Radon-in-Water Sampling Problems May Cast a Dark Shadow Over the Most Recent Federal Regulations

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Abstract

Numerous past studies of waterborne radon sampling and measurement techniques have concluded that today's most frequently used sample collection methods are cumbersome and/or require highly trained and careful technicians. All are prone to error if there is the slightest deviation from the prescribed procedure. Obtaining reasonable accuracy and precision requires a high skill level on the part of the individual collecting the water sample, a skill level that is impossible to expect from persons who are likely to perform sample collections very infrequently.

This paper summarizes the studies conducted by Vitz (1991), Burkhart, Gray and Martin (1991), and Hightower and Watson (1995) that show where most of the problems lie. It will also describe a new and proprietary sampling technique developed by the staff at Air Chek, Inc. (hereafter referred to as Air Chek) which is designed to eliminate most if not all of the sample collection problems. The problems of water sample transfer at the laboratory, as pointed out in the above-mentioned studies and revealed by our in-house studies, have also been solved by the Air Chek staff but will not be detailed here because of the highly proprietary nature of the method.

The latest release of the U.S. EPA radon-in-water MCL and AMCL is likely to bring many newcomers into the water testing industry. The impending final adoption of these Federal standards intensifies the need to incorporate better sampling techniques and standardized sample collection protocols, and to lay out a set of minimum guidelines which a measurement service must be able to meet in order to ensure that high-quality measurements are the ultimate result.

Introduction

In 1991, the U.S. Environmental Protection Agency proposed a maximum contaminant level (MCL) of 300 pCi/L for waterborne radon in municipal water supplies. 1996 Amendments to the Safe Drinking Water Act (SDWA) mandated the withdrawal of the 1991 proposed MCL and called for a new proposal by August 1999. The latest notification released in October 1999 leaves the MCL at 300 pCi/L, but adds an alternate MCL (AMCL) of 4000 pCi/L for water supplies inside specific geographic boundaries covered by an EPA-approved state program addressing radon in indoor air. The new rule will require testing for radon in municipal water

supplies for all that come under the guidelines: water systems serving 15 or more homes or 25 or more individuals. The MCL and/or AMCL will likely become the *de facto* standard for residential wells when the rule becomes law sometime in the year 2000. No EPA requirement is expected for residential wells, but the amount of residential testing may be large.

The quality of the measurement services will be a concern when waterborne radon tests are required. Several studies have shown that accurate test results required difficult procedures by skilled individuals to perform the proper sample collection (Vitz, 1991 and Hightower-Watson, 1995). The studies discuss the many variables that can affect the accuracy of radon in water measurements. The counting efficiency of liquid scintillation counters is excellent (Prichard, 1977), but when only 10-15 milliliters of water is captured using inconsistent sampling methods, the accuracy of the results suffers. This paper will introduce a new sampling procedure and briefly summarize many of the variables affecting the accuracy of radon-in-water measurements using liquid scintillation counting. The purpose is to remind everyone that proper sampling is critical to accurate analysis. The industry needs to reliably measure concentrations below the 300 pCi/L MCL proposed by EPA, and to do this we need to account for sources of error. The new Air Chek method will give water supply company staff, radon professionals, and homeowners a simple and reliable method for collecting radon-in-water samples that can then be analyzed with an expectable level of accuracy and precision.

A Description of Sample Collection Procedures

Four currently used sampling procedures will be described and reviewed. All methods use liquid scintillation for sample analysis as described first by Prichard (1977) and later by the U.S. EPA (1991). The methods reviewed are the *submerged vial* method, the *direct fill from spigot* method, the *US EPA* syringe method, and the *slow-flow* under a scintillant method. The first two methods collect a water sample into an empty vial and the second two require that the sample to be placed in a vial containing a chemical scintillant. Variables of each procedure will be described including vial material, cap liners, syringe types, and sample transfer. The Air Chek method will be described last and will be compared to the other sampling methods.

There are a few obscure, expensive, or older technologies for measuring waterborne radon. They will not be discussed because of their limited or nonexistent use today.

The Submerged Vial Method

The submerged vial method appears to require little skill to perform. No special equipment is required, except for the supplied vial. The user is asked to hold a bowl or bucket of water up to a faucet or spigot and to let it overflow a number of minutes (varies by vendor) with the water fixture outlet below the surface. When the overflow time has elapsed, the vial and cap are to be submerged entirely under the water "as deep as possible." They are to be held underwater, in a position that will allow all of the air in the vial and cap to be replaced by water. The vial is capped before it is removed from the water. Although this method is easy to set up (albeit very messy) the final results suffer the largest negative bias of all the methods described in this paper.

