RAD H_2O User Manual

Radon in Water Accessory

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INTRODUCTION

The RAD H_2O is an accessory to the RAD7 that enables you to measure radon in water over a concentration range of from less than 10 pCi/L to greater than 400,000 pCi/L. The lower limit of detection is less than 10 pCi/L. By diluting your sample, or by waiting for sample decay, you can extend the method's upper range to any concentration.

The equipment is portable and battery operated, and the measurement is fast. You can have an accurate reading of radon in water within an hour of taking the sample. The RAD H_2O gives results after 30 minutes analysis with a sensitivity that matches or exceeds that of liquid scintillation methods. The method is simple and straightforward. There are no harmful chemicals to use. Once the procedure becomes familiar and well understood it will produce accurate results with minimal effort.

It is assumed that the user has a good, working knowledge of the RAD7. If both the RAD7 and the RAD H_2O are new to the user, then time should be spent learning how to make good measurements of radon in air with the RAD7 before embarking on radon in water measurements. Instructions for RAD7 operation with the RAD H_2O are given in this manual but, for more detail about the instrument and its use, the reader is referred to the RAD7 manual.

Grateful acknowledgment is made of the significant contribution to this manual by Stephen Shefsky, who wrote most of the original NITON RAD-H_2O manual, much of which is incorporated in this version. However, all responsibility for the content now rests with DURRIDGE Company.

CONTENTS

1 GETTING STARTED

1.1 Unpacking

First make sure you have everything you are supposed to have. Examine the case contents and verify that you have all the items shown below. If anything is missing, please call DURRIDGE immediately at (978) 667-9556 or email sales@durridge.com.

Case
6, 250 ml collection vials, with septum caps
12, 40 ml collection vials, with septum caps
Aerator assembly, including:
    Stainless Steel Aerator
    Teflon Coupler
    Modified Vial Cap
    40 ml Vial
    Teflon Spacer
    Glass Frit
    Short, Vinyl Tubing
    Check Valve
Faucet Adapter
Tube of Activated Charcoal
4 Tubes of Drierite
2 Inlet Filters
Spare Modified Vial Cap
Spare Glass Frit
Long Teflon Spacer (for 250 ml vials)
Vinyl tubing: 3 pieces
Retort Stand and Clamp

1.2 General Safety Instructions

There is nothing particularly hazardous to the user in the RAD H_2O, but care should be taken to make sure that water never enters the RAD7. The check valve attached to the aerator should never be removed, as it protects the RAD7 in the event that the tube connections to the instrument are reversed.

1.3 Taking a Look

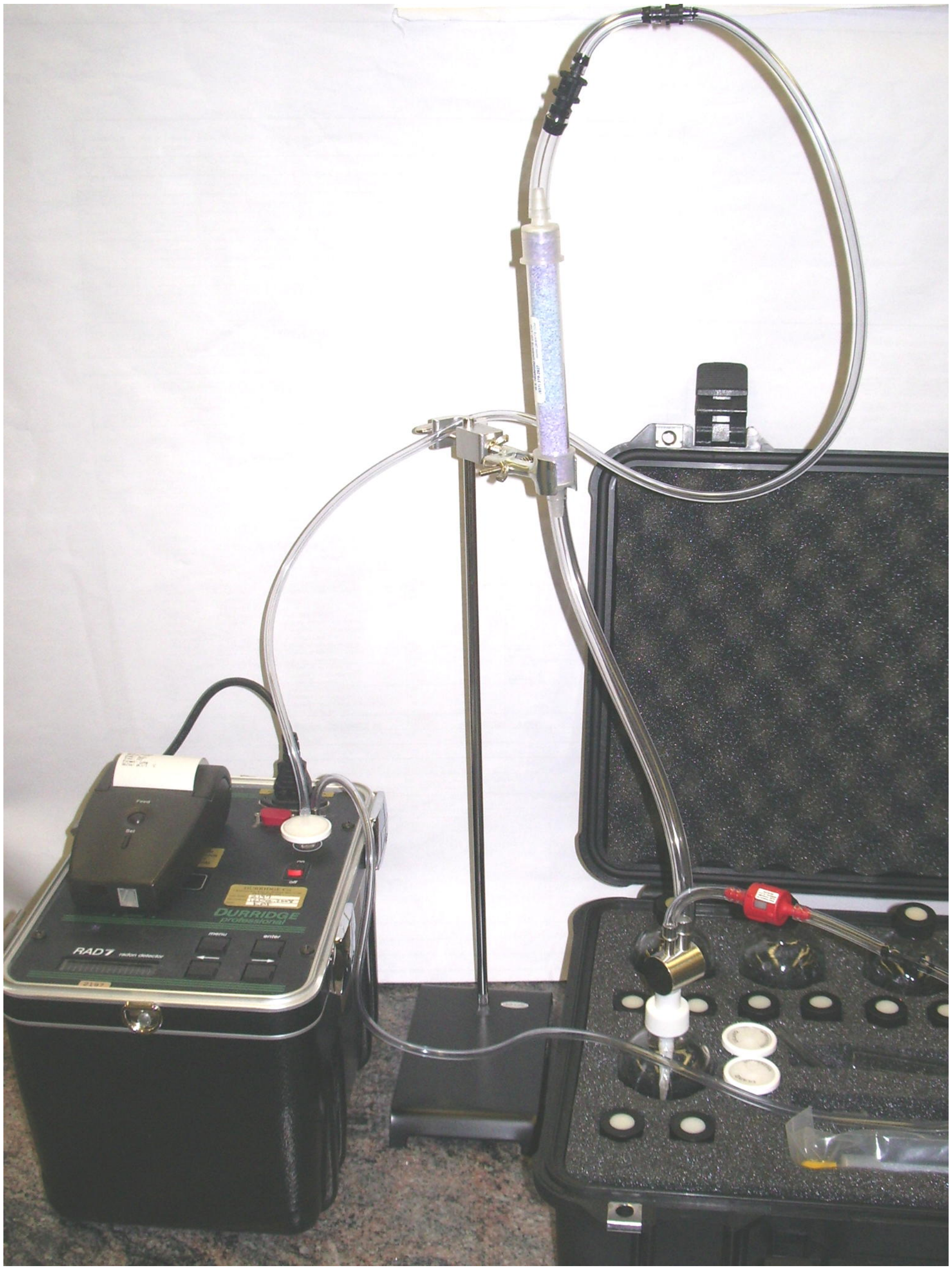


Fig. 1 Aerating a 250 ml water sample

The setup consists of three components, the RAD7, on the left, the water vial with aerator, in the case near the front, and the tube of desiccant, supported by the retort stand above. The case provides a convenient stand for the vial in the foam cavity.

Fig. 2 Aeration in progress

During the five minutes of aeration, more than 95% of the available radon is removed from the water.

