RAD H_2O

Radon in Water Accessory for the RAD8

User Manual

DURRIDGE

Radon Capture & Analytics

TABLE OF CONTENTS

INTRODUCTION 4

1 GETTING STARTED 5

1.1 Unpacking 5

1.2 General Safety Instructions 7

1.3 Running a Test 9

1.3.1 Preparing the RAD8 9

1.3.2 Collecting a Sample 9

1.3.3 Setting Up the Equipment 10

1.3.4 Starting the Test 11

1.3.5 Finishing the Test 12

1.3.6 Interpreting the Results 13

1.3.7 Graphing RAD H2O Data in Capture 14

2 BACKGROUND 15

2.1 About Radon in Water 15

2.2 Health Risks Due to Waterborne Radon 15

2.3 Physical Properties of Waterborne Radon 16

2.4 Radon as a Tracer for Groundwater movement 17

2.5 Historical Methods for Radon in Water Analysis 17

2.6 Mitigation Strategies 18

3 RAD H2O TECHNIQUE 19

3.1 The Closed Loop Concept 19

3.2 Desiccant 19

3.3 Purging the System 19

3.4 Background and Residuals 21

4 RESULTS 23

4.1 How Calculation Is Made 23

4.2 Decay Correction 23

4.3 Dilution Correction 25

5 ACCURACY AND QUALITY CONTROL 26

5.1 Calibration of System 26

5.2 Accuracy and Precision 26

5.2.1 Sampling Technique 26

5.2.2 Sample Concentration 27

5.2.3 Sample Size 27

5.2.4 Purging 27

5.2.5 Aeration 27

5.2.6 Counting Time 27
5.2.7 Temperature 28
5.2.8 Relative Humidity 28
5.2.9 Background Effects 28
5.3 Comparison of RAD H2O with Other Methods 29
5.4 Quality Assurance 30

6 CARE, MAINTENANCE, and TROUBLESHOOTING 31

6.1 Warning on Pump Direction 31
6.2 Warning on Tipping the Aeration Unit 31
6.3 Glass Frit Maintenance 31
6.4 Humidity and Residual Background 32
6.5 Foaming 32

7 DEVIANT SETUPS 35

7.1 Passive Drystik (ADS-1) 35
7.2 Laboratory Drying Unit 35
7.3 Extended Cycle Time and Cycle Count 36
7.4 Active Drystik (ADS-2, ADS-3, ADS-3R) 36
7.5 Large Water Samples 37

ACKNOWLEDGEMENTS 38

REFERENCES 39

INTRODUCTION

The RAD H_2O is an accessory to the RAD8 that enables you to measure radon in water over an activity concentration range of from less than 4 pCi/l to greater than 1,200,000 pCi/l. By diluting your sample, or by waiting for sample decay, you can extend the method's upper range to any concentration.

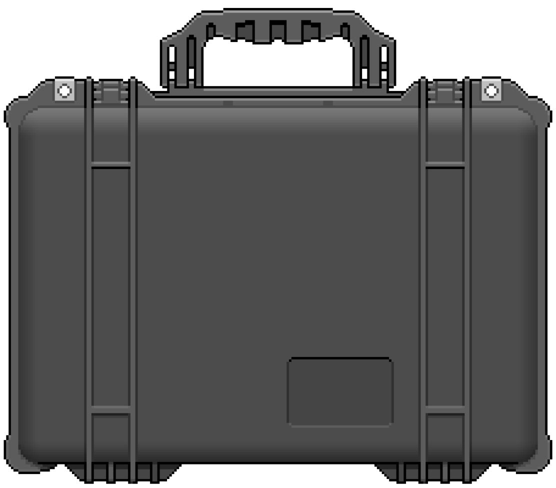
The equipment is portable and battery operated, and the measurement is fast. You can have an accurate reading of radon in water within an hour of taking the sample. The RAD H_2O gives results after a 30 minutes analysis with a sensitivity that exceeds that of liquid scintillation methods. The method 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 RAD8. If both the RAD8 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 RAD8 before embarking on radon-in-water measurements. Instructions for RAD8 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 RAD8 User Manual.

1 GETTING STARTED

1.1 Unpacking

Examine the RAD H_2O case contents and verify that you have all the items shown below. If anything is missing, please email sales@durridge.com.



RAD H_2O Carrying Case

- Rugged Pelican brand case
- Dust-proof and crush-proof
- Sculpted foam inserts to hold components

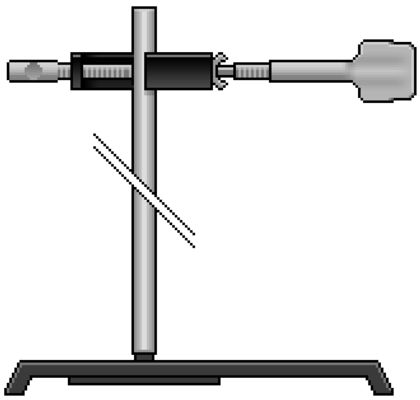
250 ml Glass Vials

- 250 ml Glass Vial (x6)
- Septum cap (x6)

40 ml Glass Vials

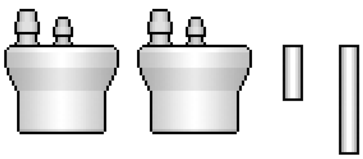
- 40 ml Glass Vial (x12)
- Septum cap (x12)
- Labels for 40 ml Glass Vials

Continued on next page.



