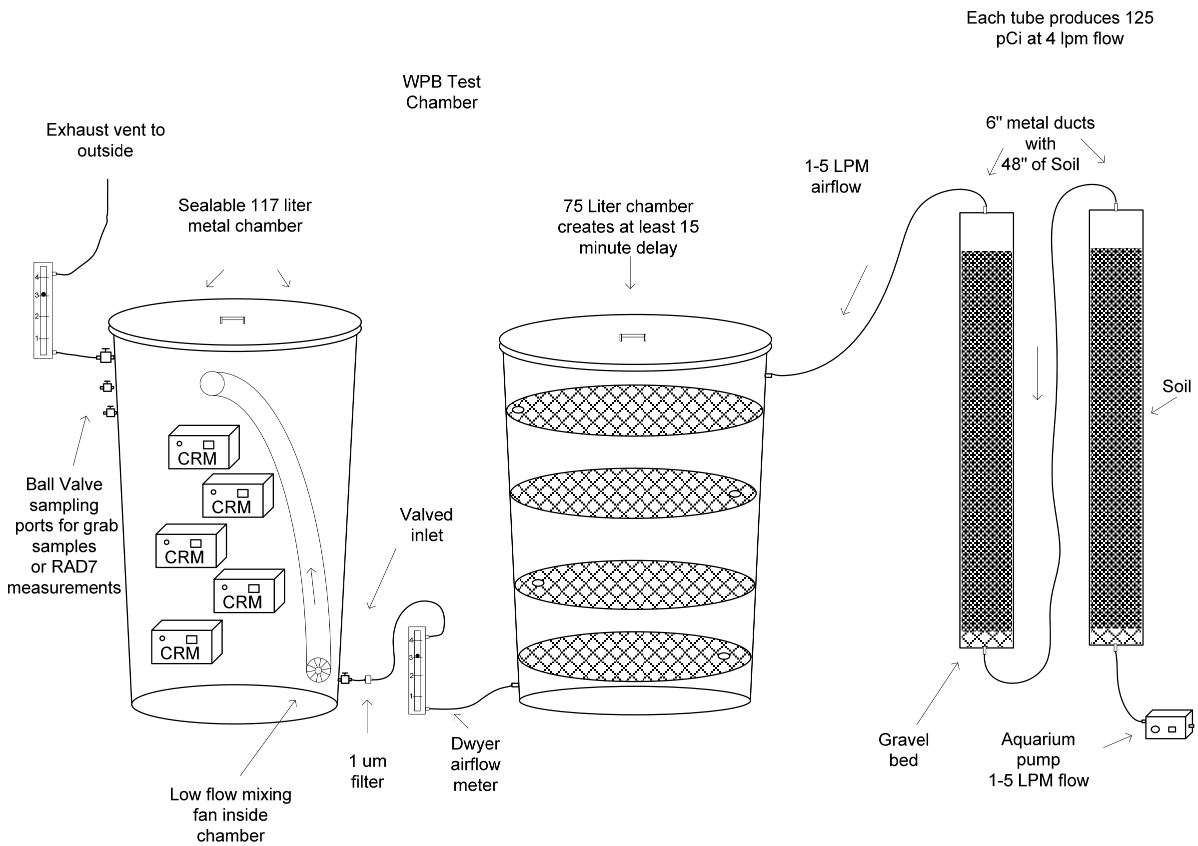

Figure 3 Soil Source Test Chamber

Ingrowth Comparison

The CRM's and E-PERM's response to ingrowth of radon was tested by sealing the detectors in a 122 liter chamber with a small radium source placed at the inlet to the interior mixing fan. The volume of the fans, CRM's and chargers placed in the chamber was subtracted from the empty chamber volume. The CRM volume was determined by measuring the components of each unit rather than the outside dimensions to factor in the free air area inside the CRM's. Table 1 below gives a table of the volume size used for each CRM. Note that the CRM volume was not based on the external CRM dimensions but the approximate mass volume of all the components of the CRM. The source of the radon is an antique toy that was manufactured in the 1920's by the same company in Pittsburgh that produced the gram of radium that was gifted to Marie Curie. The source produces no measurable 220 thoron. The radon levels would then ingrow depending upon the open volume of the chamber and the length of time the chamber was left sealed.

RS 800	Scout	EPerms	SN 1029
0.76 liters	0.56 liters	0.123 liters	0.66 liters
Pylon AB5 PRD	RS 500	Femto 510	RTCA OnGuard
2.5 liters	0.70 liters	0.61 liters	0.81 liters

Table 1 Detector volumes

A comparison of CRM measurements to an ingrowth of radon in a sealed chamber in Figure 5 below indicated the RAD7 which pumps air into its chamber every 5 minutes may have been responding to the ingrowth of radon more quickly than the other CRMs. All testing was done with the CRMs set to hourly intervals. A delayed response to an increasing radon concentration would reduce their calculated ingrowth.

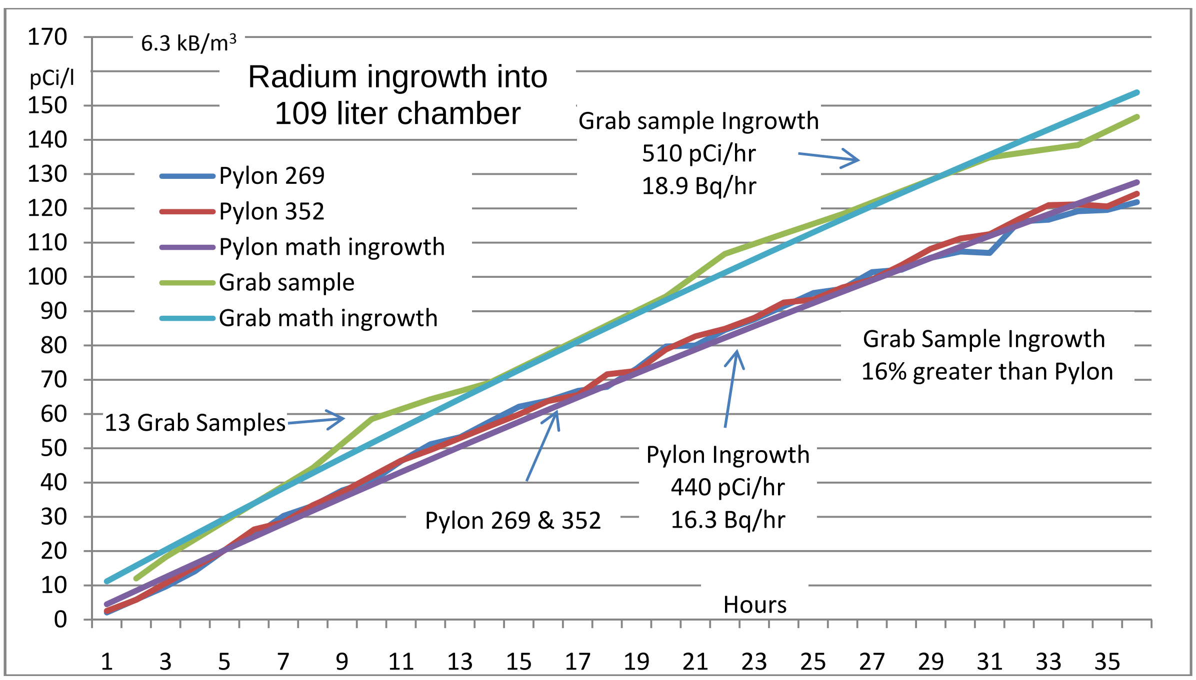

Figure 4 CRM In-growth versus Grab sample measurements

A second test was performed using a dozen Pylon 300A scintillation cells that were first measured for background count and then filled with a known radon concentration and then counted at least four hours later in order to calibrate their individual efficiency. Two Pylon AB5's and other CRM's were then placed in a sealed chamber with 109 liters of free air and a radium source. The RAD7 was not available for this second test. See the results graphed in Figure 4 above.