RAD-H_2O Schematic

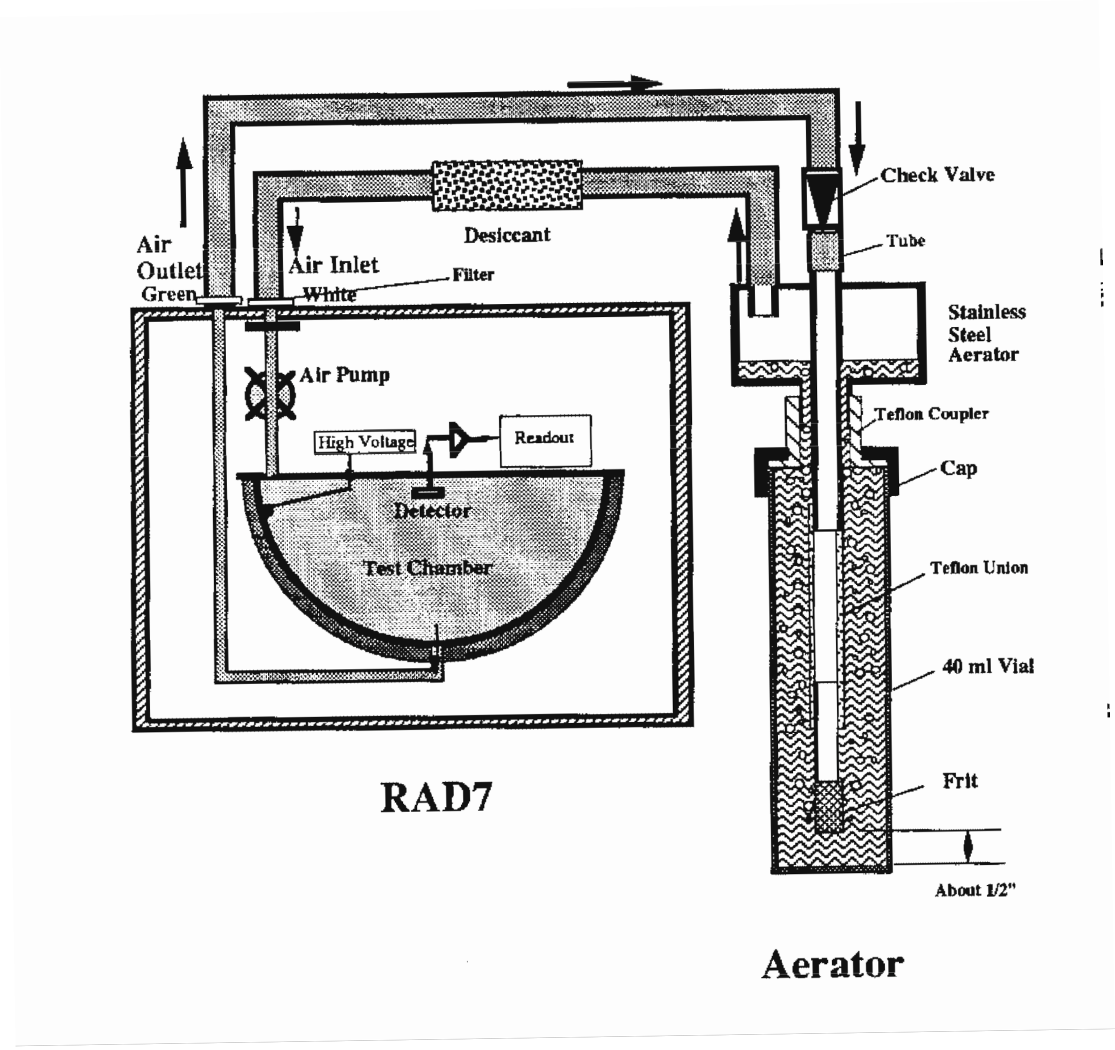


Fig. 3 Schematic

The components, as shown, automatically perform everything required to determine the radon concentration in the water.

1.4 Running a Test

These are brief, simple instructions, just to gain an initial introduction to the technique. A more thorough treatment follows later in the manual.

1.4.1 Preparing the *RAD7*

Before making a measurement, the ***RAD7*** must be free of radon, and dry. To achieve this, it should be purged for some time. It is convenient to use the larger, laboratory drying unit during the initial purging process, to save the small drying tubes for the actual measurement.

Hook up the laboratory drying unit to the ***RAD7*** inlet, with the inlet filter in place (see ***RAD7*** manual). Purge the unit with fresh dry air for ten minutes.

After 10 minutes of purging with dry air, push the **menu** button, push [ENTER] twice, to go into the status window, and push the right arrow button twice to see the relative humidity. If it is not yet down close to 6%, start purging some more. To conserve desiccant, after the first ten minutes or so, you may connect the ***RAD7*** outlet to the inlet of the laboratory drying unit, thus forming a closed loop. This will continue to dry out the ***RAD7*** but will not introduce more fresh air.

If the ***RAD7*** has not been used for some time, or if it has been left without the small tubing bridge in place between the air inlet and outlet, then it will take longer to dry it out, perhaps as much as 30 minutes of purging, or even more. Once it has thoroughly dried out, however, just 15 minutes of purging between measurements will generally be sufficient.

1.4.2 Collecting a Sample

Getting a good sample requires care and practice. Sampling technique, or lack of it, is generally the major source of error in measuring the radon content of water. The water sampled must be a) representative of the water being tested, and b) such that it has never been in contact with air.

To satisfy (a), make sure that the sample has not been through a charcoal filter, or been sitting for days in a hot water tank. To test a well, choose a faucet at the well, or outside the house, before the water enters any treatment process. Run the water for several minutes, to make sure that the sample comes freshly from deep in the well.

To satisfy (b), several techniques are used. One method attaches a tube to the faucet, and fills the vial with this tube. Another puts a bowl up to the faucet so that the water overflowing the bowl prevents the water when leaving the faucet from touching the air and the vial is filled with water at the bottom of the bowl. A third combines both methods, by having a tube attached to the faucet feeding water to the interior of the vial at the bottom of the bowl.

Using the third method, above, allow water to overflow freely from the bowl. Take a 250 ml vial if the radon concentration is probably less than 3,000 pCi/L, or 100,000 Bq/m3, or a 40 ml vial if it is probably more. Take samples in both sizes if you have no idea of the concentration. Place the vial in the bottom of the bowl, and put the tube end into the vial. Let the water flow for a while, keeping the vial full and flushing with fresh water. Cap the vial while still under the water. Make sure there are no bubbles in the vial. Tighten the cap.

Remove the vial from the bowl, dry it and immediately apply a label stating the date, time and source of the water

1.4.3 Setting up the equipment

Find the two Teflon unions, or spacers (small pieces of teflon rod with holes through the center, one longer than the other). In the instrument case, as originally shipped, the shorter spacer is in the 40 ml vial assembled on the aerator in the middle of the case. The longer spacer is in the foam at the near right-hand corner of the case. Pick the spacer appropriate to the size of vial containing the water sample: short for the 40 ml vial and long for the 250 ml vial. Note that the hole at one end of the teflon spacer is bigger than at the other. Push the end with the larger hole onto the aerator tube, on the side opposite to the check valve.

The teflon coupler and special vial cap normally stay attached to the aerator. If they have been removed, please replace them. Leave the glass frit in the case

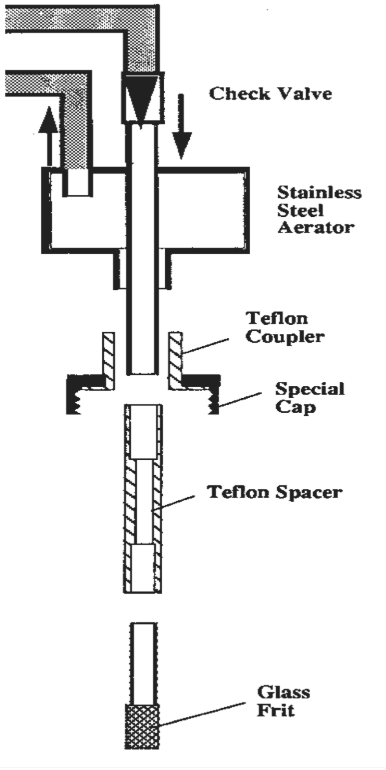


Fig. 4 Aerator assembly

until the last moment. With the 10” (25cm) of large ID vinyl tubing, connect the output of the aerator (without a check valve) to a small drying tube. If one end of the drying tube is pink, connect the aerator output to this end. Connect the other end of the drying tube, with 1/8” ID tubing, to an inlet filter mounted on the RAD7 inlet. The 5/16” to 1/8” adapter makes this connection easy and secure. Connect the RAD7 outlet (also with 1/8" ID tubing, adapted up to 3/16") to the check valve on the aerator. See figures 1, 3 &4.

With the system as connected so far, set the RAD7 to purge for another few minutes. While it is purging, clamp the small drying tube on the retort stand, thus supporting it vertically about 16” (41cm) above the table top.

Stop purging. On the RAD7, go to Setup Protocol Wat-40, or Wat250, depending on which size of vial is being used, and push [ENTER]. It is essential that the correct protocol be entered here, because this controls the pumping and counting cycle, and the calculation according to the size of sample vial. Set the Format to short. Place the printer on the RAD7. Make sure the printer has paper. Switch on the printer. Switch off the RAD7, then switch it on again. It will print its identity and a review of the setup.

While the RAD7 is printing the header, insert the glass frit in the teflon spacer. Remove the cap from the water sample and lower the glass frit into the water. Some water will spill during this procedure. ***Carefully** watch the glass frit, to make sure it does not hit the bottom of the vial*; adjust the position of the teflon coupler at the aerator if necessary. Screw the special vial cap onto the sample vial. The vial can be inserted in a space in the case, to hold it secure. It must be upright while aeration is in progress.