The cause of the low bias can be attributed to the many variables that can occur during the filling and overflow of the larger collection container. First, the depth of the container. During filling, the water is dropping from the faucet into the rising water, all the while causing a great deal of agitation and mixing with the ambient air. (Radon is released from water in professionally built radon reduction systems by agitation and mixing with air). Next, based on the size of the container, the length of time one allows the overflow to occur may or may not replace the agitated water. Although reducing the flow of water from a faucet or spigot lowers the agitation, the release of radon (or any other gas in the pressurized water) that occurs due to the sudden pressure drop and high turbulence at the faucet valve is another unknown. Also the change in temperature (usually to warmer) of the mixture has some affect on the separation of the gas from the water. Next, one has to place both hands into the container, causing an unmeasurable amount of agitation and a slight rise in the mixture's temperature, in order to fill and cap the collection vial. It is uncertain which factor leads to the major loss of the radon, but the combination of the elements leads to inconsistent and low biased results (Vitz, 1991).

Direct Fill from Spigot

Burkhart (1991) and Field (1996) used this method in sample comparison papers, which were primarily concerned with the study of the collection vials and the various sealing or capping styles. The Burkhart study used three different cap liners: poly-cone, septum, and foil. Field used Teflon-faced, silicon rubber septum caps with 15mL vials.

The direct-fill method instructs the user to fill a collection vial directly from a spigot or non-aerating faucet. This method seems to be a very user-friendly sampling method although the results are prone to inconsistency due to user-specific differences, such as what constitutes a "slow" flow rate and their perception of the correct angles and distances at which the bottles are to be held in relation to the spigot or faucet. Although the method requires no special equipment, individuals using this method could use inconsistent filling techniques and water flow rates. Depending on the level of differences in the techniques of user and other unknowns caused by varying pressure drops (from 20 to 100 PSI line pressure down to ambient in the collection vial) and the unavoidable turbulence at the faucet's valve ports, the results may vary enough to prove the method a bit unreliable. Field duplicates may have acceptable precision but user-to-user and site-to-site (with large line pressure variations) differences in percentage of total radon collected are highly possible.

Users of this method are told to flush the water lines by allowing the water to flow for several minutes before sampling. Once the lines are flushed, the flow is cut back to a moderate stream (Field, 1996). (The user is left to determine what "a moderate stream" means.) The bottle is filled to the brim and immediately closed. The vial is inverted to ensure there are no air bubbles in the vial and then returned to the laboratory for analysis.

Sample Transfer Techniques at the Laboratory for these two (above) collection methods.

There are other loss mechanisms, other than taking the sample, common to the two previous and some other collection methods. Shipping the sample without the use of an insulated cooler and ice for sample stabilization during shipment may cause the temperature of the water sample to

change drastically on its way to the laboratory. Heating of the water sample causes the release of waterborne gases such as carbon dioxide and radon. The release of any gas is obvious when the sample arrives at the laboratory containing visible air bubbles. When this occurs, transfer of the sampled water into an analysis vial containing the scintillant presents problems. Nazeroff (1987) summarized several studies indicating that the transfer of radon from water into air increases with heating and agitation. Thus, as the sample warms and is agitated during shipment to the laboratory, air bubbles begin to form, which may contain radon and other gases.

At the laboratory, the transfer of the sample into the scintillant/analysis vial usually requires a syringe and a hypodermic needle or short length of small tubing to draw a 10mL aliquot of water. The aliquot is transferred to an analysis vial pre-filled with scintillation cocktail or scintillant, the chemical that reacts with the energy being released during radioactive decay. Two transfer methods are commonly used. One procedure is to remove the cap to access the water sample, which allows any radon that has formed into a bubble to immediately escape. The second procedure uses a Teflon-lined, silicon-rubber septum, which requires that a hypodermic needle pass through the septum into the water sample without removing the cap. In both cases, as described by Vitz, the syringe exerts a vacuum (a reduction of pressure) on the water-radon mixture, increasing the likelihood of more radon degassing and forming bubbles that are virtually impossible to capture for dispersion into the scintillant. Both problems lead to lower radon concentrations in the cocktail than originally collected in the water sample. The amount of radon loss is a function of several factors including the difference in the temperature of the water at time of collection and when the sample is removed for analysis. Vials with the septum liners allow the technician to withdraw the required amount of sample using a hypodermic needle and syringe without removing the cap, while caps with foil or poly-cone liners require removal prior to extraction of the water, again usually with a syringe. Both extraction methods exert a vacuum on the water-radon mixture increasing the likelihood of more radon degassing. In other words, at this point it is anyone's guess as to how much radon gas may or may not have left the water sample from the point of collection until the point of analysis.