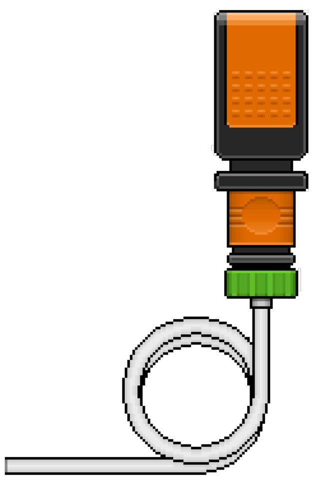
Retort Stand

- Small adjustable Retort Stand
- Clamp for Retort Stand



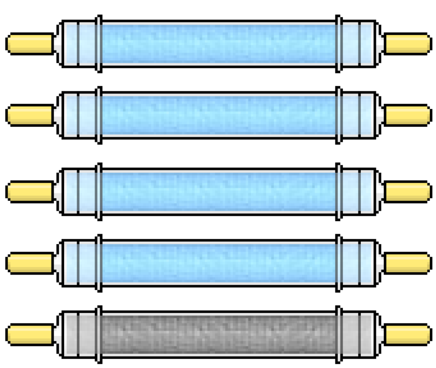
RAD H_2O Aerator Cap Kit

- Aerator Cap (x2)
- Tubing for 40 ml and 250 ml vials



Indoor Faucet Adaptor

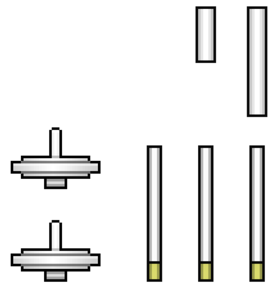
- Plastic adaptor
- 20-inch vinyl tubing



Drying and Charcoal Tube Kit

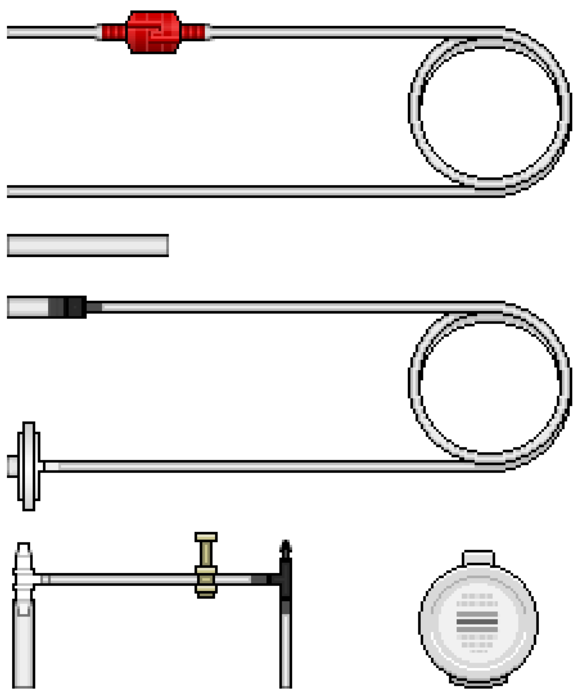
- Small Drying Tubes x 4
- Tube of activated charcoal x 1

Continued on next page.



RAD H_2O Glass Frit Kit

- Glass Frit (x3)
- RAD8 inlet filter (x2)
- Tygon Tubing spacers for 40 ml and 250 ml vials



RAD H_2O Tubing Set

- From RAD8 to Aerator Cap, with check valve (24”)
- From Aerator Cap to drying tube (3”)
- From Small Drying Tube to RAD8 (24”)
- RAD H_2O Bypass Assembly
- Container of vacuum grease (use grease when connecting tubing to the Aerator Cap to ensure a tight seal)

Fig. 1 RAD H_2O Components

1.2 General Safety Instructions

There is nothing particularly hazardous to the user in the RAD H_2O. Care should be taken to make sure that water never enters the RAD8. The check valve attached to the aerator should never be removed, as it protects the RAD8 in the event that the tubing connections to the instrument are reversed. For more information on preventing water from entering the RAD8, see Section 6.2, Warning on Tipping the Aeration Unit.

The setup consists of three components: the RAD8, the Glass Vial with Aerator Cap, and the Small Drying Tube full of indicating desiccant, which is connected to the Aerator Cap and supported by a Clamp on the Retort Stand. The components are connected to one another using the included tubing, as shown in Fig. 2 on the following page.

During the ten minutes of aeration, the radon concentration in the air loop will approach equilibrium with the remaining radon in the water.