1.4.4 Starting the test

Everything is set up, ready to go. Once the RAD7 has finished printing out the header, go to Test Start and push [ENTER]. The pump will run for five minutes, aerating the sample and delivering the radon to the RAD7. The system will wait a further five minutes. It will then start counting. After five minutes, it will print out a short-form report. The same thing will happen again five minutes later, and for two more five-minute periods after that. At the end of the run (30 minutes after the start), the RAD7 prints out a summary, showing the average radon reading from the four cycles counted, a bar chart of the four readings, and a cumulative spectrum. The radon level is that of the water, and is calculated automatically by the RAD7. All data, except the spectrum, is also stored in memory, and may be printed or downloaded to a PC at any time.

1.4.5 Finishing the Test

Unscrew the cap, raise the glass frit out of the water, and set the RAD7 to purge. This will blow water out of the frit, and also introduce fresh air into the tubing.

If no more tests are to be analyzed, the equipment may now be replaced in the case. If there is another sample for analysis, keep the RAD7 connected as above, and purging, for at least two minutes. The laboratory drying unit may then be substituted for the small drying tube. Continue the purge for another ten minutes. Check the relative humidity, as above, and continue the purge until the relative humidity indication in the instrument drops to 6% or below. After six or seven minutes, the RAD7 air outlet may be connected to the input of the drying unit, to form a closed loop, to conserve desiccant. When the relative humidity is down to 6% or less, another test may be conducted. Repeat from 1.4.1 above.

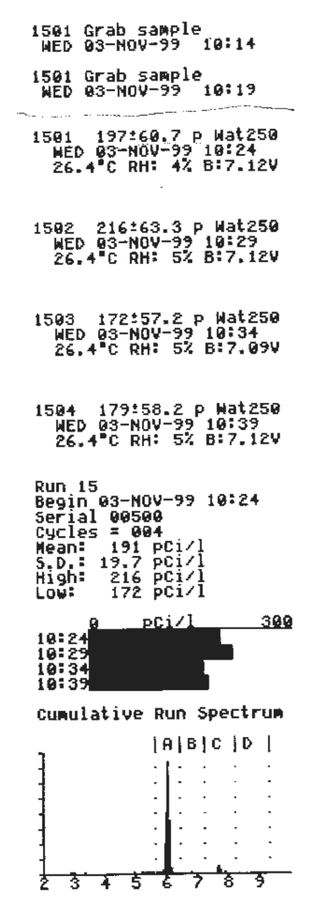
1.4.6 Interpreting the results

The printout will appear something like figure 5, below.

There are two grab sample advisory statements, four five-minute cycles and a test summary. The summary shows the RAD7 run number, the date and time of the measurement, the serial number of the instrument, the number of cycles in the test, the average value, standard deviation, highest and lowest readings, a bar chart of the complete set of readings, and a cumulative spectrum.

The radon content of the water, at the time of the analysis, is the mean value shown in the printout. This value takes into account the calibration of the RAD7, the size of the sample vial and the total volume of the closed air loop, as set up. It is important that the setup be as specified above, using the tubing and a small drying tube, as provided. Deviations from the standard setup may cause errors in the result.