US EPA Syringe Sample Collection Method (with scintillant already in the site collection vial).

Burkhart, Gray and Martin (1991) described two variations of the procedure and both compare favorably over the submerged vial method. The syringe capture method requires either an overflowing plastic bucket (with all of the same problems described in the first method above) or a funnel connected to the outside spigot by means of a length of hose. The latter eliminates the bucket-filling-till-overflow problems but introduces the cost and complication of setting up the funnel-hose assembly for the overflow process. Both are messy and require access to an area that will accommodate the overflow. The syringe capture method is currently viewed as the US EPA method for sampling radon in water using the "hose and funnel" method (US EPA 1992). The funnel method will be described. This EPA sampling method is more complicated than the previous two methods, and the skill level required to give highly consistent results is therefore increased.

After connecting the funnel/hose apparatus to the faucet and arranging for the upright support of the funnel's opening, the water is turned on and allowed to overflow the funnel for several

minutes to purge the water lines. Once the water is ready to be sampled, a 10mL syringe is filled very slowly with water drawn from deep within the overflowing funnel. The water sample is injected into a 20-25mL liquid scintillation vial containing 10mL of scintillant. The water is slowly dispensed under the scintillant to contain any escaping radon. A sample drawn well below the surface may avoid the radon losses at the air-water interface, but the syringe's vacuum-related losses noted above may still be a problem (Vitz 1991).

The type of needle/tube used may reduce some of the syringe's problems. There are two types of needles commonly used with the sampling syringe: either 18 gauge needles or short lengths of vinyl tubing. The needle is usually replaced by the vinyl tubing due to safety concerns and the fact that the increased inside diameter of the tubing also helps reduce the turbulence and pressure drop inside the syringe during sampling (Vitz 1991).

Accuracy and precision are increased with the syringe capture method, although the complexity of the procedure and use of scintillant in the field cause additional concerns. A trained technician can produce repeatable, accurate sampling, but an untrained individual may produce erratic samples due to a lack of understanding of why accuracy and precision rely on consistency in water flow rates and the rate that one fills the syringe with water. Different extraction speeds in the syringe collection process will affect the turbulence and pressure drop that may increase the likelihood of radon loss through the creation of bubbles. Carelessness during sample collection allows radon to be degassed from the water and ultimately produces low biased results with poor precision. The use of the syringe becomes a technique that requires patience and practice to perfect.

An additional problem involves the potentially harmful scintillant. Most scintillants are flammable and contain harmful chemicals such as toluene and long-chain alcholbenzenes (Burkhart 1991). There are also restrictions placed on the shipping of these chemicals via US Mail, and they may require special permits or labeling. There are less hazardous scintillants, although the counting efficiencies typically suffer.

Due to the problems of sampling complexity, potential hazards of using scintillants in the field and potential shipping restrictions, the use of the syringe capture method is typically limited to the scientific community and some radon measurement professionals. The potential risks and liabilities of introducing this method to homeowners will likely exclude its use for do-it-yourself consumer testing.

The Slow-Flow Method into Scintillant Charged Vials

Dusenbury (1992) and Hightower (1994) describe another sampling technique that has proven to be more precise and accurate than the US EPA syringe capture method. Unfortunately, this method also requires the use of scintillants during sample collection. The slow-flow method requires nothing more than the sample vial pre-filled with 10mL of scintillant. The spigot valve is slightly opened and the vial raised to contact the bottom lip of the spigot. The flow should crawl down the spigot and down the inside of the vial and settle under the scintillant. The attentiveness of the operator filling the sample vial is vital because there is a high potential of under-filling or overfilling the vial. In other words, stopping the flow at exactly the right moment

requires a quick response by the user. Under-filling and overfilling can lead to large precision differences due only to different amounts of sample if the laboratory is unable to quantify the exact amount of sample collected. Extreme overfilling would cause the cocktail to spill out of the vial causing possible contamination problems, and would require discarding the sample and starting over. Although a bit less complicated than the funnel and hose method, the attention required during sample collection is much more stringent.

The direct fill method eliminates applying a vacuum on the water. The water is transferred directly from the water supply pipes into the vial, reducing the number of steps and the opportunity for radon degassing. This could prove to be a method used effectively by researchers but becomes a liability issue for the general public due to the use of the scintillant.

A potential problem with this method involves the same problems described above in the *direct fill method,* and that is the large pressure drop and extreme turbulence inside the spigot valve ports. The water pressure is decreased inside the fixture, allowing some degassing of the radon at that point. A fully opened valve is not permitted because of turbulence and lack of control of the water entering the vial. The potential problems would require a highly skilled technician to collect the samples, which excludes do-it-yourselfers and occasional users again. During our method comparisons at Air Chek, we were unable to produce results consistent with the Dusenbury and Hightower studies. This appears to be a method more suitable for a dedicated researcher.