There were five small mixing fans inside the chamber during the 36 hour exposure. Single grab samples using the calibrated scintillation cells were taken every 2 to 4 hours during the exposure. The plotted ingrowth and the mathematical calculated ingrowth is shown in Figure 4 above along with the Pylon response and its mathematical ingrowth line. Note that the grab sample ingrowth of 510 pCi/hr (18,870 Bq/hr) is 16% greater ingrowth than the Pylon ingrowth of 440 pCi/hr (16,280 Bq/hr). The varying delayed response of different CRMs to increasing radon levels could be due to the different radon progeny each CRM counts to determine the radon levels or to other factors. The table 2 below gives the average amount of additional ingrowth each CRM would require to match the RAD7 and grab sample results based on this single test. Additional testing would be needed to confirm this response. The RadonAway RS800 and FemtoTech data is based only on the initial RAD7 data displayed in Figure 5 because their monitor results during the grab samples were significantly off.

Unit	Pylon	RTCA	Scout	SN1029	RS500	RS800	F-510
Correction %	+15%	+14%	+9%	+9%	+6%	+1%	+10%

Table 2 Correction factor for CRM in-growth delay

Although Figure 5 is a crowded graph some general CRM performance differences can be seen that repeated in other similar exposures. In general the Pylon AB5 and the RAD7 produced the smoothest line that makes determining ingrowth rate more accurate. The RadonAway RS800 had the next smoothest ingrowth line although the unit tended to under report the radon level increase during the initial 8 to 10 hours of exposure. It appears radon entry into the chamber of the RS800 is delayed thus producing the lag and facilitating the smoother line. This may be why the RS800 also had the least response to thoron. Because the RS800 tends to under respond for the first six hours, this data cannot be used for the ingrowth calculation. The FemtoTech 510 performed well until the radon levels climbed above 80 pCi/l (3000 Bq/m^3) when it would bias low. In most cases however the ingrowth measurements will not be above 80 pCi/l. Note that the RTCA On-Guard CRM does not record any results above 100 pCi/l (3700 Bq/m^3) and the RS800 does not record results above 200 pCi/l (7400 Bq/m^3). The Sun Nuclear 1029, Scout and RadonAway RS500 which are less expensive units had greater variability than the other detectors. Longer exposure period would help minimize the effect of this variability. The small size of the Scout and SunNuclear 1029 if the handle is removed does allow them to be placed under a large metal mixing bowl (7.5 liters) which also has one of the lower liters to

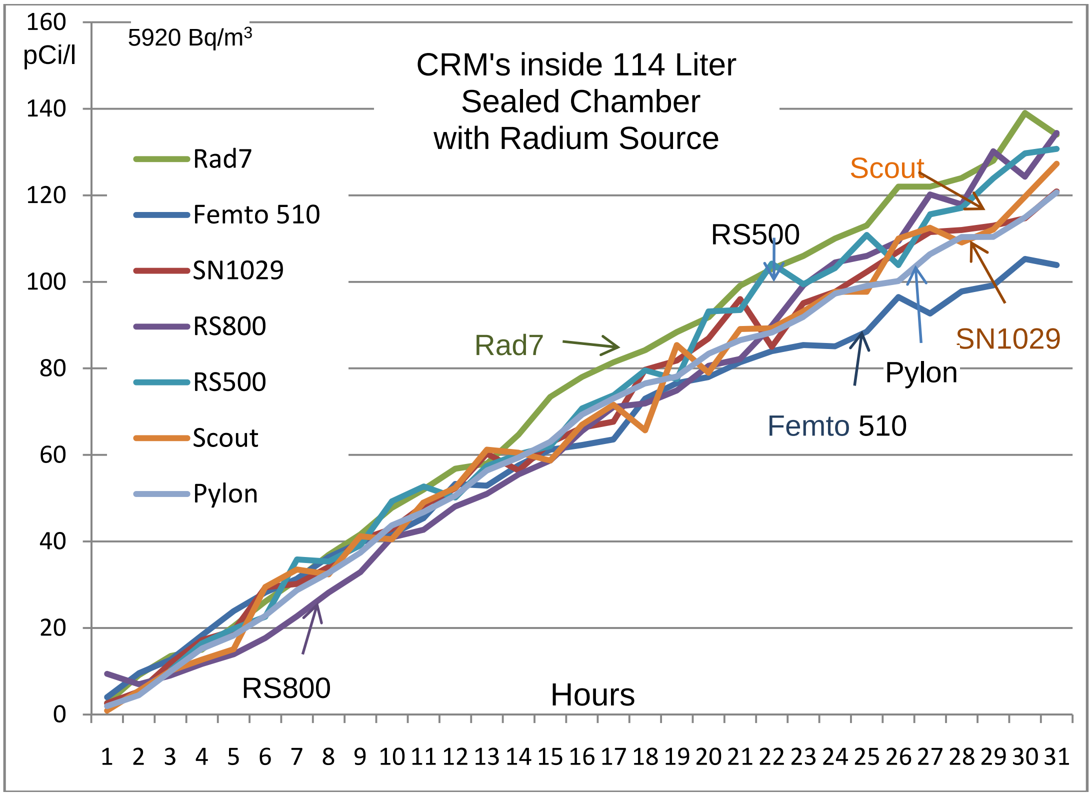

Figure 5 CRM In-growth Performance

square foot ratio and thus will produce the most radon increase per hour inside the accumulator. See Table 3 below.

Accumulator	liters	width	ft^2	m^2	ft^2/liter	m^2/liter
Small mixing bowl	2.95	8.5” 21.6 cm	0.39	0.036	0.13	0.012
Large mixing bowl	7.3	12.75” 32.4 cm	0.89	0.083	0.12	0.011
2.5 gallon bucket	9.63	10.25” 26 cm	0.57	0.053	0.06	0.006
Small trash can	8.65	8.375” 21.3 cm	0.38	0.035	0.04	0.004

Table 3 - Accumulator area to liters – larger ft^2/l or m^2/l higher the response

CRM Response to Slab with Thoron & Actinon

It was not possible to quantify CRM response to actinon because its half life of 4 seconds is too short. All of the CRM’s and E-PERMs were however tested to determine their response to thoron. In typical indoor air measurements, a detectors thoron response would not be considered important because it is assumed that thoron's half life of 55 seconds does not allow enough time for it to reach the breathing or testing zone if the source is the soil. Thoron sources inside the dwelling would be more likely to influence CRMs that were sensitive to thoron levels. Flux measurements made under an accumulator however place a radon detector in very close proximity to the source which might contain thoron. A detector that is very sensitive to thoron could cause a false interpretation of the results if thoron is present in the material. In most cases the diffusion length of the material is long enough to decay out the thoron. Because thoron's half life is very short it will reach a maximum concentration inside the accumulator during the 1st hour of exposure.

Table 4 below is the calculated response that thoron would have if there was equal alpha activity from thoron and radon and the detector only provided an average such as the Pro-Series 3 monitor or an E-PERM. If CRM's are used under an accumulator the thoron response can be eliminated by using the slope of the ingrowth after 4 hours to determine the emanation rate since the radon will continue to ingrow while the thoron will be steady state.

If only average is used for this exposure length	E-PERM bias if equal Thoron & Radon	Pro-Series 3 bias if equal Thoron & radon
12 hours	+ 0.8%	
24 hours	+ 0.4%	
48 hours	+ 0.2%	+ 1.0%

Table 4 Effect of thoron on average of detector results

All of the CRM's and E-PERMs were tested to determine their response to thoron. A 114 liter chamber was constructed with two computer type fans installed 1/3 up from the bottom of the chamber and two additional computer type fans 2/3 of the way up. The four fans created a counter clockwise air flow with a velocity of 1.3 meters per second or approximately 1 revolution around the chamber per second. Each fan had thorium coated Aladdin lantern mantles suspended in the fan's airflow. See photo below in Figure 6.

Figure 6 - 114 liter Thoron Chamber using Aladdin mantles & fans

Two sampling ports in the walls of the chamber were used to flow air through a RAD7 that is capable of measuring thoron concentrations.