The final step is to correct the measured value for decay of the radon in the water during the time between taking the sample and analyzing it.



```
1501 Grab sample
 WED 03-NOV-99  10:14

1501 Grab sample
 WED 03-NOV-99  10:19

1501  197±60.7 p Wat250
  WED 03-NOV-99 10:24
  26.4°C RH: 4% B:7.12V


1502  216±63.3 p Wat250
  WED 03-NOV-99 10:29
  26.4°C RH: 5% B:7.12V


1503  172±57.2 p Wat250
  WED 03-NOV-99 10:34
  26.4°C RH: 5% B:7.09V


1504  179±58.2 p Wat250
  WED 03-NOV-99 10:39
  26.4°C RH: 5% B:7.12V


Run 15
Begin 03-NOV-99 10:24
Serial 00500
Cycles = 004
Mean:   191 pCi/l
S.D.: 19.7 pCi/l
High:   216 pCi/l
Low:    172 pCi/l
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Fig. 5 RAD-H_2O printout

2 BACKGROUND

2.1 About Radon-in-Water

Radon originates from the radioactive decay of naturally occurring uranium and radium deposits. These elements can be found, in trace amounts, in almost all soils and rocks. Being a gas, radon can escape from mineral surfaces and dissolve in ground water, which can carry it away from its point of origin. We rarely find radon in significant concentrations in surface waters, due to its rapid dispersal into the atmosphere.

High concentrations of groundwater radon prevail in parts of New England, New Jersey, Maryland, Virginia, and the mountainous western states of the U.S. Typical groundwater sources average between 200 and 600 pCi/L of radon. Roughly 10 percent of public drinking water supplies have concentrations of over 1,000 pCi/L, and around 1 percent exceed 10,000 pCi/L. Smaller water systems appear to be disproportionally affected by high radon. [Milvy, EPA]

Radon was first noticed in water supplies by J.J. Thomson, a pioneer in the science of radioactivity, in the first decade of the 1900s. [Hess, Frame] At first, scientists and doctors believed radioactivity to have benign, even curative, effects on the human body. Early research linked high radon concentrations to natural hot springs long thought to have miraculous powers. But eventually, science came to understand the dangers of radiation exposure, after a number of serious accidents and fatalities. [Caulfield]

In the 1950s airborne radon decay products emerged as the probable cause of high incidences of lung cancer among underground mine workers. Study of environmental radioactivity revealed unusually high groundwater radon concentrations in the vicinity of Raymond, Maine. [Bell] In the 1960s, scientists began to investigate the effect of ingested and inhaled radon gas, observing the uptake of radon by digestive organs and its dispersal through the bloodstream. [Crawford-Brown] By the 1970s, radon was widely recognized as a major component of our natural radiation exposure. By the late 1970s, Maine had initiated a program to attempt to reduce public exposure to waterborne radon, having discovered cases in which groundwater concentration exceeded 1 million pCi/L. [Hess]

Federal action on the problem of radon in drinking water picked up in the 1980s with a nationwide program to survey drinking water supplies for radioactivity and to assess the risk to public health. Congress directed the Environmental Protection Agency (EPA) to take action on radioactivity in drinking water, and in 1991 the EPA officially proposed a Maximum Contaminant Level (MCL) for radon in public drinking water of 300 pCi/L. This MCL may one day become binding on public water supplies. [Federal Register, EPA]

2.2 Health Risks Due to Waterborne Radon

Waterborne radon leads to health risk by two pathways: inhalation of radon and its decay products following the release of radon gas from water into household air, and the direct ingestion of radon in drinking water.

The risk of lung cancer due to inhaled radon decay products has been well documented through the study of underground mine workers. The cancer risk due to ingestion, primarily cancer of the stomach and digestive organs, has been estimated from studies of the movement of radon through the gastrointestinal tract and bloodstream. Radon has not been linked to any disease other than cancer. The cancer risk from the inhalation pathway probably far exceeds that from the ingestion pathway. [Crawford-Brown, Federal Register]

In a typical house, with typical water usage patterns, a waterborne radon concentration of 10,000 pCi/L will yield an average increase to indoor air concentrations of about 1 pCi/L. The 10,000:1 ratio, while not to be considered a hard rule, has been verified through theoretical models and empirical evidence. [Hess] In a house with a high radon in water content, air radon concentrations tend to rise dramatically with water usage, especially in the vicinity of the water-using appliance, but decline steadily after the water usage tails off. [Henschel]

In most houses, waterborne radon is a secondary source of indoor radon, far exceeded by soil gas infiltration. It is an exception, though not a rare one, that waterborne radon is the major contributor to elevated radon in air. A homeowner who has discovered elevated air concentrations, and whose house uses private well water, should test the water for radon content to assess the water's contribution to the airborne radon. This test ought to be done before any attempt to mitigate soil gas infiltration, particularly if other wells in the area have been found to have radon. [Henschel]

2.3 Physical Properties of Waterborne Radon

Radon gas is mildly soluble in water. But, being a gas, it is volatile. It tends to leave the water upon contact with air. This is known as aeration.

The rate of radon transfer from water to air increases with temperature, agitation, mixing, and surface area. In household water usage, showers, baths, dishwashers, laundries, and toilets all provide adequate aeration to release a high percentage of the water's radon content into household air. [Prichard]

In principle, the radon will continue to be released from water as the aeration process continues, until a state of equilibrium develops. According to Henry's Law of dilute solutions, equilibrium will occur when the water concentration and air concentration reach a fixed ratio for a certain temperature. This ratio, derivable from the Henry's Law constant for radon dissolved in water, is known as the distribution coefficient or partition coefficient.
For radon in water at 20 degrees C (68 F) the distribution coefficient is about 0.25, so radon will continue to release from the water until the water concentration drops to about 25 percent of the air concentration. Remember that as the radon leaves the water into the air it raises the air concentration and lowers the water concentration. At lower temperatures the distribution coefficient increases, rising to 0.51 at 0 degrees C (32 F). At higher temperatures the distribution coefficient decreases, dropping to about 0.11 at 100 degrees C (212 F). An empirical expression for the distribution coefficient of radon in water as a function of temperature can be found in [Weigel].

2.4 Radon as a Tracer for Groundwater movement

Soil and rock typically contain significant concentrations of uranium and radium. Radon is continually being created in the ground so that groundwater often has high radon content. By contrast, open water contains very little dissolved radium. That, together with the proximity of the water surface, means that the background concentration of radon in sea and lake water far from land is very low.

Radon, then, with its 4-day half life, is an almost perfect tracer for measuring and monitoring the movement of ground water into lake and sea water along the shore [Lane-Smith, Burnett].

While open water monitoring often requires continuous, fast-response radon measurement at high sensitivity (as provided by the RAD AQUA [www.durridge.com]), for ground water in situ it is usually more convenient to use the RAD H_2O.

2.5 Standard Methods for Radon in Water Analysis

Several methods have been developed to measure radon in water. Three of these are Gamma Spectroscopy (GS), Lucas Cell (LC) and Liquid Scintillation (LS).

Gamma spectroscopy seeks to detect the gamma rays given off by radon's decay products from a closed container of radon bearing water. While simple in concept, this method lacks the sensitivity to detect radon at the lower levels now considered important.

The Lucas Cell method has been in use for decades for laboratory analysis of radon-222 and radium-226 (via radon emanation). The LC method tends to be somewhat labor intensive, using a complicated system of glassware and a vacuum pump to evacuate a Lucas (scintillation) cell, then bubble gas through the water sample until the cell fills. The cell is then counted by the usual technique. In the hands of a skilled technician this method can produce accurate, repeatable measurements at fairly low concentrations. [Whittaker, Krieger (Method 903.1)]

The Liquid Scintillation method dates to the 1970s. A liquid scintillation cocktail is added to the sample in a 25 mL glass LS vial. The cocktail draws the radon out of the water, so that when it decays the alpha particles scintillate the cocktail. The method uses standard LS counters, which are highly automated and can count several hundred samples in sequence without intervention. The EPA has determined that the LS method is as accurate and sensitive as the LC method, but less labor intensive, and less expensive. [Prichard, Whittaker, Hahn (Method 913.0), Lowry, Vitz, Kinner, Hess]

In comparison with the above, the RAD H_2O offers a method as accurate as LS but faster to the first reading, portable, even less labour intensive and less expensive. It also eliminates the need for noxious chemicals.

2.6 Mitigation Strategies

Two main strategies have emerged for the removal of radon from water. Both of these are applicable to point-of-entry (POE) water treatment in residences and small public water supplies.