Other Sampling Variables

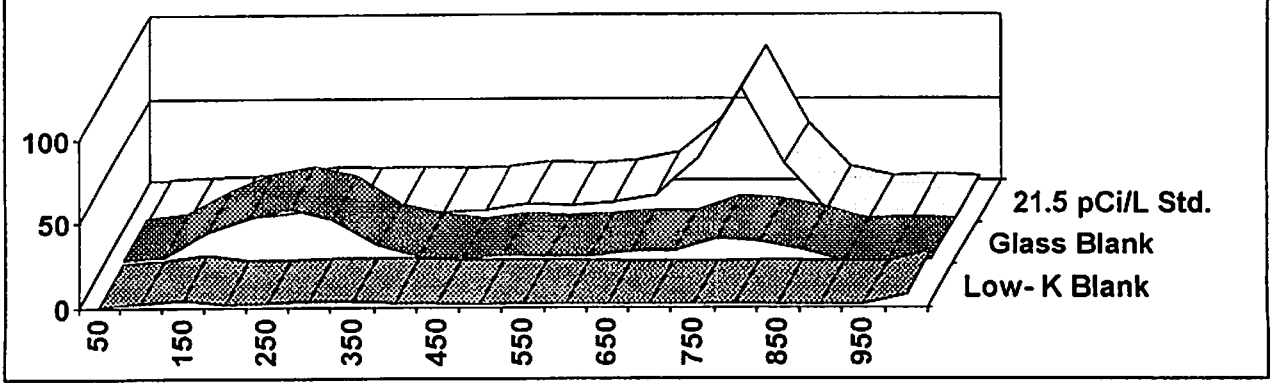
There are additional variables that often affect the sampling techniques listed above. Although the addition of the scintillant can reduce some of the effects, the problems are encountered with all methods. The problems involve the vial and cap liner materials (Vitz 1991, Burkhart 1991).

There are two general choices of vial material: plastic and glass. Typical plastic scintillation vials are made from either polyethylene terephthalate or high-density polyethylene (HDPE). The glass is normally a borosillicate material with the best type carrying the label "low-potassium". The differences in material will affect the test results, depending on sampling and transfer methods.

The plastic vials are not suitable for sample collection due to the potential loss of radon between collection and analysis (Vitz 1991). Although Vitz concluded that the use of the plastic vials might be appropriate for sample analysis, the use of plastic vials for radon-in-water measurements seems to be very limited. The chemical composition of the polyethylene materials allows for radon to diffuse through the vial walls of the low-density polyethylene, while the first matrix layer of the HDPE attracts radon (Burkhart 1991).

The glass vials are preferable to plastic because glass is impermeable to radon. However, there is a potential problem with some glass compositions. Vials not described as being low-potassium glass may create a higher counting background within the radon region of interest. See Figure 1, for an example of an energy spectrum where a high background glass was analyzed and compared to a radon counting standard.

Figure 1.: Energy spectrum showing effects of different glass vial materials.



Cap lining materials are also important. The EPA protocol for liquid scintillation measurement of waterborne radon requires either Teflon or aluminum-lined caps. There have been studies, such as Vitz 1991 and Burkhart 1991, which used other cap types. These studies concluded that using other caps, such as the poly-seal cone, is not appropriate. The poly-seal cone, for example, is constructed from a polyethylene material that could either adsorb radon or allow the radon to move into the air space under the cone.

The cap is usually a key component in the transfer of the sample to the analysis vial. For example, if a laboratory requests that water samples be taken using a vial or bottle not pre-filled with scintillant, then a transfer procedure must take place prior to analysis. The most popular procedure involves drawing 10mL of water from the sample vial and injecting the sample under the scintillant. This can be done with the cap on if it is an open-top cap with a silicone/Teflon liner. This type of cap allows for the needle of the syringe to puncture the liner and remove the water sample without opening the vial and allowing radon to escape from the sample container. Without this type of configuration, the top would have to be removed, which can lead to a loss of radon in the gas bubble. However, it has been documented that the inversion of the septum in open-top caps (a potential problem if laboratory QC is slack) can lead to severe radon loss during transit and holding times (Vitz 1991 and Field 1996).