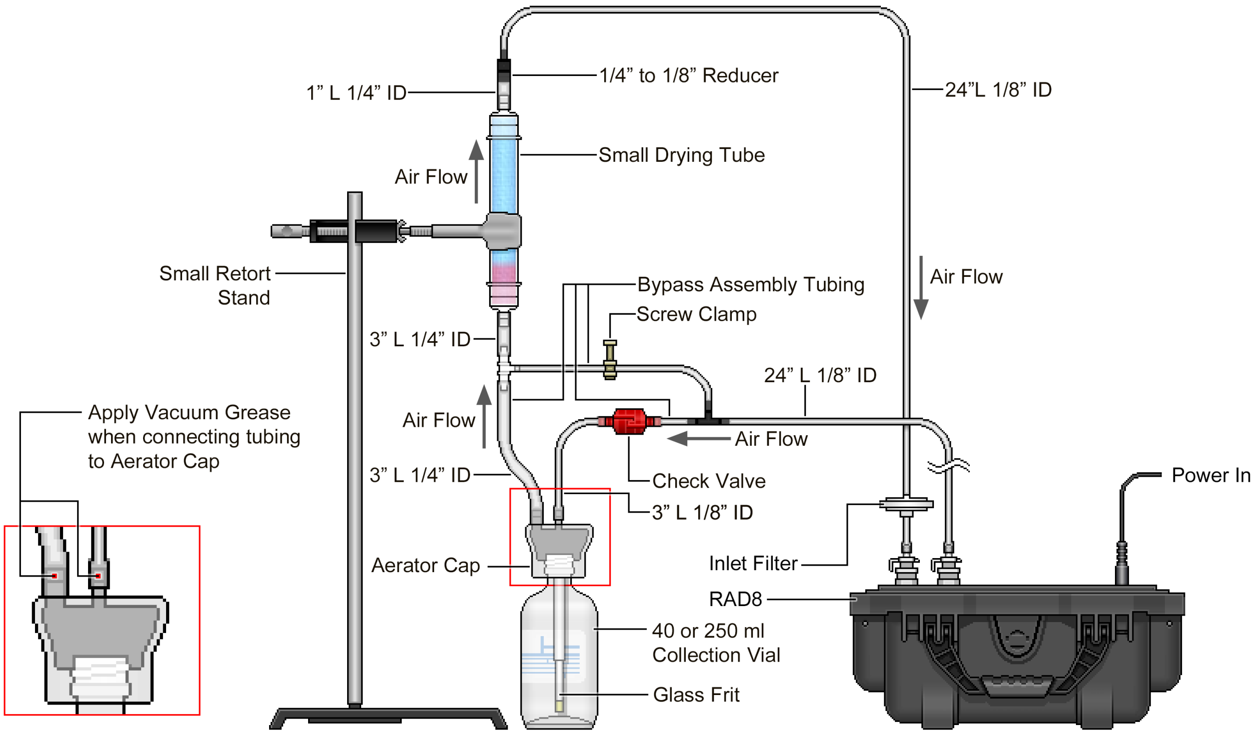


Fig. 2 RAD H_2O Schematic

When the RAD8 is set to either the ‘H_2O 40 ml’ or ‘H_2O 250 ml’ Preset Protocol, it automatically calculates the radon concentration in a 40 ml or 250 ml water sample based on the radon concentration of the air entering the instrument. For this calculation to be performed accurately, the components must be assembled exactly as shown.

1.3 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.

1.3.1 Preparing the RAD8

Before making a measurement, the RAD8 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 RAD8 inlet, with the inlet filter in place (see RAD8 manual). Purge the unit with fresh dry air for at least ten minutes (Start Test > Purge).

Continue purging until the relative humidity (RH) is reduced to 5% or below. To conserve desiccant, after the first ten minutes or so, you may connect the RAD8 outlet to the inlet of the Laboratory Drying Unit, thus forming a closed drying loop. This will continue to dry out the RAD8 but will not introduce more fresh air.

If the RAD8 has not been used for some time, or if it has been left without a 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 usually be sufficient.

1.3.2 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 an hour, to make sure that the sample comes freshly from deep in the well.

To satisfy (b), one of three techniques may be used. The first is to attach a tube to the faucet and fill the Glass Vial using the tube. The second is to hold a bowl up to the faucet so that water overflowing from the bowl prevents the water leaving the faucet from touching air. The vial is then placed at the bottom of the bowl and allowed to fill. The third method combines the first two, 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 Glass Vial if the radon concentration in the water is presumed to be 100,000 pCi/l, (3,700,000 Bq/m^3) or lower. For significantly higher radon concentrations, a 40 ml Glass Vial is recommended. 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 Glass Vial from the bowl, dry it and immediately apply a label stating the date, time and source of the water.