Granular Activated Carbon (GAC) attempts to filter the water by adsorbing radon on a charcoal bed that holds onto the radon until the radon decays. GAC systems can be effective and relatively inexpensive for residential use, but can create new problems. As the radon and its progeny decay in the GAC column, they give off gamma radiation. The gamma radiation may be a health concern to residents when the influent radon concentration is high, the GAC column is poorly shielded for high energy radiation, and the residents are likely to spend significant periods of time in the radiation field. Over time, a long lived decay product, lead-210, builds up in the column, which may pose disposal problems in systems with moderate to high radon concentrations in the influent. For that reason GAC is most often recommended for influent concentrations of up to around 5,000 pCi/L. GAC maintenance is simple and inexpensive, and the GAC bed has an expected service life of 5 to 10 years. [Henschel, Lowry, Rydell]

Aeration brings water into contact with a stream of low radon air, which strips the radon from the water, then exhausts the radon bearing air to the atmosphere. Aeration systems offer effective removal of radon without the buildup of gamma radiation or waste material, but tend to be substantially more expensive than GAC to install and maintain in a residential setting. Aeration can be used over the entire range of influent concentrations, though very high influent concentration may require a multiple stage system to reduce the effluent concentration to acceptable levels. [Henschel, Lowry, NEEP]

3 RAD H_2O TECHNIQUE

3.1 The Closed Loop Concept

The RAD-H_2O method employs a closed loop aeration scheme whereby the air volume and water volume are constant and independent of the flow rate. The air recirculates through the water and continuously extracts the radon until a state of equilibrium develops. The RAD-H_2O system reaches this state of equilibrium within about 5 minutes, after which no more radon can be extracted from the water.

The extraction efficiency, or percentage of radon removed from the water to the air loop, is very high, typically 99% for a 40 mL sample and 94% for a 250 mL sample. The exact value of the extraction efficiency depends somewhat on ambient temperature, but it is almost always well above 90%. Since the extraction efficiency is always high, we see little or no temperature effect on the overall measurement.

3.2 Desiccant

The RAD-H_2O requires that the desiccant be used at all times to dry the air stream before it enters the RAD7. If the desiccant is not used properly, the RAD7 may give incorrect radon concentrations, or may become damaged due to condensation on sensitive internal components.

For water sample analysis, always use the small drying tubes supplied, as the system has been calibrated with these tubes. Do not use the large drying column as its much larger volume would cause improper dilution of the radon.

Make it a habit to inspect the RAD7 humidity reading to be sure the desiccant is and has been effective through the entire measurement session. All relative humidity readings during the measurement should remain below 10%. In the worst case, at least the first two counting cycles should be below 10%. If the relative humidity is higher than that, then the RAD7 should be purged, see below. See the RAD7 Operator's Manual for more information on maintaining the desiccant.

3.3 Purging the System

After performing a water or air measurement, the RAD7's internal sample cell will continue to contain the radon that was measured. If this radon is still present when you start a new measurement, it will erroneously influence the next measurement. This is of special concern when the radon concentration of the last measurement was high relative to the next measurement. To prepare for the next water measurement, you must remove, as thoroughly as possible, the radon from the RAD7 and its air conducting accessories, including the aerator head, tubes, and desiccant. This procedure is known as "purging the system."

To purge the system, you must have a source of radon-free (or relatively radon-free) air or inert gas. For most occasions ambient air is good enough, but see below. Put the RAD7 into a purge cycle with the "Test Purge" command, and allow the RAD7 pump to flush the clean air through the entire system for at least 10 minutes. After measuring very high radon concentrations, you should purge the system for at least 20 minutes. A purge time of 30 minutes should be long enough to remove almost all the radon after measuring a sample at 100,000 pCi/L.

Be sure to allow all the hoses and fittings to flush thoroughly by keeping them attached during the purge cycle for at least the first five minutes. Also be sure that the drying tube does not deplete its desiccant during the purge cycle. If the depleted (pink) desiccant gets to within 1 inch of the drying tube outlet, replace the tube with a fresh (blue) drying tube. After the first two or three minutes or purging, you may replace the small drying tube with the large laboratory drying unit, to conserve the small drying tube desiccant, and continue purging the system.

Be careful about the air you use to purge! Ambient air may not be adequately free of radon to properly prepare the system for a low level sample. The radon present in the purge air will add unwanted "background" to the next measurement. For example, a purge air radon concentration of 4 pCi/L will give about 4 x 25, or 100 pCi/L additional radon concentration to the next water result (40 mL water sample). This is too much background to neglect when measuring samples below 1,000 pCi/L, but if you are measuring only water samples above 1,000 pCi/L, you may consider this amount of error to be acceptable. To reduce the error due to purge air radon you may either subtract off the background from every measurement, or adopt strategies to reduce the background to acceptable levels. In any case, for levels below 1,000 pCi/L you should preferably use 250 ml vials when ambient air of 4 pCi/L will give only 20 pCi/L additional radon concentration to the next water result.

The best way to determine the background is to measure a "blank", a water sample containing no radon. To get radon free water, purchase distilled water from your local pharmacy, or fill a container with tap water, and allow the container to stand closed and undisturbed for 4 weeks or more. The 4 week period allows any radon present in the water to decay away. Store your radon free water in a closed air-tight container. Remember that the background due to purge air radon will change when the air radon concentration changes, so if you intend to subtract background you should measure a blank sample at every measurement session.

An alternative method to determine background is to make a measurement of the air in sniff mode and note the count rate in window A, after 15 minutes. From a previous printout of a water measurement, with the format set to medium or long, you can see the count rate in window A corresponding to the water radon concentration measured. Typically, for a 250 ml vial, 1,000 pCi/L in the water will generate about 50 cpm in window A. A background count rate of 0.5 cpm in window A (equivalent to about 2 pCi/L in air) will then produce an error of 1% in the final reading.

The obvious way to reduce background is to purge with very low radon air. Outdoor air rarely exceeds 0.5 pCi/L at several feet above the ground, so you can probably get the water background to below 13 pCi/L by simply using outdoor air to purge. To get even lower radon air, fill a tank or balloon with outdoor air and let it age for several weeks. If you are using compressed air or inert gas, be very careful not to allow the RAD7 to pressurize, as this may cause internal damage to the pump or seals.

Another method to reduce background is to use charcoal adsorption to clean the remaining radon from the system following the purge. A small column containing 15 grams of activated carbon can remove up to 98% of the remaining radon from the RAD-H_2O system when connected in a closed loop. This will reduce the system's radon to truly negligible levels for the most accurate low level radon in water measurement. The charcoal filter works best if you use it only after a complete purge with low radon air, which avoids overloading the filter with radon. If the charcoal filter becomes badly contaminated with radon it can give off some of the radon and actually increase the background after a purge. Store the charcoal filter with the end caps installed to allow the filter to "self-clean" by waiting for adsorbed radon to decay over several weeks time. Always keep the charcoal dry by using it in conjunction with a drying tube, since water vapor can adversely affect charcoal's capacity to adsorb radon.

Even if you choose not to use fancy methods to reduce the background, you should always purge the system between samples. It is much better to purge with ordinary room air than not to purge at all. In any case, it is also necessary to purge to remove any accumulated water vapor from the system, and bring the relative humidity back down to close to 5%.

3.4 Background and Residuals

Purge air is one among several causes for background counts in the RAD-H_2O. The most significant other causes are radon daughters and traces of radon left from previous measurements. The RAD7 has the unusual ability to tell the difference between the "new" radon daughters and the "old" radon daughters left from previous tests. Even so, a very high radon sample can cause daughter activity that can affect the next measurement.

After the high radon sample has been purged from the system, its decay products stay behind until they decay away. The polonium-218 isotope decays with a 3 minute half-life. In the 30 minutes following the purge, the polonium-218 decays to about a thousandth of its original activity. That still leaves a background of 100 pCi/L after a 100,000 pCi/L sample.

In addition to polonium-218, the RAD7 is sensitive to polonium-214, which can give counts for several hours after the radon has been removed. The RAD7 uses alpha energy discrimination to reject polonium-214 counts from a measurement, but a very small percentage of the polonium-214 decays slip past the discriminator. This can add background to a measurement that follows a high radon sample. The solution to the problem of daughter activity is time. Simply wait for the activity to decay away. Check the background with a blank sample. If it is still too high, keep waiting, and keep checking. The length of time you will wait depends on just how much radon your high radon sample had, and just how much background you are willing to tolerate before the next measurement. If you expect the next sample to be high also, you may want to go ahead with the next measurement right away, considering a small amount of background acceptable.