The CRM's and E-PERMs were exposed in the sealed chamber for 18 to 48 hours. The 4 to 12 Aladdin mantles produced enough thoron to maintain the chamber at 200 to 600 pCi/l of thoron as measured by the RAD7. The thoron concentration was measured by averaging 30 minutes of sampling data taken during two periods during the exposure length. The RAD7, which was located outside the chamber, was set up with short tubing and the small desiccant holder to minimize thoron decay loss.

In each exposure outdoor air was blown into the chamber prior to sealing the chamber to minimize radon levels. Any activity above background radon levels that the detectors recorded above the chamber radon background was assumed to be caused by thoron.

Table 5 below demonstrates the dramatically different thoron response of the CRM monitors that were tested. The RadonAway RS800 had very little response to thoron. When the RS800 was exposed to 550 pCi/L (20,300 Bq/m^3) of thoron it only displayed an average of 3.4 pCi/l (126 Bq/m^3). The RadonAway RS500 which has a very similar metal case however responded dramatically to thoron concentrations. It also had an increasing response which may have been due to a response to the decay products of thoron inside the chamber. See Figure 7 below. This increasing response would bias the results if there was significant thoron in the material being flux tested. The Femto-Tech 510 also responded to thoron but did not have an increasing concentration over the exposure. The Scout, Sun Nuclear 1029 and Pylon AB5 PRD had some limited response. The inexpensive Pro-Series 3 radon monitor also responds significantly to thoron. E-PERM S-Chambers with short term electrets had an average response to thoron of 4%.

RS 800	Scout	EPerms	SN 1029	On-Guard
0.5%	6.4%	4.0%	5.5%	10.9%
Pylon AB5 PRD	RS 500	Femto 510	Pro-Series 3	
2.8%	67%	17%	22%	

Table 5 - Detector Response to 220 Thoron

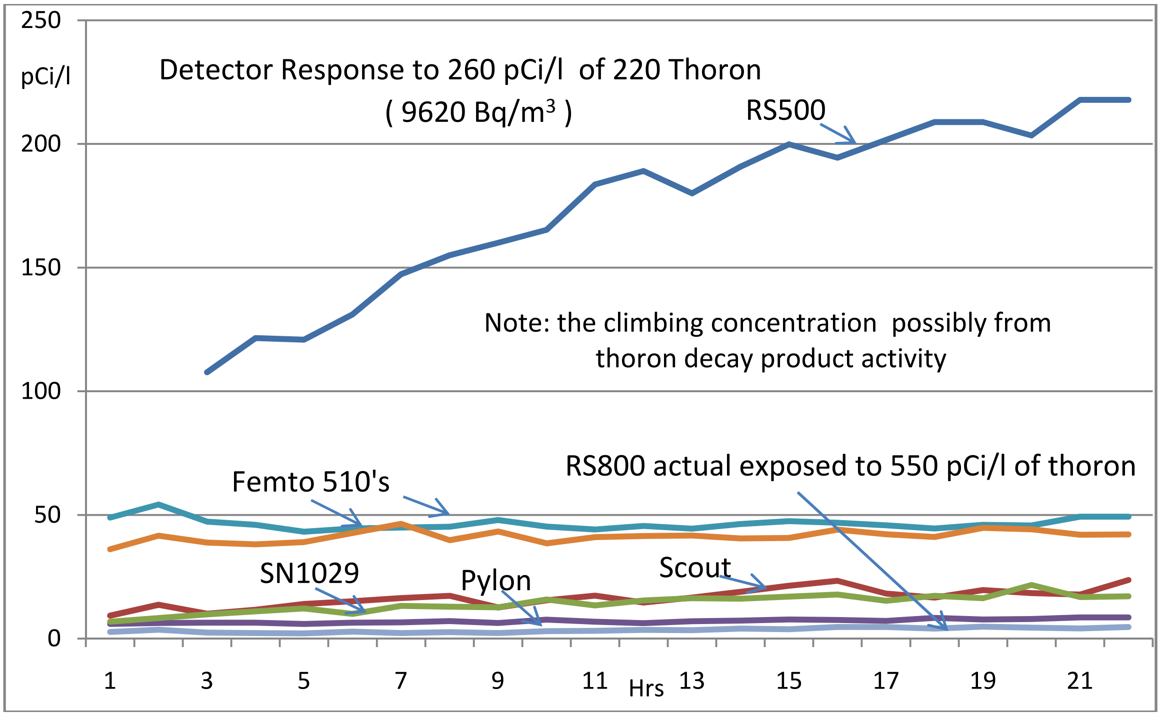

Figure 7 - Detector response to steady state 220 Thoron

Reducing Thoron Response

Any lengthening of the time it takes for thoron to reach the detectors sensors will reduce the detectors response to thoron. Radon, thoron and actinon will pass through but be slowed down by thin plastic depending on the plastic density and molecular structure. If one is trying to use the E-PERM thoron chambers to measure thoron it is important to know the background radon without having the detector respond to the thoron. Readily available zip lock food storage bags were tested to determine if they could reduce entry of thoron. The data in table 6 below was obtained by exposing different configurations of S-Chamber E-PERMs for one to two days in the thoron chamber at two different concentrations and once to only an ingrowth of radon. In each thoron test all the EPERMs were suspended in the center of the chamber to allow free circulation of thoron enriched air around them. Three different diffusion barriers were tested, Tyvek envelope, Ziploc brand vegetable bag that has pin holes in the plastic every centimeter (3/8") and double Hefty One Zip brand bags. The thickness of the plastic was not available. In order to induce a longer travel path for the thoron an E-PERM was placed inside an open Hefty bag and both were then placed inside a second open Hefty bag. E-PERMs without any bag covering were also exposed.

E-PERM setup	550 pCi/l 20.3 kBq/m^3 thoron	191 pCi/l 7 kBq/m^3 thoron	Just radon
No covering	3.6%	4.0%	100.0%
Inside Tyvek bag	N/A	3.7%	100.0%
Inside Vegetable bag	1.7%	2.8%	97.5%
Inside 2 zip-loc bags	0.6%	1.5%	85.0 %

Table 6 – Thoron & Radon Reduction from plastic bags

Building Materials

Two concrete slabs were hand mixed and poured in forms. Sakrete 5000 plus concrete mix was purchased locally from a building supplier and used for both slabs. This higher strength concrete was used to closer mimic commercial post stressed concrete. Each slab was carefully mixed using the water to concrete ratio specified by the manufacturer. The drying time of the slabs was reduced by keeping the slabs covered and occasional misting them with water for 14 days. The slabs were allowed to dry for at least 60 days before any testing was done on the slabs. One of the slabs referred to hereafter as the “mixed slab” had 9 ounces of high radon/thoron/actinon soil thoroughly mixed in with the cement to raise the radon emanation rates. The mixed slab is 17” by 17” by 3.5” thick (43x43x8.9 cm) (36.7 kg). The 3.5” edge around the perimeter of the slab was covered with 17 mil aluminum tape to allow radon emanation from only the two flat surfaces for a total area of 4 square feet (0.37 m^2). See photo of this slab in Figure 19 below. The second slab referred hereafter as the “cold slab” is 16” round by 4.5” thick (40 cm round x 11.4 cm thick)(31.7 kg). The 4.5” perimeter of this slab is also covered with aluminum tape. This slab has 2.8 square feet (0.26 m^2) of exposed slab.