1.3.3 Setting Up the Equipment

Find the two short pieces of Tygon tubing (One tube is longer than the other). In the instrument case, as originally shipped, the shorter tube is in the 40 ml Glass Vial assembled on the aerator in the middle of the case. With the vial removed, the end of the Glass Frit should be 75 mm or 3 inches from the bottom of the Aerator Cap. Measure and adjust as necessary. The longer tube is in the foam at the near left-hand corner of the case (immediately to the right of the 6th 250 ml vial). The end of the Glass Frit should be 115 mm or 4 7/16" from the bottom of the Aerator Cap. Adjust it as necessary. Pick the tube appropriate to the size of vial containing the water sample: short for the 40 ml vial and long for the 250 ml vial. Push one end onto the aerator barb, on the side opposite the check valve.

Apply vacuum grease to the two hose barbs on the top of the Aerator Cap. This causes a tight seal to be formed between the tubing and the hose barbs. Without sufficient vacuum grease, air leakage can occur, resulting in a low radon-in-water reading.

With the 3" (7.6 cm) of 1/4" ID vinyl tubing, connect the output of the aerator (without a check valve) to a Small Drying Tube. Use vacuum grease to improve the fit of the tubing over the hose barbs on the Aerator Cap. If one end of the Small Drying Tube is pink, that end should face down, towards to the aerator outlet. Connect the other end of the Small Drying Tube, with 1/8" ID tubing, to an inlet filter mounted on the RAD8 inlet. The 1/4" to 1/8" adapter makes this connection easy and secure. Connect the RAD8 outlet to the check valve on the aerator. The Bypass Assembly may be added as a precaution against foaming, as discussed in Section 6.5.

With the system as connected so far, set the RAD8 to purge for another few minutes. While it is purging, clamp the Small Drying Tube on the Retort Stand, thus supporting it vertically.

Stop purging. On the RAD8, go to `Start Test > Preset Protocols > H2O 40 ml` or `H2O 250 ml`, depending on which size of vial is being used, but do not begin the test yet. It is essential that the correct protocol be chosen here, because this controls the pumping and counting cycle, and the factor used to convert from the measured radon-in-air activity concentration to the target radon-in-water activity concentration, according to the size of sample vial (17.88 and 2.82 for the 40 ml and 250 ml Glass Vials, respectively). Insert the Glass Frit into the Tygon tubing extending down from the Aerator Cap.

The following procedure should now be performed as quickly as possible, to minimise radon loss from the water sample before it has been inserted into the air loop. Remove the septum cap from the water sample and lower the Glass Frit into the water. Some water will spill during this procedure. Screw the Aerator Cap onto the Glass Vial to close the air loop.

The Glass Vial can be inserted in a slot in the RAD H_2O case to keep it secure. It must be upright while aeration is in progress. See Fig. 2 and 3.

1.3.4 Starting the Test

Start the Test with the appropriate RAD H_2O Preset Protocol. The pump will run for ten minutes, fully aerating the sample and delivering the radon to the RAD8, which will begin to collect the polonium-218 ions from radon decays onto its alpha detector. After 10 minutes, the RAD8's pump will stop, and the RAD8 will start counting.

After a further five minutes, the RAD8 will plot a data point on the time series chart (`Test Status > Chart`). The same thing will happen again five minutes later, and for two more five-minute periods after that. The radon level is that of the water, and is calculated automatically by the RAD8. All data is stored in the .rd8 data file, which may be viewed on the RAD8's colour touchscreen (`Manage Test Data > View`), viewed in Capture Cloud (Capture 8 Pro licence required), or downloaded to a computer at any time.