In the case of extremely high radon samples, you may develop a background that is more persistent than daughter activity. That is possibly due to off-gassing of residual radon that has absorbed into internal surfaces. In particular, rubber and plastic parts can absorb a small fraction of the radon that passes through the system. A small fraction of a very large amount can still be a significant amount. The radon may desorb from these materials over many hours. In the worst case you may have to allow the system to sit idle for a day or more for the absorbed radon to finish leaking out of these materials, then purge the system again to remove the radon. A radon concentration high enough to cause a concern of this kind is very rare in natural ground water, but is possible in artificial radon sources such as radium crocks or "Revigators".

Sustained counting of very high radon concentrations can lead to the buildup of long lived lead-210 contamination of the RAD7's alpha detector. This possibility is described in the RAD7 Operator's Manual. It suffices to say that the RAD7's ability to distinguish alpha particles by energy makes it far less susceptible to the build up of lead-210 related background than other radon monitors.

4 RESULTS

4.1 How Calculation Is Made

The RAD7 calculates the sample water concentration by multiplying the air loop concentration by a fixed conversion coefficient that depends on the sample size. This conversion coefficient has been derived from the volume of the air loop, the volume of the sample, and the equilibrium radon distribution coefficient at room temperature. For the 40 mL sample volume the conversion coefficient is around 25. For the 250 mL sample volume the conversion coefficient is around 4.

The RAD7 does not presently make any correction for the temperature of the water sample. In theory, such correction would slightly improve the analytical accuracy for the larger (250 mL) sample volume, but would make little or no difference for the smaller sample volume.

4.2 Decay Correction

If you collect a sample and analyze it at a later time (rather than immediately), the sample's radon concentration will decline due to the radioactive decay. You must correct the result for the sample's decay from the time the sample was drawn to the time the sample was counted. If the sample is properly sealed and stored, and counted within 24 hours, then the decay corrected result should be almost as accurate as that of a sample counted immediately. Decay correction can be used for samples counted up to 10 days after sampling, though analytical precision will decline as the sample gets weaker and weaker.

The decay correction is a simple exponential function with a time constant of 132.4 hours. (The mean life of a radon-222 atom is 132.4 hours, which is the half-life of 3.825 days multiplied by 24 hours per day divided by the natural logarithm of 2.) The decay correction factor (DCF) is given by the formula DCF = exp(T/132.4), where T is the decay time in hours.

You will notice that decay times of under 3 hours require very small corrections, so you can ordinarily neglect the decay correction for samples counted quickly.

To correct your result back to the sampling time, multiply it by the decay correction factor (DCF) from the chart, figure 6 opposite.

4.3 Dilution Correction

If you intend to count samples that have very high radon concentrations, you may wish to dilute the sample by a fixed ratio, then correct the result back to its undiluted concentration.

Example: You take a 4 mL sample and dilute it with 36 mL of distilled water in a 40 mL sample vial. Overall, this would be a 10:1 ratio of final volume to initial volume, so you must multiply the result by 10 to correct for the dilution. If the RAD-H_2O reports a result of 9,500 pCi/L for the 10:1 diluted sample, then the original concentration must have been 10 X 9,500, or 95,000 pCi/L. Great care must be taken in this process to avoid loss of radon from the sample. The syringe should be filled and refilled several times from under water that is a true sample, see method 2 in section 1. The 40 ml vial should contain 36 ml of radon-free water. 4 ml of the undiluted sample should be injected slowly at the bottom of the vial, and the vial quickly capped. Any air bubble should be very small.

Hours	DCF	Hours	DCF	Hours	DCF	Hours	DCF	Hours	DCF
0	1.000	1	1.008	2	1.015	3	1.023	4	1.031
5	1.038	6	1.046	7	1.054	8	1.062	9	1.070
10	1.078	11	1.087	12	1.095	13	1.103	14	1.112
15	1.120	16	1.128	17	1.137	18	1.146	19	1.154
20	1.163	21	1.172	22	1.181	23	1.190	24	1.199
25	1.208	26	1.217	27	1.226	28	1.236	29	1.245
30	1.254	31	1.264	32	1.273	33	1.283	34	1.293
35	1.303	36	1.312	37	1.322	38	1.332	39	1.343
40	1.353	41	1.363	42	1.373	43	1.384	44	1.394
45	1.405	46	1.415	47	1.426	48	1.437	49	1.448
50	1.459	51	1.470	52	1.481	53	1.492	54	1.504
55	1.515	56	1.526	57	1.538	58	1.550	59	1.561
60	1.573	61	1.585	62	1.597	63	1.609	64	1.622
65	1.634	66	1.646	67	1.659	68	1.671	69	1.684
70	1.697	71	1.710	72	1.723	73	1.736	74	1.749
75	1.762	76	1.775	77	1.789	78	1.802	79	1.816
80	1.830	81	1.844	82	1.858	83	1.872	84	1.886
85	1.900	86	1.915	87	1.929	88	1.944	89	1.959
90	1.973	91	1.988	92	2.003	93	2.019	94	2.034
95	2.049	96	2.065	97	2.081	98	2.096	99	2.112
100	2.128	101	2.144	102	2.161	103	2.177	104	2.194
105	2.210	106	2.227	107	2.244	108	2.261	109	2.278
110	2.295	111	2.313	112	2.330	113	2.348	114	2.366
115	2.384	116	2.402	117	2.420	118	2.438	119	2.457
120	2.475	121	2.494	122	2.513	123	2.532	124	2.551
125	2.571	126	2.590	127	2.610	128	2.629	129	2.649
130	2.669	131	2.690	132	2.710	133	2.731	134	2.751
135	2.772	136	2.793	137	2.814	138	2.836	139	2.857
140	2.879	141	2.901	142	2.923	143	2.945	144	2.967
145	2.990	146	3.012	147	3.035	148	3.058	149	3.081
150	3.105	151	3.128	152	3.152	153	3.176	154	3.200
155	3.224	156	3.249	157	3.273	158	3.298	159	3.323
160	3.348	161	3.374	162	3.399	163	3.425	164	3.451
165	3.477	166	3.504	167	3.530	168	3.557	169	3.584
170	3.611	171	3.638	172	3.666	173	3.694	174	3.722
175	3.750	176	3.778	177	3.807	178	3.836	179	3.865
180	3.894	181	3.924	182	3.954	183	3.984	184	4.014
185	4.044	186	4.075	187	4.106	188	4.137	189	4.168
190	4.200	191	4.232	192	4.264	193	4.296	194	4.329
195	4.361	196	4.395	197	4.428	198	4.461	199	4.495
200	4.529	201	4.564	202	4.598	203	4.633	204	4.668
205	4.704	206	4.739	207	4.775	208	4.811	209	4.848
210	4.885	211	4.922	212	4.959	213	4.997	214	5.035
215	5.073	216	5.111	217	5.150	218	5.189	219	5.228
220	5.268	221	5.308	222	5.348	223	5.389	224	5.429
225	5.471	226	5.512	227	5.554	228	5.596	229	5.638
230	5.681	231	5.724	232	5.768	233	5.811	234	5.855
235	5.900	236	5.945	237	5.990	238	6.035	239	6.081

Fig. 6 Decay Correction Factors

5 ACCURACY AND QUALITY CONTROL

5.1 Calibration of System

The RAD-H_2O method relies on a fixed-volume closed-loop extraction of radon from water to air. Since the volumes are constant and the physical properties of radon are constant, we do not anticipate a need to routinely adjust the conversion coefficient. The only factors we anticipate will require "calibration checks" are sampling and laboratory technique, and the RAD7 unit.

In sample handling you can lose a significant fraction of the radon if you do not follow consistent procedures. For this reason we recommend that you regularly review your method, and compare your results to those of other methods in side-by-side comparisons. One way to check the accuracy of your analysis technique is to take side-by-side identical samples, analyze one yourself and send the other to an independent laboratory.

As part of your quality assurance plan, you should regularly check the RAD7 unit for its ability to determine radon in air, and periodically send the RAD7 in for a check-up and recalibration. Government agencies usually recommend or require annual or bi-annual recalibration of radiation measurement instruments. You can find more information about calibration in the RAD7 Operation Manual.

Durridge recommends against the use of radium-226 solutions in the RAD-H_2O system due to the risk of permanent contamination.

5.2 Accuracy and Precision

A number of factors affect the accuracy and precision of a radon in water measurement. Most critical among these factors is the sampling technique, which was discussed in greater detail in a previous section. Other factors include the sample concentration, sample size, counting time, temperature, and background effects.

5.2.1 Sampling Technique

You can expect a sample-to-sample variation of from +/-10% to +/-20% due to sample taking alone, probably caused by the uneven aeration of the sample and the loss of a fraction of the radon. By paying very careful attention to detail, you may be able to get the variation down to under +/-5%.

5.2.2 Sample Concentration

You can usually determine high concentrations with a better precision than low concentrations (when precision is expressed in terms of percent error). This is because a higher concentration gives a greater number of counts per minute above the background and its fluctuation, yielding more favorable counting statistics. If the concentration is too high, however, you can exceed the upper limit of the RAD7's range.

5.2.3 Sample Size

A larger sample size gives a greater number of counts per minute above back- ground, so improves sensitivity and precision at low radon concentrations. But the larger sample size limits the method's range somewhat, and increases temperature effects.

5.2.4 Counting Time