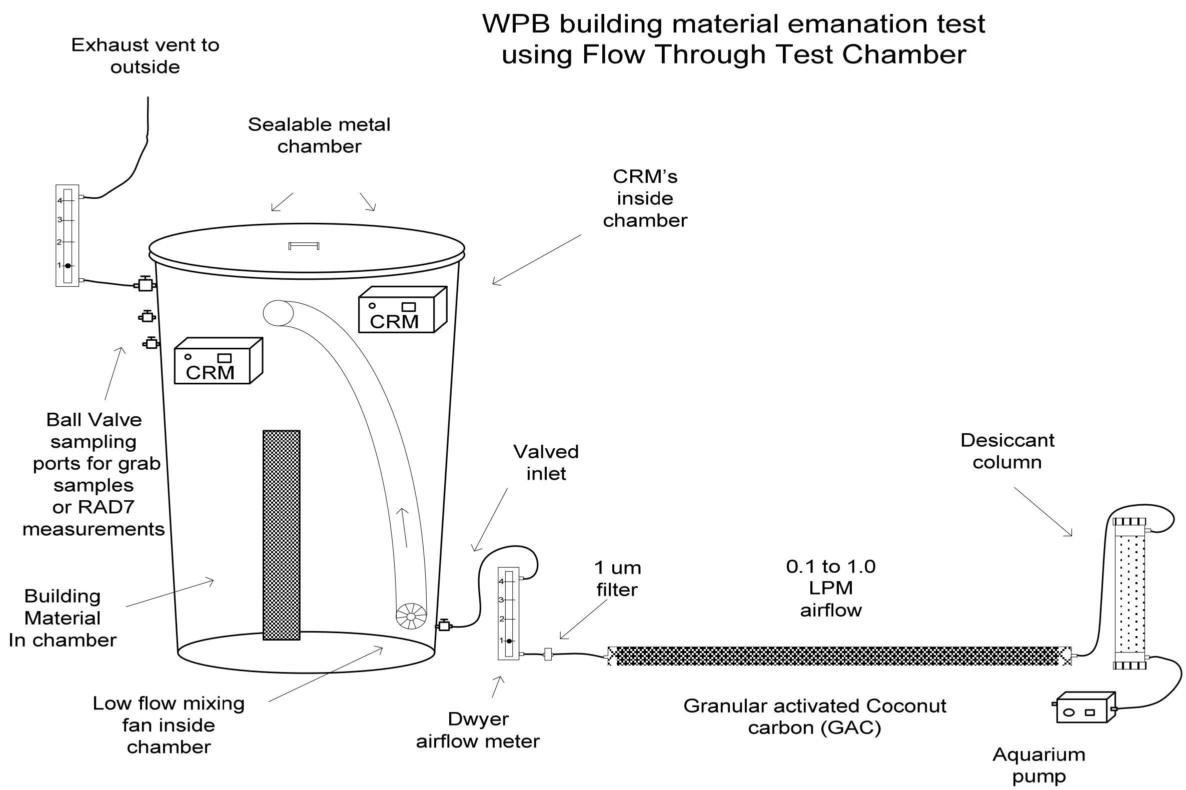

Figure 8 – Slab Flow through Measurement Chamber

Testing Cold & Mixed Slab with Ingrowth & Flow through

The radon emanation rate for both slabs was determined by placing them individually inside a sealed metal chamber and measuring the ingrowth that takes place. To test the ingrowth method the mixed slab emanation rate was also measured by a flow through method. The cold slab did not have a high enough emanation rate to allow a flow through test. The flow through method eliminates the need to know the exact volume inside the chamber and the determination of the emanation rate is a straight forward calculation but the exact flow rate through the chamber must be known and the radon levels of the inflowing air must also be know. The flow rate was determined by using a Dwyer airflow gauge that was cross compared to a lab research bubble film flow gauge. Note that the authors six flow gauges vary from 8% high to 5% low compared to the cross calibrated unit.

Any radon in the inflowing air will bias the reading. Even outdoor air can often exceed 1 pCi/l (37 Bq/m^3) at night. In order to eliminate the need to measure the radon levels of the inflowing air a radon filtering method was tested. A 3" PVC pipe, 10 feet long (3.6 cm X 3 meters) was filled with 0.5 cubic feet (14 liters) of granular activated coconut carbon (GAC). To test the effectiveness of the carbon filter, one lpm of desiccant dried air containing 150 pCi/l (5500 Bq/m^3) was pushed through the carbon. It took eight days and six hours of continuous steady flow rate of 1 lpm before radon broke through the carbon. This carbon was then replaced with fresh carbon. The GAC filled PVC pipe makes an excellent pre-filter to eliminate any need to subtract background radon from the measured radon levels produced inside the chambers. The air entering the carbon tubes should be dried with a desiccant to maintain maximum radon reduction. Figure 8 above illustrates how a flow through chamber for testing building materials can be set up. The mixed slab was tested with a modified flow through setup by adding a second chamber that the CRM's were placed in to allow thoron to decay out and minimize their influence on the CRM's.

The following three charts represent the three different methods of measuring emanation rate of the slab that had hot soil mixed into it. Figure 9 is the flow through method. Figure 10 is the total slab in a sealed chamber method. Figure 12 is different CRMs sealed under accumulator metal buckets. Note that the ingrowth emanation rate is determined by using the formula in Table 7 below. These methods produced results that varied from a high of 200 pCi/ft^2/hr to a low of 150 pCi/ft^2/hr or a total variation of about 25%.

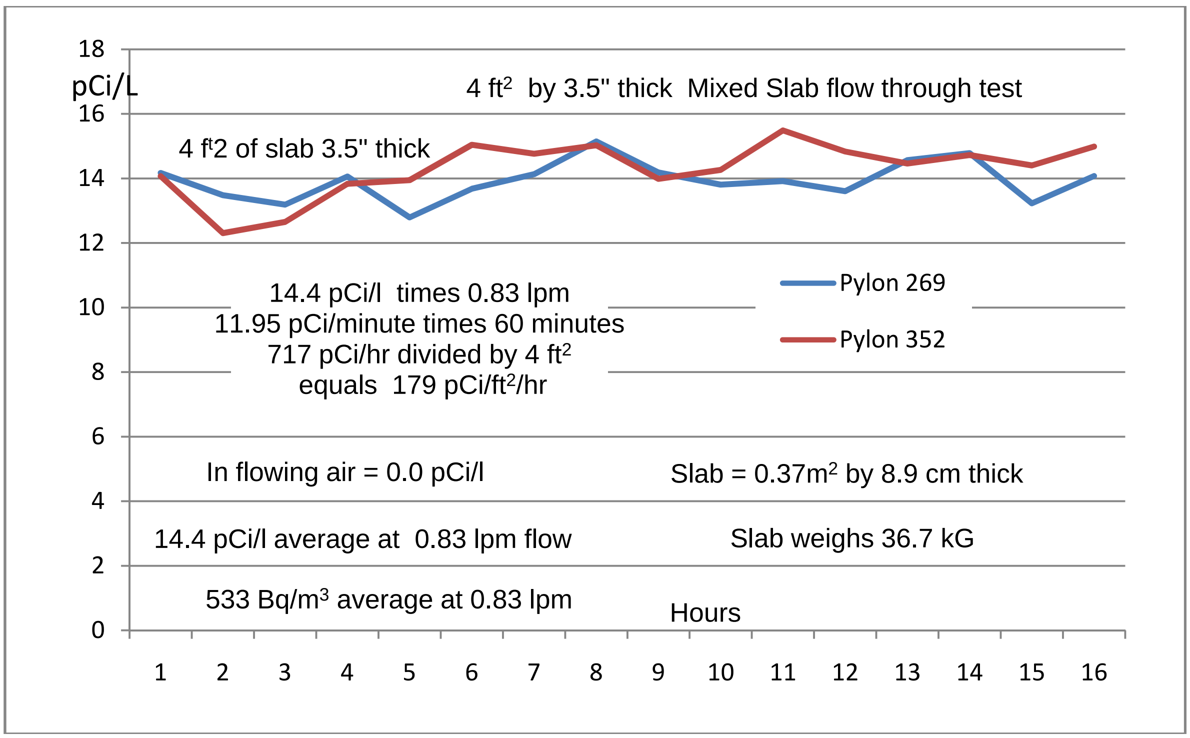

Figure 9 – Slab Flow through Measurement Chamber

The ingrowth of radon into a sealed chamber or accumulator in Figure 10 below is compared to the mathematical ingrowth using the formula in Table 7. Using this formula allows any exposure duration to be used and the initial radon in the chamber to be subtracted from the ingrowth created by the building material. Unless carbon filtered air is used it will be necessary in most cases to approximate this initial radon concentration based on ambient radon measurements or make a grab sample measurement.

The mathematical ingrowth needs to incorporate the free air volume of the accumulator (accumulator volume minus the volume of the detector(s) & building material), the area of the slab that is exposed and the initial radon levels when the detector is sealed in the accumulator.