Air Chek, Inc. Method

Air Chek's staff members have developed a radon-in-water sample collection system that allows for consistent and repeatable sampling by seasoned professionals or the first time do-it-yourselfer, all without the use of messy and potentially hazardous scintillants in the field. Although additional comparisons with the other sampling techniques are ongoing, our preliminary results show the Air Chek method to be simplest and most repeatable while providing results with the highest precision and accuracy of the tested methods. In other words, more radon makes it into the analysis system, per sample vial, when compared to the amounts from all of the above described methods.

Purging the water lines precedes the sampling as with all of the previously mentioned collection methods. The Air Chek radon-in-water test kit consists of a proprietary faucet-adapter apparatus only slightly larger the collection vial itself, an empty 25mL glass scintillation vial with a septum cap, instructions, and return shipping materials. The user is instructed to conduct the sampling immediately after heavy water usage or after the supply system has been thoroughly purged of standing water. If the purging was not performed at the sampling location, the spigot is to be opened to remove any standing water and air bubbles in its supply line. Once the water has been thoroughly purged and turned off, the Air Chek sampling apparatus is loosely attached to the spigot and then the spigot is opened only very slightly. This allows water to escape around the threads purging the air from inside the faucet and sampling apparatus. After about 15 seconds of this final purging, the apparatus is hand tightened just enough to stop the flow of water from around the faucet threads and then the spigot is fully opened.

The Air Chek sampling apparatus incorporates a proprietary adapter that prevents turbulence during the pressure drop from full water system pressure to the ambient pressure inside the collection vial. The resulting water flow from the sampling hose is very gentle. The collection vial is held up to the sampling apparatus so the lower end of the apparatus is in contact with the inside bottom of the collection vial. The water is allowed to slowly fill the vial until the water overflows the vial for five seconds or more. The vial is then gently lowered from the sampling apparatus. The vial is capped and then turned upside down to ensure that no air bubbles are in the sample. The user is instructed to pour out the sample and begin again if any bubbles appear. The total time needed to install the sampling apparatus and fill the vial is usually less than a minute. No other method comes close to the simplicity and reproducibility of this procedure.

The sample is returned to the laboratory as soon as practical for analysis using Air Chek's proprietary liquid scintillation counting system. The laboratory procedures require the use of a high efficiency mineral oil scintillator prior to analysis. The Air Chek method uses a technique that collects radon from gas bubbles formed during shipment. This new collection and elution method has the lowest negative bias for radon in water sampling and analysis of any technique we have tested.

Sampling Method Comparisons

There are interesting comparisons of the sampling methods performed by Vitz, Field, Burkhart and Hightower. We will briefly describe the results of the comparisons and introduce some of our own data that further compare the most popular sampling methods. The new sampling technique developed by Air Chek contains a proprietary mechanism that will be further investigated as a new standard sampling technique for non-scintillant field sampling.

Vitz 1991 compared the results of two sampling methods and concluded that the syringe capture method was superior to the submerged vial method. Dr. Vitz used a subset of 180 tests from his database of approximately 1000 duplicate submerged vial tests. The average difference in the duplicate measurements was 24% and an absolute standard deviation of the percent differences was 40%. For the syringe capture comparison, a typical subset was chosen and the average difference was 10%, with an absolute standard deviation of 22%.

Burkhart, Gray and Martin compared the submerged vial and syringe capture sampling techniques with similar conclusions. While Dr. Vitz used plastic collection vials for the syringe capture method and glass vials for collection using the submerged vial method, the Burkhart study used glass vials with various cap liners. The mechanism for comparing the measurement methods in the Burkhart study was the Student *t*-test. Since the bucket-syringe method was viewed as the US EPA sampling method at the time, it was hypothesized that it would show the best results. A 97.5% confidence level was used to determine a *t* value of 2.365. Results higher than this *t* value show less accuracy. The syringe capture method (funnel) resulted in a *t* value of 1.389 while the submerged vial method showed a resulting *t* value of 3.21. The syringe capture method using a funnel was much better than the submerged vial method.

The direct flow method showed promise depending on the cap liner material (Burkhart, 1991 and Field, 1996). The use of a poly-cone liner did not fare well in Burkhart 1991 with a *t* value of 10.75, compared to the 4.05 and 1.98 values of the septum and foil liners, respectively. In fact, the 1.98 value of the direct flow method using foil-lined caps was better than the EPA method using a plastic bucket. The downfall of the foil lids is the requirement that the cap be removed for sample transfer in the laboratory. Field (1995) concluded that the use of the 15mL vials with septum caps proved comparable to the results of professionals using the hose and funnel method. Field's study indicated that several measurements were excluded from the study due to homeowner sampling mistakes including evidence of large (> 4mm diameter) air bubbles and inversion of the septa in some caps.