Longer counting times improve sensitivity and precision by accumulating a greater total number counts above background, which gives more favorable counting statistics. Increasing the usual 20 minute count time to 80 minutes (4 times 20) will improve counting statistics by a factor of 2 (square root of 4). For this to work, however, it is necessary that the RAD7 be thoroughly dried out, so that the relative humidity does not climb too high during the 80 minutes of count time. It is possible, during a measurement, to set the pump from GRAB to ON, which will turn it on, thus moving air through the desiccant and into the RAD7. When the relative humidity is down once more, the pump must be set back to GRAB.

5.2.5 Temperature

The temperature effect on accuracy is very small with the 40 mL sample vial, but may begin to become noticeable with the 250 mL vial at very low or high temperatures. The RAD-H_2O system has been calibrated for a sample analysis temperature of

20 degrees C (68 degrees F). At colder temperatures the water "holds back" a little more of the radon during the aeration process, and at warmer temperatures the water "gives up" the radon more readily.

The maximum temperature effect at equilibrium for the 40 mL sample is about +/-1% over the range of 0 to 40 degrees C (32 to 104 degrees F). The maximum temperature effect at equilibrium for the 250 mL sample is about +/-6% over the same range.

5.2.6 Relative Humidity

If the RAD7 is thoroughly dried out before use, the relative humidity inside the instrument will stay below 10% for the entire 30 minutes of the measurement. If not, then the humidity will rise during the 25 minutes that the RAD7 is counting and the pump is stopped, and may rise above 10% before the end of the measurement period. High humidity reduces the efficiency of collection of the polonium-218 atoms, formed when radon decays inside the chamber. At around 60% humidity, the collection efficiency may be only half that at 10% relative humidity or below. However, the 3.05 minute half life of polonium-218 means that almost all the decays that are actually counted come from atoms deposited in the first 20 minutes of the measurement. So a rise in humidity above 10% over the last ten minutes of the counting period will not have a significant effect on the accuracy of the result.

If the first two counting periods are below 10% relative humidity, you may ignore humidity effects. On the other hand, if the humidity rises above 10% before the end of the first counting cycle, there will be an error whose size is indeterminate. However, you can be sure that any error due to high humidity will be in a direction to reduce the reading, so that the true value must be higher than the observed value.

For accurate readings, the RAD7 should be dried out thoroughly before making the measurement, see section 1.

5.2.7 Background Effects

By careful attention to details, you can reduce the background in the RAD-H_2O system to insignificant levels. We previously discussed how to control the background due to purge air radon content and residual radon and its progeny. The uncontrollable, or "intrinsic", background of the RAD7 is low enough to ignore in all but the most demanding cases. The intrinsic background of the RAD7 is less than 1 count per hour, corresponding to a 40 mL water sample concentration of less than 2 pCi/L (even lower for the 250 mL sample). In principle, you can achieve a background this low if you completely eliminate all radon and progeny from the system before a measurement, but that will require a fair amount of effort and patience. A more realistic background to shoot for in routine analysis might be between 10 and 20 pCi/L. Remember, if you know the background well enough, you can subtract it off and have reasonable confidence in the result.

5.3 Comparison of RAD-H_2O with Other Methods

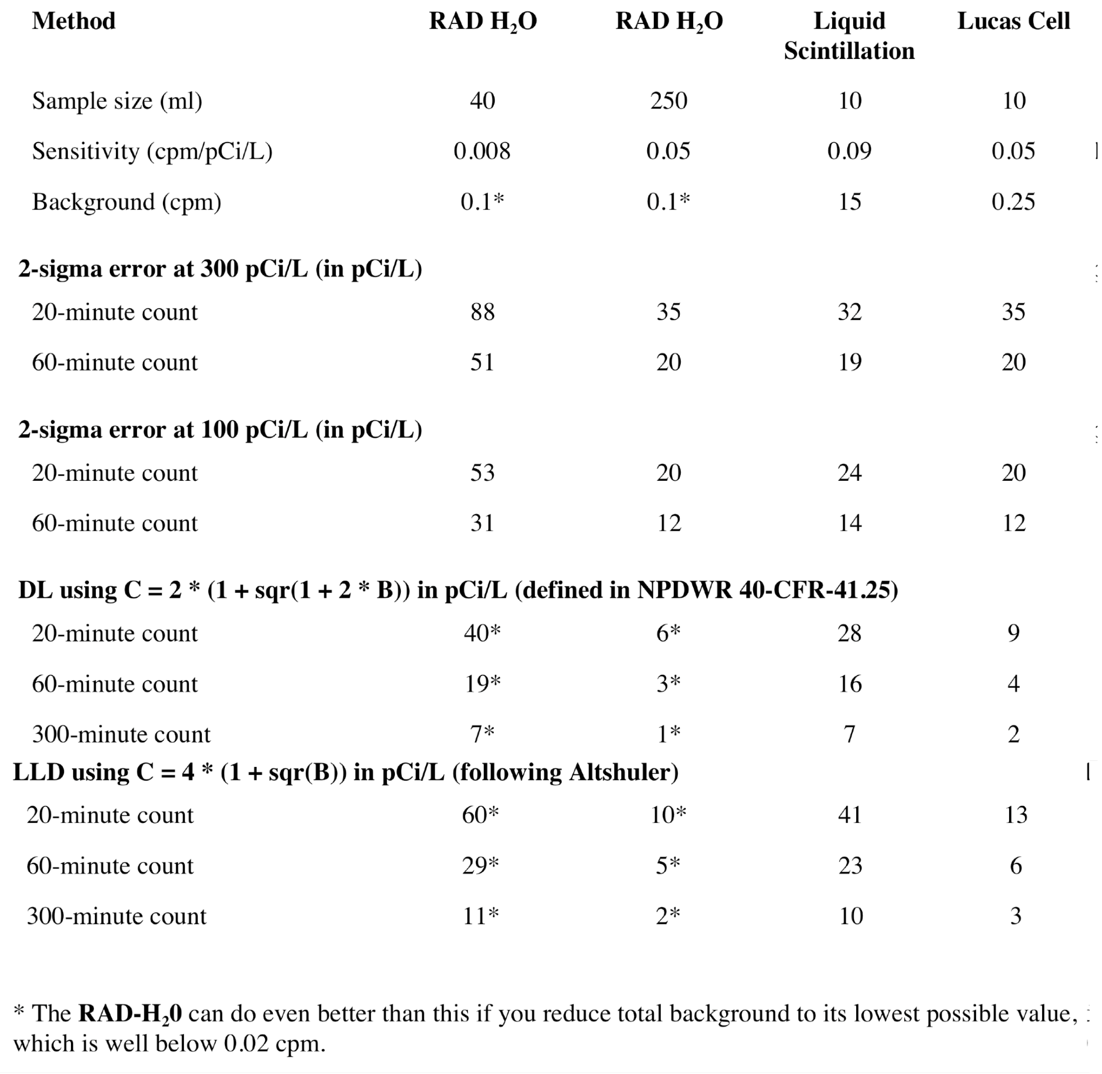
Fig. 7 is a table of typical numbers to give a basis for comparison. Some laboratories may be able to get better results than this table indicates, while others may not. The precision figures include counting statistics only, with no adjustment for sampling variation or decay of the sample.

Note that standard laboratory analysis often entails a long delay between sampling and analysis, which can significantly increase the error and raise the detection limit (DL) and the lower limit of detection (LLD). Also note that the background figure used to calculate the RAD-H_2O precision, DL, and LLD is conservatively estimated to reflect typical field usage. The most demanding and patient RAD-H_2O operator should be able to reduce background to less than 0.02 cpm (rather than the 0.10 cpm given in the table), which will allow for DL's and LLD's lower than those listed.

5.4 Quality Assurance

A proper quality assurance plan should follow the guidelines set by the USEPA as described in [Goldin]. Compliance with future certification programs will certainly require an approved quality assurance plan.

The elements of a quality assurance plan include blank samples, duplicate samples, and spiked samples. Often, the plan provides for blind samples to be measured in an inter-comparison program. If a quality control measurement deviates beyond the acceptable range, the operator must cease to make measurements until the cause of the deviation has been discovered and corrected. Therefore, the quality assurance plan should specify the range of acceptable measurement deviations, often in the form of a "control chart". The operator should maintain complete records of the quality control measurements and their deviations.



Method	**RAD H_2O**	**RAD H_2O**	**Liquid Scintillation**	**Lucas Cell**
Sample size (ml)	40	250	10	10
Sensitivity (cpm/pCi/L)	0.008	0.05	0.09	0.05
Background (cpm)	0.1*	0.1*	15	0.25
2-sigma error at 300 pCi/L (in pCi/L)				
20-minute count	88	35	32	35
60-minute count	51	20	19	20
2-sigma error at 100 pCi/L (in pCi/L)				
20-minute count	53	20	24	20
60-minute count	31	12	14	12
DL using C = 2 * (1 + sqr(1 + 2 * B)) in pCi/L (defined in NPDWR 40-CFR-41.25)				
20-minute count	40*	6*	28	9
60-minute count	19*	3*	16	4
300-minute count	7*	1*	7	2
LLD using C = 4 * (1 + sqr(B)) in pCi/L (following Altshuler)				
20-minute count	60*	10*	41	13
60-minute count	29*	5*	23	6
300-minute count	11*	2*	10	3

* The **RAD-H$_2$0** can do even better than this if you reduce total background to its lowest possible value, which is well below 0.02 cpm.

Fig. 7 Method Comparison

6 CARE, MAINTENANCE and TROUBLE SHOOTING

6.1 Warning on Pump Direction

The RAD-H_2O system cannot tolerate the reversal of the air connections at the aerator head or the RAD7. A check valve should be used at all times to prevent the disastrous possibility of sucking water into the RAD7, should a connector be accidentally reversed. If a reversed connection occurs, the check valve prevents the water from rising past the aerator head by blocking its path. Do not allow the RAD7 to continue pumping against a blocked check valve, as this may cause damage to the pump or to the RAD7's internal seals.

6.2 Warning on Tipping the Aeration Unit

Never operate the RAD-H_2O aeration unit in any position other than upright! If the aeration unit tips to any direction it may allow water to pass through the outlet tube toward the RAD7 unit. If liquid water reaches the RAD7, it could permanently damage critical internal parts, resulting in an expensive repair bill.

Use a solid, stable base to hold the aerator unit when you operate the system. The RAD-H_2O case makes a good base when placed on a level surface.

6.3 Frit Maintenance

After performing many radon in water measurements, the glass frit may begin to show stains or even begin clogging due to the buildup of mineral deposits. If the mineral buildup is light and low in radium content, we see no reason for concern. Heavy deposits may be removed from the frit by soaking it in a strong acid solution, followed by a thorough rinse with clean water.

6.4 High Humidity

While the pump is stopped, during the 25 minutes after aerating the sample, water molecules will continue to desorb from internal surfaces. If the relative humidity rises beyond 20% by the last counting cycle, the result of the measurement will be low by more than 5%. To prevent this from happening, more time may need to be spent drying out the system, with the laboratory drying unit in the sample path, before the measurement

After the initial purging of five minutes or more, the humidity can be monitored by starting a SNIFF test (Setup, Protocol, Sniff, Enter, Menu, Enter, Right-arrow, Enter) and going to the third status window (Menu Enter Enter Right-arrow Right-arrow). The relative humidity is displayed in the upper right hand corner.

Watch the humidity as it comes down below 10%RH. With experience you will learn just how long to keep the run going. In any case, the humidity must come down to 6% and you may find that 5% or lower is necessary.

At the same time as the humidity is coming down, you can go to the fifth status window to observe the count rate in window A. Provided that you have purged all the radon out of the system, the window A count rate will be due to residual 218-Po on the alpha detector surface. This will halve every 3 minutes until it approaches equilibrium with the radon concentration in the air in the measurement chamber. The residual A-window count rate must be much less than the value it reaches during a sample measurement.

After utilizing SNIFF mode to monitor the humidity and A-window count rate before and between sample measurements, please remember to put the RAD7 back into WAT 40 or WAT250 mode for the actual water measurement. If a water measurement is started with the RAD7 still in SNIFF mode, and the error noticed within the first few minutes, the measurement can be stopped (Test, Clear), the protocol changed to the correct one and the test restarted without fear of introducing error.

6.5 Foaming

While clean water causes no problem, some natural waters contain foaming agents that will cause bubbles to rise up out of the aerator. With the current RAD H_2O setup, a piece of 5/16” ID tubing extends up from the aerator to the small tube of desiccant held vertically in the retort stand. This arrangement makes it difficult for bubbles to rise up as far as the desiccant and reduces the concern about foaming.