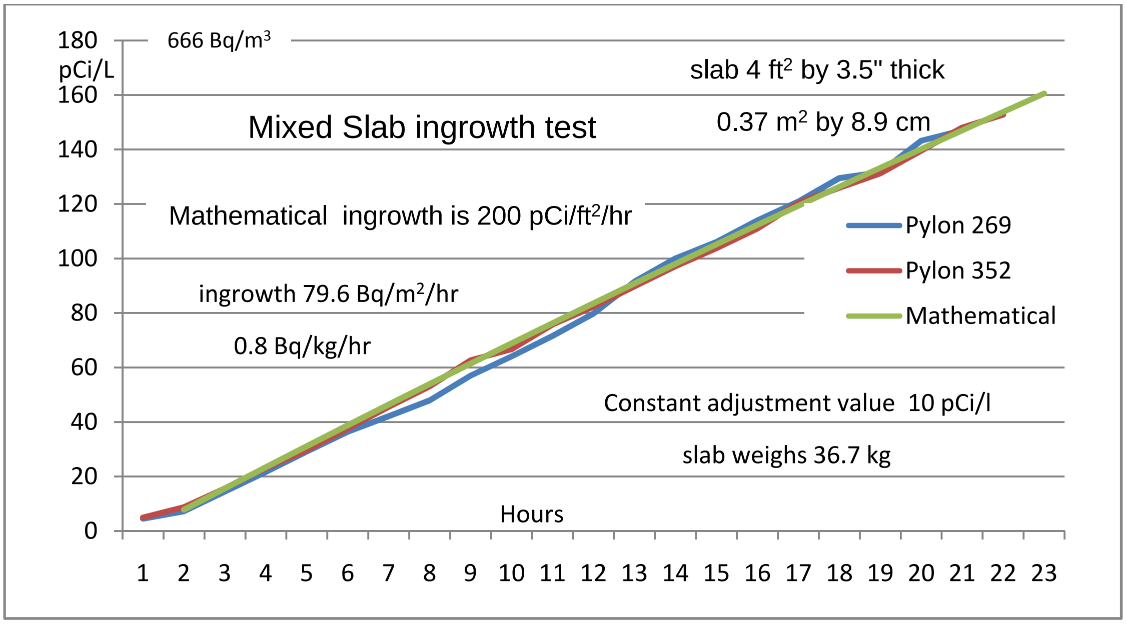

Figure 10 – Slab In-Growth Measurement Chamber

The following formula, which can be entered into a spreadsheet program, is repeated each hour to obtain the mathematical radon concentration at each hour during the exposure:

SR = Starting Radon under the accumulator
HR = Exposure hour
AR = Area accumulator covers in square feet
(this can be m^2 if source strength is changed to $Bq/m^2/hr$)
VOL = Free air volume inside accumulator in liters
X = Multiplication addition & subtraction symbols
CAV = Constant Adjustment Value
SS = Source Strength in pCi/sq ft/hr
(this can be $Bq/m^2/hr$ if area is changed to m^2 and Bq units are used)

(SR X (exp(-0.1813 X (HR / 24))))
+
((((SS X AR) X 24) / (VOL X 0.1814)) X (1 – (exp(-0.1814 X (HR / 24))))) – CAV

Table 7 – CRM Accumulator Source Strength (SS) Formula

Note that the first part of the formula is used to subtract out the diminishing effect of radon trapped under the accumulator at the start of the exposure. The second formula includes a Constant Value Adjustment (CAV) which is used to adjust the mathematical ingrowth line up or down so that it lines up with the CRM data plotted on the chart. The CAV must be a constant value throughout the exposure so that it does not affect the slope of the mathematical ingrowth only it's placement on the chart. The need to adjust the mathematical ingrowth is due to CRM response delay, thoron, or different detector starting times versus chamber sealing. The CRM data and mathematical ingrowth value from the accumulator formula are both plotted in a spreadsheet. The Source Strength value and Constant Value Adjustment (CAV) of the accumulator formula are varied until the slope of the mathematical ingrowth matches the slope of the CRM data.

Flux Testing the Slabs with Accumlator Chambers

The emanation rate of both slabs was tested by sealing a metal chamber (accumulator) on top of the slabs with a CRM installed inside. In each case the slab was elevated off the floor to allow open air circulation. The accumulator, which should be made of metal or glass to avoid any diffusion of radon out of the chamber, can be a metal mixing bowl or metal bucket. All seams in the accumulator must be caulked or foil taped diffusion tight. The accumulator should be just large enough for the CRM to fit inside to maximize the radon ingrowth. The volume of the accumulator in liters needs to be obtained by carefully measuring the interior dimensions or by filling the accumulator up with a known quantity of water. The material volume of the CRM or E-PERM needs to be known and subtracted out of the accumulator volume The volume of each CRM was measured and the approximate values are given in Table 1 above.
Flexible plumbers putty was used to seal the accumulator with the CRM inside to the slab. The area of exposure needs to include one half of the area the putty covers. Most putty's have some oil content and will leave a stain if the surface is porous. See photo in Figure 11 below of the RS800 and a 2.5 gallon (9.6 liter) metal bucket. All seams inside the bucket were sealed.

Figure 11 – RS800 sealed under 9.6 Liter Accumulator for Mixed Slab

The CRM's need to be left under the accumulator for 12 to 48 hours. The data is input into a spreadsheet graph and the source strength value of the mathematical ingrowth formula and the Constant Adjustment Value (CRV) are adjusted until the mathematical ingrowth matches the actual CRM ingrowth. The source strength value is the emanation rate of the material in pCi/ft^2/hr or Bq/m^2/hr.

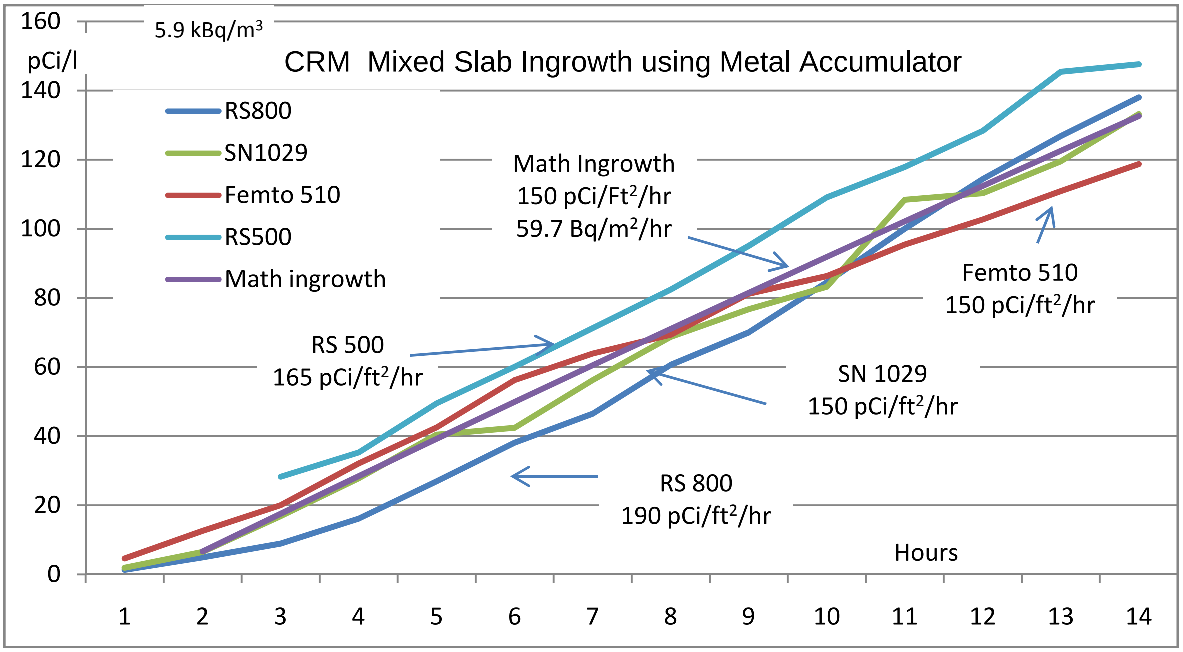

Figure 12 – CRM's sealed under Accumulator over Mixed Slab

Figure 12 shows the difference in CRM performance and the emanation rate based on using the mathematical ingrowth formula as previously discussed. RS 800, which is the least sensitive to thoron lags behind and then over responds by 25% compared to the SN1029 and Femto-Tech 510. The Femto-Tech 510 starts to fall off the ingrowth slope at 85 pCi/l but it responds well up to that point. The RS 500 has a 10% higher ingrowth than the Scout and SN 1029. No E-PERMs were exposed under the accumulator with the mixed slab because of a high gamma reading.