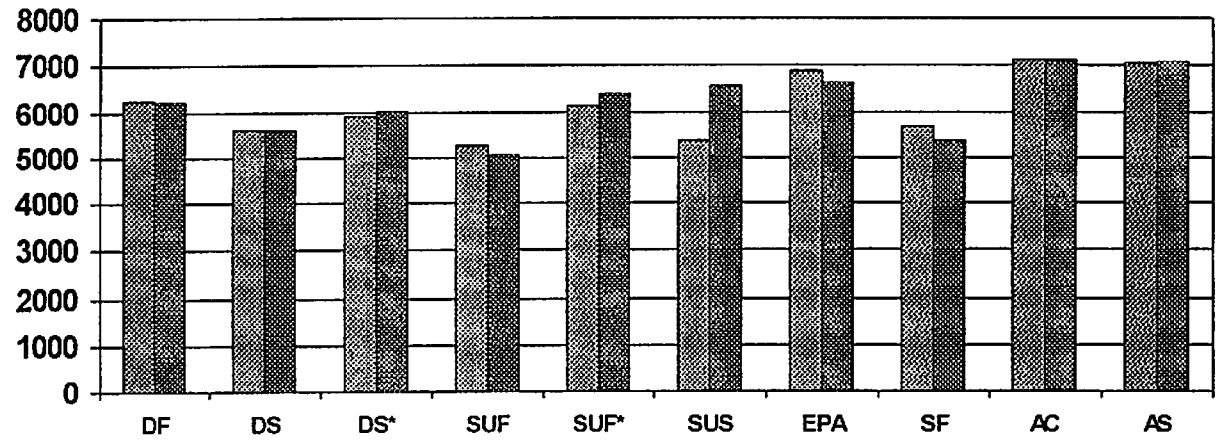
Dusenbury and Hightower both concluded that the slow-flow method produces better results than the EPA syringe capture method. Hightower collected and analyzed nearly 1400 samples and used the Wilcoxon signed rank (WSR) test and the paired *t*-test to conclude that the slow-flow method was superior. Overall, the results of the slow-flow method showed higher radon concentrations than the syringe capture method meaning that there was less loss of radon during the collection process. Hightower also concludes that the slow-flow method may be the preferred method of radon in water sampling. Although many of the samples collected with the slow-flow method and the syringe capture method were similar, the average difference was 5.1% higher for results using the slow-flow method when statistical differences in the two methods were noted.

The Air Chek method has compared most favorably against all of the currently popular methods during our initial investigations. The first comparisons of the three methods with the Air Chek method were performed in-house using water from a local well containing approximately 7000 pCi per liter of radon. Side-by-side samples were drawn and the results were recorded in terms of counts per minute (CPM) per gram of water. The submerged vial method averaged 38.31 CPM/gram with a standard deviation of 5.91. The funnel and hose (EPA) method averaged 44.67 CPM/gram with a standard deviation of 1.90. Finally, the Air Chek method had an average activity of 44.94 CPM/gram with a standard deviation of 0.91.

A second round of method comparisons has been completed and the results can be found in Table 1 and Figure 2.

More recent comparisons have supported the initial conclusions that the Air Chek method provides the most precise sampling techniques without the need of a sampling specialist. Some homeowners and radon professionals have reviewed the method and returned very positive feedback. Although the initial comparisons were made with in-house, side-by-side sampling, external comparisons are planned. Initial results from field duplicates have shown that high precision remains when untrained homeowners perform the sampling. Most recently, the Air Chek method was used in comparing results from current radon-in-water laboratories. This exercise is described in more detail later in this paper.

Figure 2: Comparison of duplicates collected with various sampling and transfer techniques.



LEGEND

DF = Direct Flow w/foil cap
DS = Direct Flow w/septum cap
SUF = Submerged Vial w/foil cap
SUS = Submerged Vial w/septum
EPA = Funnel and Hose (scintillant)
SF = Slow-Flow (Dusenbury w/ scint.)
AC = Air Chek Method
AS = Air Chek Method (scintillant)

* sample transfer to scintillant performed by different person

The outstanding precision and lack of negative bias of the Air Chek method is exceptional considering that scintillant is not required during sampling. The lack of scintillant is important for a laboratory that does not routinely make field measurements but requires samples to be collected by homeowners, health departments, and home inspectors. We believe the Air Chek method is a very user-friendly sampling technique that can be employed by radon professionals and homeowners to obtain results comparable or superior to those obtained by experienced field specialists using other sampling techniques.