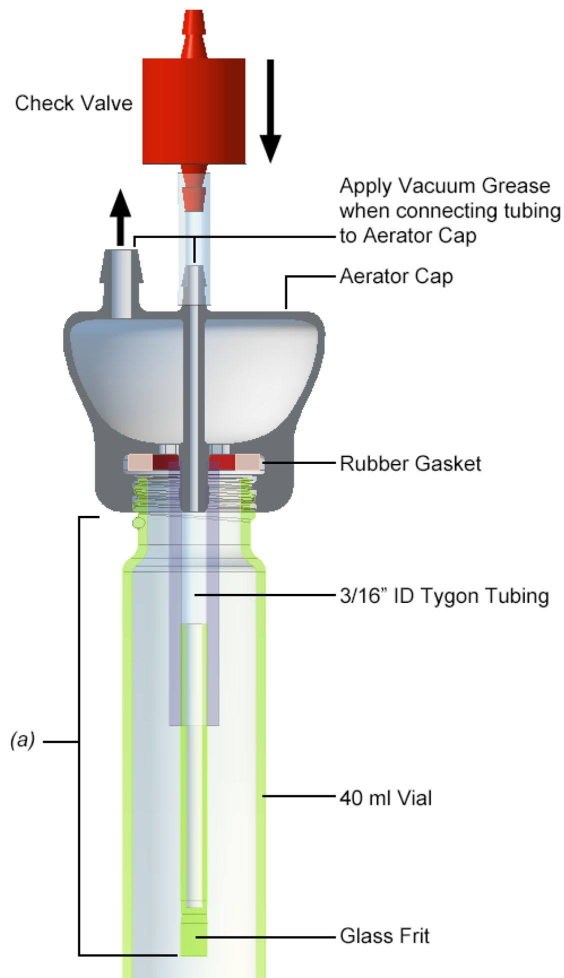


Fig. 3 Aerator assembly

(a) 75 mm for 40 ml; 115 mm for 250 ml

1.3.5 Finishing the Test

Once the RAD8 has finished counting the sample, unscrew the Aerator Cap from the Glass Vial, raise the Glass Frit out of the water, and set the RAD8 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 RAD8 connected as above, and purging, for at least two minutes. The Laboratory Drying Unit may be substituted for the Small Drying Tube. Continue the purge for another ten minutes. Check the RH, as above, and continue the purge until it drops to 5% or below. After six or seven minutes, the RAD8 air outlet may be connected to the input of the Laboratory Drying Unit, to form a closed loop, to conserve desiccant. When the RH is down to 5% or less, another test may be conducted. Repeat from 1.3.1 above.

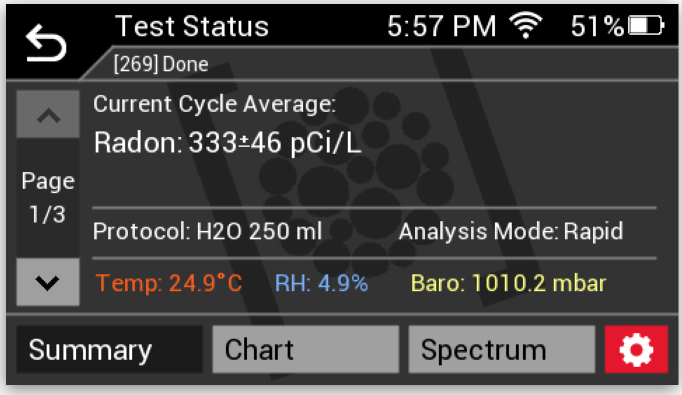
1.3.6 Interpreting the Results

The results as shown in the Manage Test Data menu are shown in Fig. 4, below.

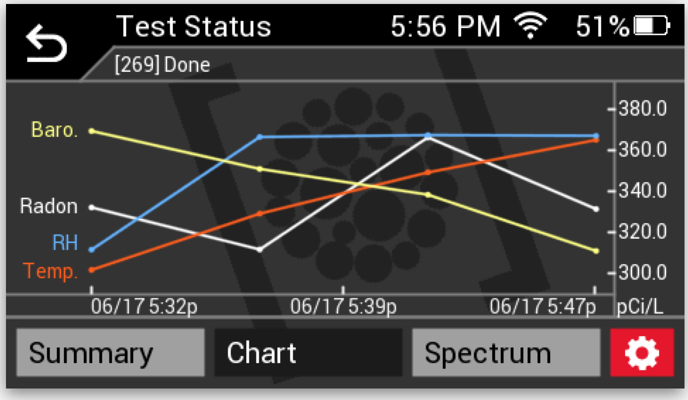
The Summary Screen shows the mean radon content of the water, at the time of the analysis, along with its associated 2-sigma uncertainty. The Chart screen shows a chart of the results of the four individual five-minute cycles, whilst the Spectrum screen shows a cumulative alpha energy spectrum from the full 20-minute test.

The result shown on the Summary screen takes into account the calibration of the RAD8, 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.



RAD8 Test Summary screen



RAD8 Chart screen

Fig. 4 Viewing RAD H_2O results

1.3.7 Graphing RAD H_2O Data in Capture

RAD H_2O data can be graphed using Durridge's Capture software, with no additional configuration required. A "Radon In Water" graph line will appear automatically, and there will be no "Radon In Air" graph line. A label above the first data point will indicate that the graph contains RAD H_2O data.

The Show Error Bars checkbox can be used to visualize the statistical error of each data point. Often the statistical error will overwhelm any variations in the radon concentration between data points.

Additionally, the Show Selection Average checkbox can be used to visualize the average radon in water concentration of the entire RAD H_2O data test. The blue shaded region indicates the uncertainty of this average.

If nonstandard testing components such as a large Laboratory Drying Unit or Drystik are used in a RAD H_2O test, Capture's Test Parameters Window should be used to specify exactly which components are used, so that the program can account for these items when calculating Radon in Water concentrations. For additional details, see Section 7, Deviant Setups.

For more information and to download the Capture software, visit [www.durridge.com/software/capture/].