Emanation from unaltered Retail Concrete

A second slab without any additional soil added was made with "Sakrete 5000 plus" concrete mix obtained from a local building supplier. The emanation rate of radon from this mix is too low to use the flow through method to measure the entire slab (16" round by 4.5" thick - 40 cm round by 11.4 cm thick). Instead the entire slab was sealed inside a chamber with two AB5 Pylons. See the results in Figure 13 below.

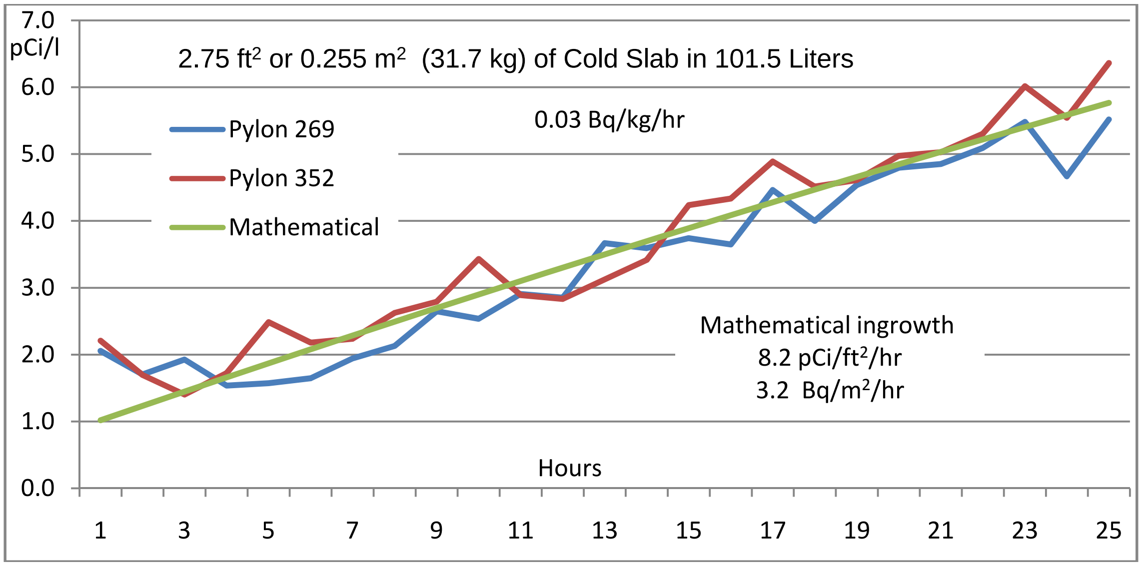

Figure 13 – Pylon ingrowth data compared to mathematical ingrowth

The mathematical ingrowth is determined by using the formula in Figure 17 above and adjusting the source strength and CAV until the CRM data and the mathematical ingrowth match. A thoron sniff measurement using the RAD7 during the ingrowth did not reveal any significant thoron concentrations coming from the cold slab.

The ability to obtain similar results using CRM's and E-PERMS under smaller accumulators is displayed in the graph in Figure 14. The CRM's were placed under either a 9.6 liter or 7.4 liter metal bucket that was sealed on top of the slab. Note the variation in measurements when using a less precise Scout, SN1029 or RS500. These monitors need to be exposed for longer periods to improve accuracy. The full slab test in Figure 13 indicated an emanation rate of 8.2 pCi/ft^2/hr (28.2 Bq/m^2/hr). The SN1029 and RS 500 are within 10% of the total slab measurement while the RS 800 was 27% lower and the FemtoTech 510 is 39% lower.

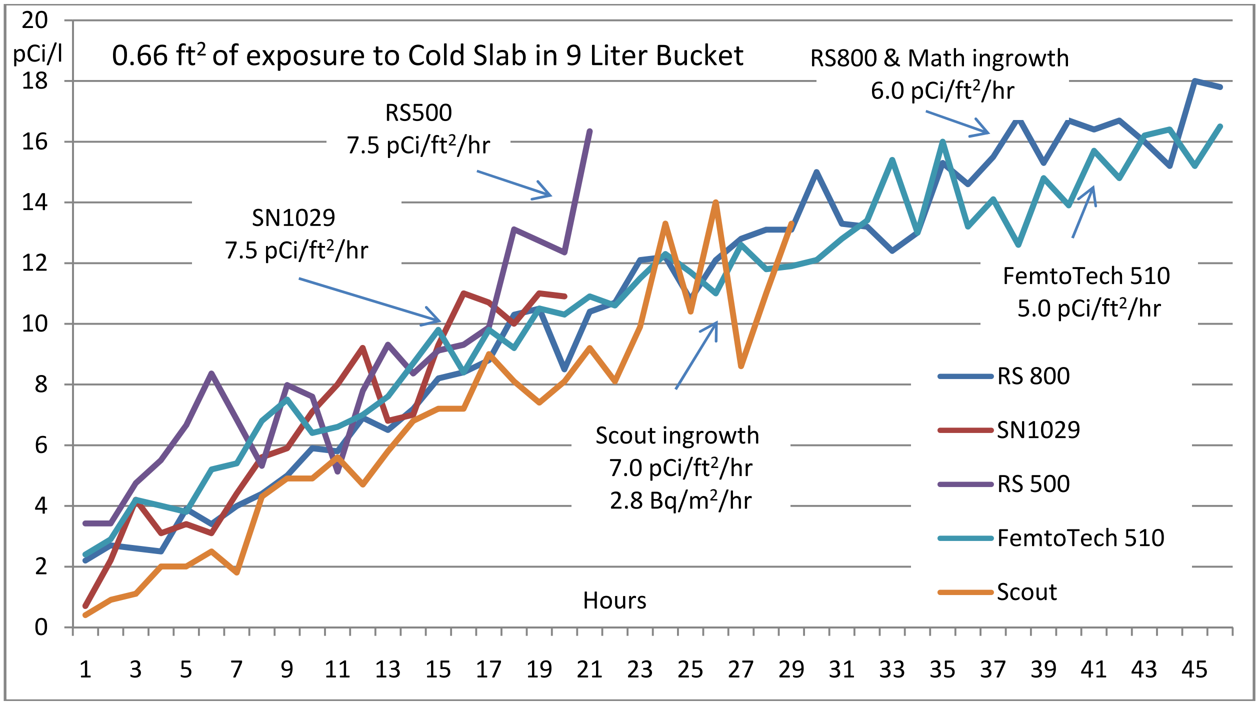

Figure 14 – CRM compared to mathematical ingrowth

E-PERM's were also exposed a number of times under accumulators. For E-PERM measurements it is important to know the initial radon levels at the start of the measurement and the gamma emanation which might be elevated in some cases above background from the building material. Gamma measurements can be made with a properly calibrated gamma survey instrument or more accurate measurements can be obtained by using 2 mR gamma dosimeters obtainable from Rad Elec Inc that are exposed over a one to two day period and then re-charged with a portable charger. See photo in Figure 15.

Figure 15 – 2 mR Gamma Dosimeter & re-charger

The ambient radon in air concentration trapped inside the accumulator that is decaying during the exposure period needs to factored out of the ingrowth measurement. A less precise method is to approximate the initial radon measurement based on average radon in air measurements made in the same location and then use the first part of the formula in Table 8 to determine the Starting Radon Influence (SRI). A more precise method if the initial radon concentration is not known is to seal an E-PERM in a glass jar at the beginning of the measurement. The average radon concentration of the E-PERM in the jar is the SRI value. The SRI value is subtracted from the radon measurement obtained under the accumulator (RUA).