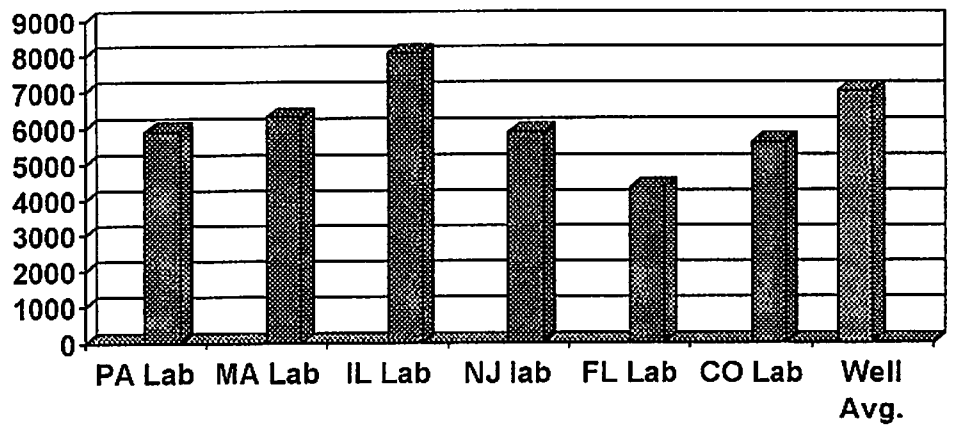
Current Industry Practices

The re-release of the proposed radon in water regulations is expected to increase the demand for radon in water testing. Although the regulations target drinking water systems supplying either 25 individuals or 15 buildings/connections, homeowner awareness of the regulations will likely stir the highest number of inquires. Homeowners are likely to search through yellow page ads and the Internet for companies offering radon-in-water testing services.

During September 1999, we performed numerous searches on the Internet using well-known search engines. The search strings entered into the search engines included the words "radon in water". Although a majority of the web sites appearing in the search engine's summaries were not offering radon in water testing, the web sites were visited in the order of the search results until water-testing companies were located. The top two or three testing companies were recorded from each search engine to compile the master list of companies.

A master list of the seven most frequently occurring providers was compiled. Orders for single radon-in-water kits were placed with each company. Four orders were placed directly through the company web sites and three were made by telephone, per the instructions on the web pages. The orders were all placed on September 27, 1999. As of October 9, 1999, six of the seven kits had been received. The seventh kit had not arrived as of October 21, 1999 and the charges were not found on the credit card bill used to obtain the other six kits.

Figure 3: Results from the laboratories in the "blind" intercomparison.



Upon arrival, the test kits were inspected and instructions read to determine which sample method was prescribed. Five of the kits indicated that samples were to be collected using versions of the submerged vial method and one recommended the direct flow method to fill duplicate samples. Three of the vials had foil-lined caps while the other three had septum caps. All instructions stated that samples should be mailed within one day of the collection, but only one laboratory recommended the use of one- to two-day delivery to the lab.

A side-by-side comparison was performed with the vials obtained from the Internet search. The plans called for filling each vial according to the accompanying instructions, with an Air Chek vial being filled after each competitor sample. The water lines and holding tank at Air Chek were purged to allow the use of fresh water from our well, which is drilled to a depth of approximately 400 feet. The filling of the vials began at 3:00 p.m. on October 21, 1999. All the sampling was recorded on videotape.

The first five vials were filled using the submerged vial method and the water was allowed to run for several minutes between samples. The last vials filled were the ones using the direct fill method. The six Air Chek vials were filled using the Air Chek method. The video shows that in

the submersion method the displacement caused by putting one's hands in the water to capture the sample and then cap the vial caused a considerable spillage on the counter top and floor. Results from the intercomparison can be found in Table 2 and Figure 3.

Conclusions

The radon-in-water rules will undoubtedly become a law sometime in the future and boost the radon industry. The multimedia mitigation approach to the radon-in-air programs may cause the quality of the water program to be overlooked. Testing for waterborne radon will likely increase in areas where municipal water supplies use groundwater sources, and homeowners will probably use the MCL and/or AMCL as their *de facto* standard.

There are several methods for analyzing water samples to determine radon levels but EPA currently approves only two. By far, the industry preference seems to be the liquid scintillation method but it is only as good as the sampling procedures. This is true for all measurement methods regardless of whether we are measuring air or water. Accurate analysis requires accurate sampling procedures. Sampling is the first step in providing a quality measurement service. There are several choices a water laboratory has to make regarding sampling procedures. The current methods that appear to be the most accurate also lead to a significant problem, which is introducing scintillant to the tester or homeowner. Most labs will probably choose to avoid the scintillant problem by collecting pure water samples.

There have been several studies referenced in this paper that show significant differences in waterborne radon analysis due to sampling differences. There will be no easy way to assess whether a laboratory meets a minimum level of competency and accuracy without standardization and proficiency testing. There will be a potential for unreliable services without methods of ensuring competency and accuracy.