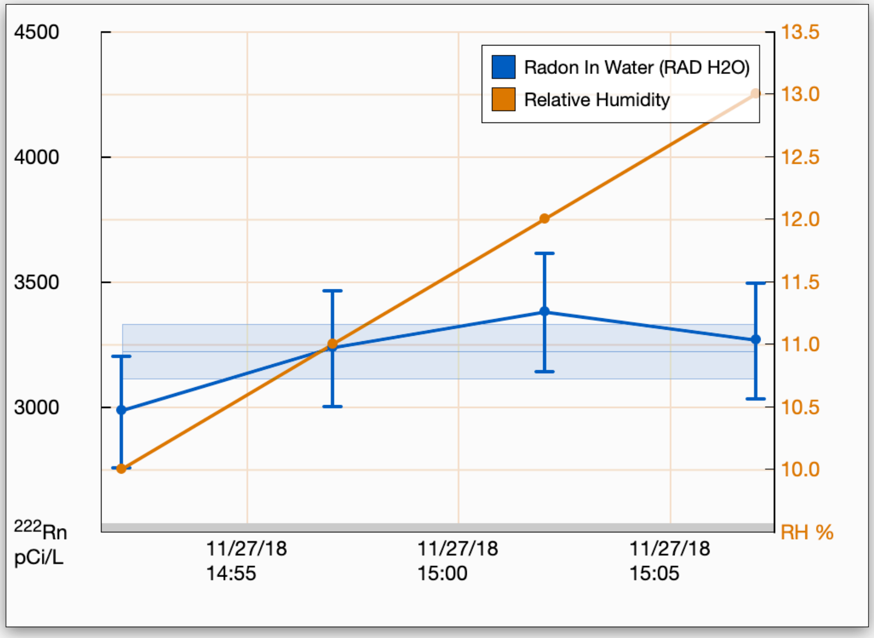


Fig. 5 RAD H_2O Data Graph in Capture Software

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. Radon is rarely found in large 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 are 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, scientists 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. The cancer risk from the inhalation pathway probably far exceeds that from the ingestion pathway. [Crawford-Brown, Federal Register] Recent epidemiological studies have also linked radon exposure to non-cancer conditions such as hypertensive disorders of pregnancy. [Papatheodorou]

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 degassing or 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 partition coefficient.

For radon in water at 20°C (68°F) the partition coefficient is about 0.25, so radon will continue to release from the water until the water activity concentration drops to about 25 percent of the air activity 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 partition coefficient increases, rising to 0.51 at 0°C (32 °F). At higher temperatures the partition coefficient decreases, dropping to about 0.11 at 100°C (212°F). An empirical expression for the partition coefficient of radon in water as a function of temperature can be found in [Weigel], and as a function of both temperature and salinity in [Schubert].

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 (where degassing to the air occurs), means that the background concentration of radon in sea and lake water far from land is very low.

Radon, then, with its 3.8-day half life, is an almost perfect tracer for measuring and monitoring the movement of groundwater 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 groundwater in situ it is usually more convenient to use the RAD H_2O.

2.5 Historical 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 RAD8 + RAD H_2O system reaches this state of equilibrium within 5-10 minutes, after which no more radon can be extracted from the water.

3.2 Desiccant

It is best practise to use indicating desiccant at all times to dry the air stream before it enters the RAD8. For water sample analysis, always use the supplied Small Drying Tubes, as the system has been calibrated with these tubes. Do not use the larger Laboratory Drying Unit, as its much larger volume would cause improper dilution of the radon and yield artificially low results.

Make it a habit to inspect the RAD8 humidity reading to be sure the desiccant is and has been effective through the entire measurement session. All RH readings during the measurement should remain below 5%. In the worst case, at least the first two counting cycles should be below 5%. If the relative humidity is higher than that, then the RAD8 should be purged (see below). See the RAD8 Operator's Manual for more information on maintaining the desiccant.

3.3 Purging the System

After performing a water or air measurement, the RAD8'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 RAD8 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 instructions are given later in this section for very low-level measurements that demand purging with ultra-low-radon air.

Before purging, ensure that the tubing bridge is in place between the RAD8's Pump Out and Detector In front panel ports, and that the Sample In and Sample Out ports are also populated with connectors. All RAD8 air fittings are ‘normally closed’, so no airflow is possible with unpopulated ports.

Put the RAD8 into a purge cycle (Start Test > Purge) and, with no sample vial attached to the Aerator Cap, allow the RAD8 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. If the Bypass Assembly was in place during the test, open it for a few minutes to purge any radon from the short length of bypass tubing.

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 Small Drying Tube does not deplete its desiccant during the purge cycle. If the depleted (pink) desiccant gets to within 1 inch of the Small Drying Tube outlet, replace the tube with a fresh (blue) Small Drying Tube. After the first two or three minutes of purging, you may substitute the Small Drying Tube for the larger 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 18, or 72 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, where ambient air of 4 pCi/l will give only 4 x 3, or 12 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 and note the count rate in window A after 15 minutes. From a previous water measurement (Manage Test Data > View), 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 140 cpm in window A. A background count rate of 0.5 cpm in window A (equivalent to about 1.25 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 2 pCi/l (250 ml vials) 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 RAD8 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 below 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 RAD8 has the unusual ability to tell the difference between the "new" radon daughters (polonium-218) and the "old" radon daughters (polonium-214 and, later, polonium-210) 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 appears in the 'A' window of the alpha energy spectrum, and 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 RAD8 is sensitive to polonium-214, which can give counts in the 'C' window for several hours after the radon has been removed. The RAD8 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 will lead to the deposition and buildup of long-lived lead-210 contamination on the RAD8's alpha detector, as described in the RAD8 User Manual. The RAD8's ability to distinguish radon daughters by their alpha decay energy makes it immune to the buildup of lead-210 related background.