The formula for obtaining this measurement is given in Table 8. Note that the lower the emanation rate the more critical it is to measure the starting radon concentration.

If the E-PERM is immediately closed up at the end of the accumulator exposure the E-PERM's response delay to the in-growing radon will bias the average reading low. This effect is more pronounce for an in-growth exposure of increasing radon concentration than a steady state exposure because the highest radon concentration happens at the end of the exposure. One method of compensating for the final out-gassing of radon in the chamber after the exposure and the final decay of the radon short lived decay products left in the E-PERM chamber is to leave the E-PERM open an additional 3 hours in a low radon environment. This would be in-practical in most cases because of the availability of a low radon environment and the time constraint of waiting three hours. To test the amount of bias at the end of an ingrowth exposure, 12 E-PERMs were exposed to a radon ingrowth inside a sealed chamber. Six of the E-PERMs were read immediately and 6 were left open in a lower radon environment (outside mid-afternoon) and read three hours later. The difference equaled about 10% higher emanation rate which is added to the formula in Table 8. This is similar to the CRM bias.

If the influence of the starting radon concentration is not measured using the E-PERM sealed in a jar method then the starting radon influence (SRI) is determined by the first formula given below which can be entered into a spreadsheet. The SRI is then included in the second formula to determine the emanation rate.

RUA = E-PERM average radon under accumulator measured by an E-PERM
ARL = Approximate ambient radon level when E-PERM is sealed
SRI = Starting Radon influence
(use either E-PERM average in sealed jar or 1st part of formula in Figure 24)
EXD = Exposure Days
AR = Area accumulator covers in square feet
(this can be m^2 if source strength is changed to $Bq/m^2/hr$)
VOL = Free air volume inside accumulator in liters
X = Multiplication symbol

SS = Source strength in pCi/sq ft/hr

SRI = (ARL X (1- exp(-(0.1813 X EXD))) / (0.1814 X EXD))

SS = ((((RUA-SRI) X VOL X 0.1814) / AR) / (1-((1- exp(-0.1814 X EXD)) / (0.1814 X EXD))) / 24) X 1.1

Table 8 – E-PERM Accumulator Source Strength (SS) Formula

Note that the first calculation (SRI) determines the diminishing effect of radon trapped under the accumulator at the start of the exposure. Single S-Chamber E-PERM's were exposed under an accumulator sealed on top of the cold slab.

Pylon average	E-PERM smooth side	E-PERM rough side
8.2 $pCi/ft^2/hr$	5.5 $pCi/ft^2/hr$	6.0 $pCi/ft^2/hr$
Ingrowth correction	Final decay correction	Final decay correction
1.15	1.1	1.1
9.4 $pCi/ft^2/hr$	6.0 $pCi/ft^2/hr$	6.6 $pCi/ft^2/hr$
3.7 $Bq/m^2/hr$	3.5 $Bq/m^2/hr$	3.6 $Bq/m^2/hr$

Table 9 – E-PERM under accumulator versus Pylons with cold slab ingrowth

The E-PERM's were placed under 3 liter accumulator bowls and they calculated emanation rate was 33% lower than the Pylon. It is unclear why they responded so much less. The Pylon exposure with the total concrete slab was not repeated to determine if the total emanation rate out of the concrete was reduced because the summer months had higher outdoor humidity levels that the slab was exposed and there may have been a decreased emanation rate because of humidity being greater than 80%. See paper on radon emanation and moisture content of concrete in references below.

Measuring Granite Tiles & Countertops

Granite typically contains 238 uranium and 226 radium which decays into 222radon which will escape into the air. There is concern that granite with unusually high levels of radium could significant increase the radon levels if it was installed in an air tight homes or areas of the home that had limited air exchange. Several pieces of granite were obtained that had higher than average emanation rates of radon in order to test the ability to measure the emanation rate using the accumulator method. These pieces of granite were first measured by placing them in a sealed chamber with one or two AB5 Pylons. The graph of 1.25" (3 cm) thick granite in Figure 18 is the highest emanating granite slab that was tested. Granite emanation rate in this study uses units of square feet or square meters of the polished top side but the granite is actually emanating from both sides of the material although not at equal rates. Note that the emanation rate across the granite surface is also likely to vary significantly.

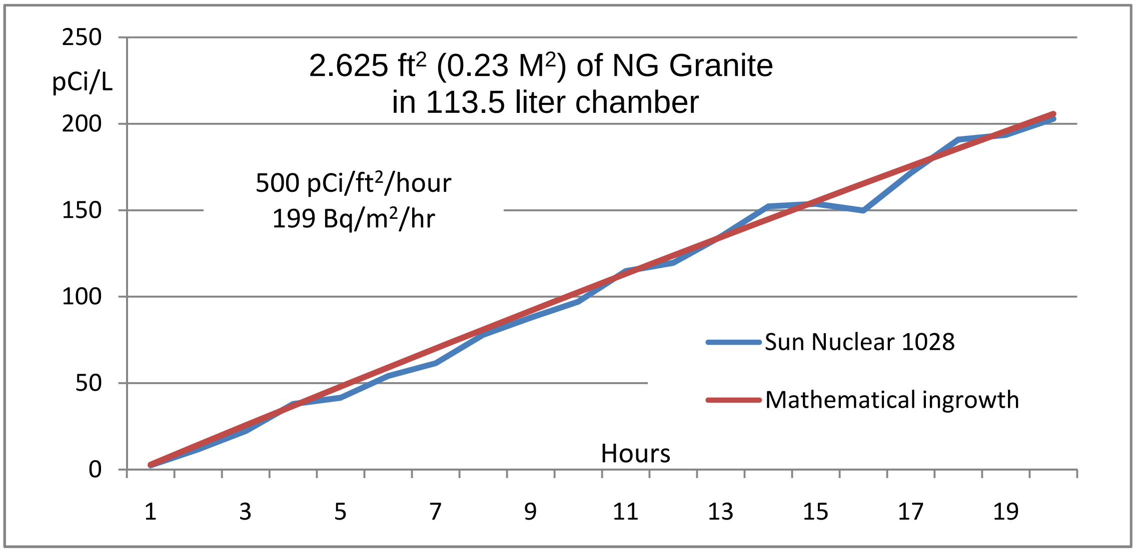

Figure 16 – Granite Emanation Rate in a sealed Chamber

The accumulator method was used to measure the emanation rate of the granite samples by sealing a metal trash can (7 to 8 liter size) with a CRM's inside to either side of the granite. The volume of the CRM is subtracted from the volume of the accumulator to determine the actual free air. It was determined that the granite area the accumulator covered needed to include half the width of the putty placed around the accumulator as additional area emanating into the chamber.