If the water is so contaminated that the foam can climb the 5/16” tubing, an empty small desiccant tube can be substituted for the tubing (with short pieces used just to make the connections). The empty tube provides an even greater inside diameter to prevent bubbles from reaching the desiccant. The increase in total air-loop volume is insignificant so that no correction is necessary to the reading.

6.6 Technical Support

DURRIDGE does not expect the RAD-H_2O apparatus to require routine maintenance or service beyond the replacement of damaged parts. The RAD7 unit may require periodic service beyond routine calibration, particularly the air pump and rechargeable batteries. For help, contact service@durridge.com or phone (978)-667-9556.

7 DEVIANT SETUPS

7.1 Passive DRYSTIK

Use of a 12” passive DRYSTIK is not really a deviant setup but rather a supplement to the standard setup. The DRYSTIK may be installed with the membrane tubing upstream of the desiccant and the purge line between the RAD7 outlet and the aerator.

Great care should be taken to ensure that no liquid or foam enters the membrane tubing. Water inside the DRYSTIK can , at best, temporarily disable it and at worst destroy it.

With normal, clean water, the DRYSTIK placed vertically above the aerator and with 12” of 5/16” tubing between the two, there should be no problem. But if the water sample is particularly foamy, the DRYSTIK should not be used in the system until it is determined the setup is such that no foam will climb up into it.

With the 12” DRYSTIK installed the RAD7/RAD H_2O system will behave normally in every respect except that the desiccant will last about five times longer before it needs to be regenerated or replaced. WAT 40 protocol will give readings of the radon in the water when 40 ml vials are used and similarly WAT250 when 250ml vials are used.

7.2 Large Drying Unit

A large “laboratory” drying unit, as used for 2-day protocol monitoring, may be used with the RAD H_2O but it increases the volume of air in the system, so reducing the concentration of radon in the loop after aeration of the sample. To accommodate the change in air-loop volume a multiplying factor of 2.0 must be applied to the RAD H_2O reading. Thus a reading of radon in the water of 300 pCi/L taken with a laboratory drying unit in the setup instead of a small drying tube, the radon concentration in the water was 600 pCi/L.

The multiplying factors for 40ml vials and 250ml vials are sufficiently close to the same that only one figure needs to be remembered.

The multiplying factor of 2.0 was derived from a series of experiments performed at DURRIDGE Company. The precise factor for any setup depends also on the choice and length of tubing.

For the most reliable assessment users should perform their own experiments with their own setup. Collect a number of equal samples - say six at least. Be very careful in the sample taking to be sure they are all indeed the same. Analyze half the samples with a standard setup and the other half with the deviant setup to determine the average multiplying factor. Corrections for sample decay over the period of the experiment should be applied.

At the end of each analysis a big proportion of the radon will be in the drying unit. It is necessary to purge this out of the system before the start of the next reading. To that end, the drying unit and RAD7 must be purged for at least ten minutes after each measurement.

Please note that by increasing the air volume the sensitivity of the system is reduced. With a large drying unit installed instead of the small drying tube the sensitivity is halved. Thus the lower limit of detectability is doubled and the uncertainty of any reading is increased by SQR(2) or by a factor of 1.4.

7.3 Oversized Dome

Some RAD7s have high-gain modifications installed, one of which may be an oversized measurement chamber, or dome. This will increase the volume of the air loop.

For an otherwise standard setup, the multiplying factor to compensate for the oversized dome is 1.2. If the large dome setup also uses the laboratory drying unit instead of the small drying tube, the multiplying factor will be 1.68.

7.4 Extended Cycle Time and Cycle Count

After choosing the preset protocol WAT 40 or WAT250, depending on the size of vials used, both the cycle time and cycle number (Recycle) may be increased to give more counts and hence higher sensitivity to the radon-in-water measurement.

The pump will, in any case, stop after 5 minutes, which is long enough to aerate the sample. The final reading will be the same as for standard protocol except that it will be more precise. So no multiplying factor is required.

Apart from it taking longer to finish the analysis, the only issue is humidity which will have more time to build up to unacceptable levels.

A solution is to run the pump for short periods during the analysis, so circulating dry air through the RAD7 and bringing down the humidity (Setup, pump on [ENTER] and Setup, pump, off [ENTER]). A problem with this, though, is that it aerates the sample and delivers more water molecules to the desiccant, so depleting it.

To be able to circulate sample air through the desiccant and through the RAD7 without aerating the water sample any further a bypass may be made for the air flow to bypass the aerator. A valve in this bypass must be turned off during the first five minutes while the water sample is being aerated. It may be opened for later circulation of the air round the loop, to keep the RAD7 dry.
It would be possible to use an entirely different protocol from WAT 40 or 250. In that case with, say, SNIFF protocol and 10-minute cycle times, the pump will run for five minutes at the beginning of every cycle. After the first cycle the by-pass valve may be opened to prevent further aeration of the sample.

To determine the original radon concentration in the water sample after a SNIFF protocol reading it will be necessary to multiply the radon in air measurement by a factor whose value may be found from a measurement with WAT 40 or WAT250 protocol. In fact the two could be made with the same sample. First make a normal RAD H_2O measurement then, without changing the physical setup, change the preset WATXXX protocol to SNIFF, bypass the aerator (to conserve desiccant) and start a new run. The readings will now be radon in air and may be compared directly with the previous WATxxx readings of radon in the water.

7.5 Active DRYSTIK

If an active DRYSTIK is used instead of a passive device, the RAD7 pump must be switched off and the DRYSTIK pump used instead. This circulates air at only 0.2 L/min. It will therefore take 20 minutes instead of five to aerate the sample. It is recommended, therefore that, after presetting WAT 40 (or 250), the pump be turned off (Setup, pump, off [ENTER]) and the cycle time be extended to 10 minutes. It will take an hour to make the analysis, but virtually no desiccant will be used if the RAD7 was initially dried out properly.

7.6 Large Aerator

A number of users have fabricated their own aerator system using large water sample containers (Lee and Kim). Such an approach increases the sensitivity of the system so lowering the lowest limit of detection. Disadvantages are a) a significant increase in the complexity of the method, b) increased difficulty in collecting the sample, c) the need for calibration of the setup and d) significant temperature dependence of the sensitivity.

For a given air volume, increasing the water volume gives reducing returns as the water volume gets bigger. For a system with a laboratory drying unit and RAD7, the air volume is about 2 litre. For such a setup, there is little to be gained by having a water sample bigger than around 6 litre.

Aquarium aerator stones may be used to aerate the sample. An array of them at the bottom of the flask containing the sample would be good.

Care must be taken to ensure that the water sample being analyzed has not lost any of its radon by exposure to air before it is placed in the loop. It should be filled and sealed entirely under water. If valves are placed in the inlet and outlet connections to the sample flask, they should be kept closed at all times except when aeration is actually taking place.

It will take longer than 5 minutes to aerate the sample. With the system connected, put the RAD7 in SNIFF mode. Start a measurement. See how many 5-minute cycles it takes for the reading to reach close to the equilibrium value. Subtract one cycle for the RAD7 response time, multiply the resulting number by five and you have how many minutes it takes to aerate the sample in a flask of that size.

You can complete the measurement with the RAD7 in SNIFF protocol, using five-minute cycles if you wish. To conserve desiccant, however, you may wish to assemble an aerator bypass and switch to a longer cycle time or a different protocol, e.g. 1-day that has half-hour cycles, and continue the analysis until you have enough counts to give you the statistical precision you desire.

With such a setup, the sensitivity of the RAD H_2O system can be improved by an order of magnitude over standard protocol and standard setup.

With a large water sample, the RAD7 preset protocols, WAT 40 and WAT250, are no longer of service. The user has to decide on the protocol to use and then has to calibrate the system using that protocol. One way to calibrate the system is to take multiple samples of the same water and analyze them in different ways, including with the large aerator sample flask. Direct comparison with a standard analysis using the standard setup of a RAD7 and RAD H_2O would work. Comparison with a RAD AQUA measurement would also be good.

The temperature dependence will vary from setup to setup, depending principally on the volume of the water sample and the volume of the air loop. One way to deal with this is always to allow the sample to reach the same, laboratory temperature as that when the system was calibrated before making the analysis. Another would be to calibrate the system at different temperatures and determine the temperature coefficient. A third would be to calculate the temperature coefficient from the theoretical equations and the dimensions of the equipment.

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