4 RESULTS

4.1 How Calculation Is Made

The RAD8 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 partition coefficient at an assumed water temperature of 20°C. For the 40 ml sample volume the conversion coefficient is 17.9. For the 250 ml sample volume the conversion coefficient is 2.82.

The RAD8 does not presently measure or 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. To give extreme examples at the opposite ends of the RAD8's operating temperature range… with a 250 ml sample, a water temperature of 0°C leads to a 12% underestimate of the radon concentration, whereas a water temperature of 50°C leads to a 5% overestimate.

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 table, Fig. 6.

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

Fig. 6 Decay Correction Factors

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.

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 RAD8 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 RAD8 unit's ability to measure radon in air, and periodically send the RAD8 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 RAD8 User 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 is the sampling technique, which is discussed below, and in Section 3. Other factors include the sample concentration, the sample size, the counting time, the 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 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%.

When taking a sample, it is important that the water being sampled has never been in contact with air. When sampling from a body of water, it is best to take the sample from beneath the surface, as close to the source as possible. Even opening an empty bottle beneath the surface does not completely satisfy that criterion because the air in the bottle itself can take radon away from the initial water entering the bottle. It is very easy to lose radon from the sample in the process of collecting it.

It is also important to collect all of the samples to be analyzed at around the same time, so that the results can be compared without having to make separate corrections for radon decay or any other time-based factors. See Section 1.3.2 for more information on sampling technique.

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 extremely high, however, you can exceed the upper limit of the RAD8's linear range.

5.2.3 Sample Size

A larger sample size provides more counts per minute above the background, improving sensitivity and precision at low radon concentrations. But the larger sample size also limits the method's range somewhat, and increases the effect of the water temperature on the result. For more information see Section 5.2.7, Temperature, and Section 7.6, Large Water Samples.

5.2.4 Purging

A common cause of error is incomplete purging of the system before a measurement. If residual radon exists in the RAD8 and tubing when the RAD H_2O vial is hooked up to it, that residual radon will be added to the radon provided by the aeration of the sample. In the case of a 40 ml vial, 1 Bq/L of residual radon in the air loop will be reflected as 18 Bq/L additional radon in the original 40 ml water sample.

5.2.5 Aeration

If a 250 ml analysis reads low, a common reason is because the Glass Frit was not at the bottom of the bottle, but set for a 40 ml vial, thus incompletely aerating the 250 ml sample. Care should be taken to check that the Glass Frit is close to the bottom of the vial. If a mistake is discovered after the system is properly set up, it is permissible to allow some aeration to take place before the 'H_2O 250 ml' measurement is started. That way, the water can be partly aerated, with some of the radon already in the closed loop at the start of the test, allowing a more complete overall aeration after the 10 minutes of aeration at the start of the measurement. Section 6.5 provides instructions on how to begin aerating a water sample in advance of the actual test.

5.2.6 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 RAD8 be thoroughly dried out, so that the relative humidity does not climb too high during the 80 minutes of count time.

5.2.7 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° C (68° 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 -2/+1% over the range of 0 to 50°C (32 to 122°F). The maximum temperature effect at equilibrium for the 250 ml sample is about -12/+6% over the same range.

5.2.8 Relative Humidity

If the RAD8 is thoroughly dried out before use, the RH inside the instrument will stay below 5% for the entire 30 minutes of the measurement. If not, then the humidity will rise during the 25 minutes that the RAD8 is counting and the pump is stopped, and may rise above 5% 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 20°C and 50% RH, the collection efficiency may be only around two thirds that at minimal (2-3%) RH. 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 5% 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 5% relative humidity, you may ignore humidity effects. On the other hand, if the humidity rises above 5% 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 reported value.

For accurate readings, the RAD8 should be dried out thoroughly before making the measurement (See section 1.3.1).

5.2.9 Background Effects

By paying 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 RAD8 is low enough to ignore in all but the most demanding cases. The intrinsic background of the RAD8's Rapid analysis mode is less than 1 count per day, corresponding to a 40 ml water sample concentration of 0.027 pCi/l, or a 250 ml water sample concentration of 0.0042 pCi/l . 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 1 and 10 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 provides a basis for comparing different methods of measuring radon in water samples. The numbers are typical, and 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 0.01 cpm (rather than the 0.10 cpm given in the table), which will allow for DL's and LLD's lower than those listed.