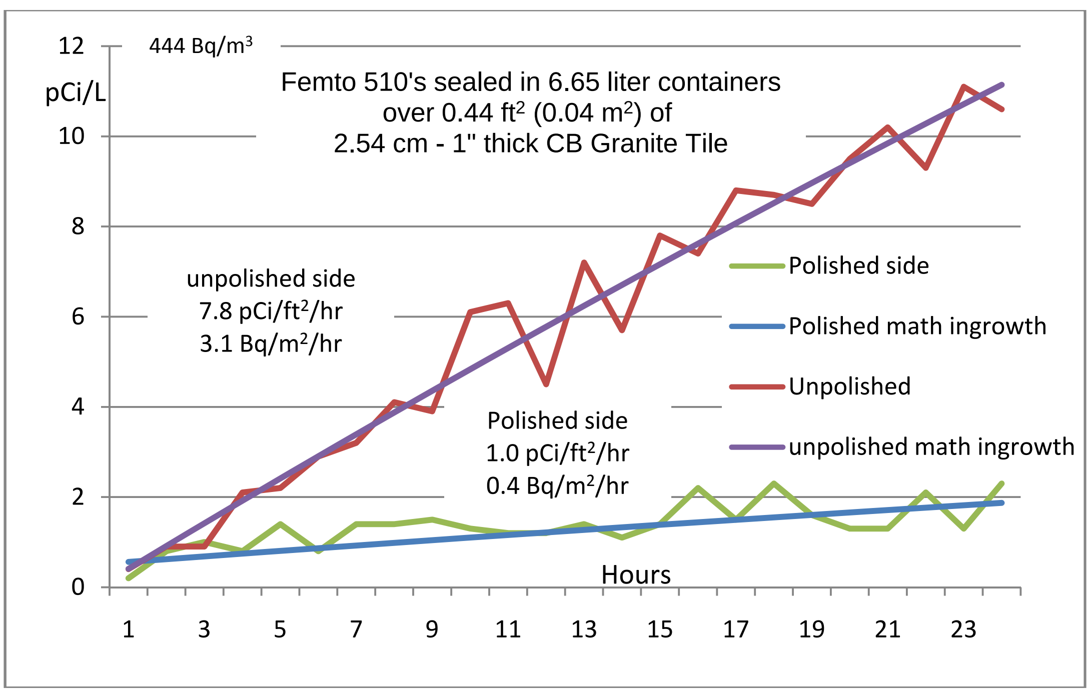

Figure 17 – Granite Emanation Rate Variation

Table 10 and 11 below depicts the significant difference between emanation rates of the polished side versus the un-polished side. The JB granite had a plastic fiber re-enforced coating that is apparently stopping 98% of the radon emanation out of the un-polished side. The CB granite was the reverse with almost 8 times more radon emanation from the un-polished side versus the polished side. The NG granite had 40% more emanation from the un-polished side versus the polished side. The difference between emanation rates is due to the increased surface area of the un-polished side and the different sealing methods used on the polished side. Polished granite typically has fillers installed to fill the small indentations in the granite before it is final polished. These results indicate the need to measure both sides of a granite counter top to avoid significant errors. It may be possible to test the underside of a granite kitchen slab by removing a cabinet drawer to gain access for the accumulator.

The last three columns in Table 10 gives the radon emanation rate determined by measuring the entire piece in a sealed chamber. The sum of the CRM accumulator measurements versus the total emanation matches within a few percentage points for two of granites. The NG granite has a total emanation rate that is almost 20% less than the sum of measurements of the two sides. Variation between measuring the total granite piece and individual sides could be due to variations in emanation across the surface of the granite.

Granite type	Polished emanation pCi/ft^2/hr	Unpolished emanation pCi/ft^2/hr	Total emanation pCi/ft^2/hr	Total emanation pCi/m^2/hr	Total emanation Bq/m^2/hr
NG granite	240	345	490	5274	195
JB granite	120	2	125	1345	50
CB granite	1.0	7.8	8.6	92.6	3.4

Table 10 – Granite Emanation Rate calculated with CRM's

Granite type	Polished emanation pCi/ft^2/hr	Unpolished emanation pCi/ft^2/hr
NG granite	199	376
JB granite	107	1.4
CB granite	1.6	11.9

Table 11 – Granite Emanation Rate calculated with E-PERMs

The likely variation across the granite surface and the difference in emanation rate between the polished and un-polished side can easily produce a significant bias in a single accumulator test of only one side of a granite slab.

The gamma rates of the four granite pieces were measured with a Bicron Micro Rem gamma meter that had been recently calibrated as well as with the Rad Elec 2 mR/hr gamma dosimeters. There was only a 10 to 15% difference in measurement results between the two types of gamma measurements. See picture of gamma dosimeters in Figure 15 above. The gamma measurements are compared to the measured radon emanation rate in Table 12 below. In each case the average of the background gamma was subtracted from three gamma dosimeters placed on top of the granite pieces. This small sample of four granite pieces indicates the ratio between the gamma emanation rate and the radon emanation rate varies by a factor of 8. The variation in the ratio between gamma measurements and radon emanation rate will likely indicate which granite pieces are unlikely to increase radon levels but are not likely to be able to indicate how much radon emanation is coming off granite based on gamma measurements.

Granite type	Gamma μR/hr above background	Total emanation pCi/ft^2/hr	pCi/ft^2/hr per μR/hr above background
NG granite	99.3	490	4.9
FS granite	25.0	508	20.3
JB granite	12.7	125	9.8
CB granite	3.4	8.6	2.5

Table 12 – Gamma emanation rate versus radon emanation

Calculating Radon Increase from Building Material Emanation Rates

Determining the increase in radon levels from a building material is difficult even if the building material has a uniform emanation rate. Radon emanation from concrete may be reduced by the materials placed over the concrete such as vinyl flooring or ceramic tile although drywall, paint, texture coatings or carpeting may provide very little reduction in emanation rate.
This total emanation rate per hour from the material is divided by the liters of outdoor air moving into the structure or room every hour to obtain the radon level increase. The amount of outdoor air entering a building can obviously change hour by hour depending upon wind load, temperature difference inside to outside, exhaust fan operation and window and door position. Any change to this ventilation rate will have a linear effect on the radon levels since the emanation rate from building materials is likely to be fairly consistent. The introduction of outdoor air into the dwelling will likely be well mixed if the unit has an air handling system that is operating. If there is no air handling system or it is not operating then the increased radon in air from the building material will vary from room to room depending on the room's volume versus exposure to the building material and the natural mixing taking place from room to room. If some assumptions are made, one can calculate the contribution of increased radon in a small home that is very air tight. An air tight home would be most influenced by building material emanation rate. The condominiums the author worked on had air change per hour (ACH) rates less than 0.1 ACH. If we use 0.1 ACH with a 1250 ft^2 (116 m^2) condominium the ventilation rate would be 28,316 liters per hour. If 40 ft^2 (3.72 m^2) of granite was installed in this size dwelling assuming even mixing of the air by an operating air handling system the radon levels

would be increased by the amounts given in Table 13 below. If the condominium floors and ceilings were constructed of concrete, as they typically are, there would be 2500 ft^2 of concrete exposure. If the emanation rate of the cold slab (9.4 pCi/ft^2/hr) is used, the radon increase will be around 0.8 pCi/l. The cold slab was however only 3.5 inches thick (8.9 cm) while a typical condominium slab is 7 to 8 inches thick (18 to 20 cm). The "diffusion length" of concrete (point where only 37% of the element is escaping) has been measured by other researchers to be around 10 cm (4"). The double thickness of the actual slab versus the tested cold slab will increase the surface radon emanation but it would likely not be linear. Note however that the concrete even using the cold slab emanation rate increases the radon levels a greater amount than the granite having an unusually high emanation rate.

CB Granite	JB Granite	NG Granite	Concrete
0.1 pCi/l	0.2 pCi/l	0.7 pCi/l	0.8 pCi/l
4 Bq/m^3	7 Bq/m3	26 Bq/m^3	30 Bq/m^3

Table 13 – Radon increase in 1250 ft^2 (116 m2) dwelling with 0.1 ACH
from 40 ft^2 (3.7$m^{2)}$ granite or 2500 ft^2 (232m^2)concrete at 9.4 pCi/ft^2/hr emanation

Summary

In most cases it will not be possible to take a sample of a building material and place it inside a sealed chamber with a radon monitor to measure the emanation rate. This study has demonstrated that placing a continuous radon monitor or E-PERM inside a metal or glass accumulator that is sealed to the emanating material surface is a reasonably reliable method for determining the emanation rate assuming the emanation rate is consistent across the surface of the material. It appears from the small number of granite samples tested that granite can have significant variation in emanation rates between surfaces . Concrete slabs however are likely to have significantly more uniform emanation rates assuming the material came from the same source and if there have been no coatings applied to one side of the concrete. To obtain emanation rates, it is necessary to know the exact volume of the accumulator, the amount of free space taken up by the detector and the area the accumulator is covering. The detector should be in place from 24 to 48 hours. Materials with low emanation rates should have 48 hour exposures. The emanation rate in pCi/sq ft/hr or Bq/m^2/hr can be determined by using the formulas given in this paper. The CRM ingrowth rate will need to be matched to a mathematical ingrowth rate obtained from the formulas and adjusted until it matches the ingrowth of the CRM data to determine the emanation rate. This emanation rate times the area of the material exposed inside the dwelling divided by the ventilation rate will give the expected radon increase provided by the material. Changes in the radon concentration will therefore be directly related to the ventilation rate of the dwelling.

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