Unfortunately, there are no private calibration facilities for radon-in-water analysis labs. As a replacement, many ways to "spike" water have been developed using radium-bearing materials, but there is no entity acting as the standard bearer of radon-in-water spiking services. Until there is a common calibration source, there is a potential for errors with radon-in-water analysis labs.

Counting standards allow for the calculation of detector efficiencies. This is necessary to quantify radon sample analysis, but it does not indicate whether all of the radon from the source water made it into the analysis vial. Thus, counting standards alone cannot be an indication of sample collection efficiency. A calibration source may be required to determine a "collection efficiency" which will be required to determine the efficiency of both the sampling and detection efficiencies.

The current radon-in-air industry has all of these abilities. However, radon proficiency and certification programs are needed to ensure that radon services will be of high quality. Until a proficiency program adds a radon-in-water credential and the EPA or another agency makes a clear performance standard, there will be many laboratories and radon companies offering unsupervised sampling and analysis services. Unfortunately this opens the door for the

"mayonnaise jar" to make a comeback. Hopefully, standardization will occur before too much damage is done.

The October release of the EPA Proposed Radon in Drinking Water Rule should increase the demand for radon-in-water testing due to the requirements imposed on community water systems and the publicity that will accompany the new regulations. The audience looking for radon-in-water-laboratories will be radon professionals, water company personnel, home inspectors and homeowners. We at Air Chek do not believe that radon-in-water accuracy should rely on a highly skilled individual to perform the sampling. To ensure that homeowners and others wanting to test their drinking water for radon can get high quality services at competitive prices, Air Chek has worked to develop an easy and accurate sampling method for homeowners and home inspectors. This type of method should ensure that radon-in-water testing can go from the laboratory to routine testing and be extended affordably to individuals.

Table 1: Results of the duplicates collected with various sampling and transfer techniques.

Sample ID	Sampled	Net CPM	CPM/mL	Rn222
Direct Flow w/ Foil Cap				
DF-1	10/27/99 @ 18:14	471.5	55.1	6254.1
DF-2	10/27/99 @ 18:14	467.7	54.8	6225.5
Direct Flow w/ Septum Cap				
DS-1	10/27/99 @ 18:16	419.4	49.4	5622.1
DS-2	10/27/99 @ 18:16	417.0	49.3	5603.1
DS-3*	10/27/99 @ 18:16	215.0	52.6	5905.0
DS-4*	10/27/99 @ 18:16	218.2	53.4	6004.6
Submerged Vial w/ Foil Cap				
SUF-1	10/27/99 @ 18:18	395.8	46.5	5280.8
SUF-2	10/27/99 @ 18:18	379.3	44.6	5072.6
SUF-3*	10/27/99 @ 18:18	220.0	54.4	6109.5
SUF-4*	10/27/99 @ 18:18	230.2	57.0	6407.0
Submerged Vial w/ Septum Cap				
SUS-1	10/27/99 @ 18:20	398.8	47.2	5364.9
SUS-2	10/27/99 @ 18:20	477.9	57.9	6576.9
Direct Syringe (EPA Method w/ 10mL scintillant)				
EPA-1	10/27/99 @ 18:22	531.3	60.3	6863.1
EPA-2	10/27/99 @ 18:22	512.2	58.2	6623.9
Slow-Flow (Dusenbury method w/ 10mL scintillant)				
SF-1	10/27/99 @ 18:27	423.5	49.2	5679.3
SF-2	10/27/99 @ 18:27	400.1	47.5	5380.7
Air Chek Method				
AC-1	10/27/99 @ 18:33	703.7	62.4	7123.2
AC-2	10/27/99 @ 18:33	698.9	62.3	7103.0
Air Chek Method w/ 10mL scintillant				
AS-1	10/27/99 @ 18:37	660.4	61.9	7044.8
AS-2	10/27/99 @ 18:37	672.4	62.2	7061.9

Table 2: Results from the laboratories in the "blind" intercomparison.

Sample	Sampled	Rn222	% Difference
Pennsylvania Lab	10/21/99 @ 14:50	5917.01	-15.5%
Massachusetts Lab	10/21/99 @ 15:07	6300	-10.0%
Illinois Lab	10/21/99 @ 15:16	8065	15.2%
New Jersey Lab	10/21/99 @ 15:18	5864.07	-16.2
Florida Lab	10/21/99 @ 15:30	4328.9	-38.2%
Colorado Lab	10/21/99 @ 15:39	5600	-20.0%
Well Average	**10/21/99**	**7000**	

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