Method	RAD H_2O 40	RAD H_2O 250	Big Bottle System	Liquid Scintillation	Lucas Cell
Sample Size (ml)	40	250	2500	10	10
Sensitivity (cpm/ pCi/l)	0.022	0.14	0.76	0.09	0.05
Background (cpm)	0.1*	0.1*	0.1*	15	0.25
2-sigma uncertainty at 300 pCi/l (in pCi/l)					
20-minute count	56	21		32	35
60-minute count	31	12	5.2	19	20
120-minute count	22	8.5	3.7	14	14
2-sigma uncertainty at 100 pCi/l (in pCi/l)					
20-minute count	35	13		24	20
60-minute count	19	7.1	3.0	14	12
120-minute count	13	5.0	2.1	10	8.5
DL (C=2*(1+sqr(1+2*B)) in pCi/l) (NPDWR 40-CFR-41.25)					
20-minute count	14*	2.3*		28	9
60-minute count	6.9*	1.1*	0.20*	16	4
300-minute count	4.5*	0.71*	0.13*	7	2
LLD (C=4*(1+sqrB)) in pCi/l (Altshuler)					
20-minute count	22*	3.4*		41	13
60-minute count	10*	1.6*	0.30*	23	6
300-minute count	6.6*	1.1*	0.20*	10	3

Fig. 7 Method Comparison

5.4 Quality Assurance

A proper quality assurance plan should follow the guidelines set by the USEPA as described in [Goldin]. 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.

6 CARE, MAINTENANCE, and TROUBLESHOOTING

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 RAD8. A check valve should be used at all times to prevent the possibility of sucking water into the RAD8, 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 RAD8 to continue pumping against a blocked check valve, as this may cause damage to the pump or to the RAD8's internal seals.

6.2 Warning on Tipping the Aeration Unit

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.

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 RAD8 unit. If liquid water reaches the RAD8, it could permanently damage critical internal parts, resulting in an expensive repair bill.

If water ever enters the RAD8 it will probably cease to operate properly, and immediate steps should be taken to minimize the impact on the instrument.

Keep the RAD8 upright. This will prevent any water inside the measurement chamber from touching the sensitive alpha detector. Put a piece of tubing on the RAD8 outlet with the other end in a sink. Use the RAD8 pump if it still works or, otherwise, an external pump into the inlet, to blow air through the instrument. When water ceases to be blown out of the outlet, put desiccant upstream of the RAD8 and blow air through the RAD8 for several hours to thoroughly dry it out.

Once there is no visible water in or on the instrument, it can be put in an oven at just below 50°C for a few hours to dry out completely. Additionally, desiccated air can be passed through the air path until the relative humidity of the air leaving the RAD8 drops below 5%. At this point the instrument should be returned to Durridge for service.

6.3 Glass 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 Glass Frit by soaking it in a strong acid solution, followed by a thorough rinse with clean water. If you suspect that your frit has been contaminated with radium, it should be replaced to avoid adding background to your measurements.

6.4 Humidity and Residual Background

While the pump is stopped, during the 20 minutes after aerating the sample, water molecules will continue to desorb from internal surfaces. If the relative humidity rises much above 5% by the end of the second counting cycle, the result of the measurement will be low. 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. The humidity can be monitored on the Test Summary screen (Test Status > Summary) by starting a Sniff test (Start Test > Preset Protocols > Sniff) and going to the Summary screen. The relative humidity is displayed at the bottom, along with temperature and ambient air pressure.

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

At the same time as the humidity is coming down, you can go to the third Summary screen (Test Status > Summary > [down] > [down]) 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 polonium-218 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 performing a short Sniff test to monitor the humidity and A-window count rate, the RAD8 is now ready to be used in the next sample measurement.

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 standard RAD H_2O setup, a piece of 1/4” ID tubing extends up from the aerator to the Small Drying Tube 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 1/4” 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. This increases the air loop volume by 5% which, in turn, increases the air-water conversion factor by 4.5%. You may consider this negligible, or you may choose to multiply your results by 1.045 to account for the presence of the bubble trap.

The force of the RAD8’s internal pump may also influence the water level in the RAD H_2O. Reducing the effective pump strength can prevent water from breaching the aerator and saturating the desiccant. This is accomplished using the included Bypass Assembly, which allows some air to bypass the aerator and flow directly from the RAD8 outlet to the Small Drying Tube. The RAD H_2O Bypass Assembly should be connected as shown in Fig. 8.

When the screw clamp on the Bypass Assembly is loosened, less air will be injected into the water and the turbulence will be reduced, but as a result the aeration process may require more than the standard 10 minutes that is included in the RAD8's RAD H_2O present protocols. This issue is more common with 250 ml samples than with 40 ml samples.

Where incomplete aeration is a problem, it is necessary to do some initial pumping before starting a measurement with either of the preset 'H_2O 40 ml' or 'H_2O 250 ml' protocols. In fact this initial pumping is necessary in order to be able to determine the optimal screw clamp tightness on the Bypass Assembly. Start by opening the bypass fully. Next, turn the pump on by starting a purge (Start Test > Purge). Gradually close the screw clamp to divert air through the sample. Stop tightening the clamp when you have found the maximum air flow rate that can be achieved without foam rising up into the desiccant. Depending on how slow the permissible flow rate is, let the pumping continue for a few minutes to aerate the sample. Then stop the purge, and start an 'H_2O 40 ml' or 'H_2O 250 ml' test. If you judged it right, the sample will be fully aerated after ten more minutes of pumping. If you are not sure, start another test immediately without disconnecting the tubing, and check that the next reading is nearly the same (it will likely be slightly lower due to tiny leaks).

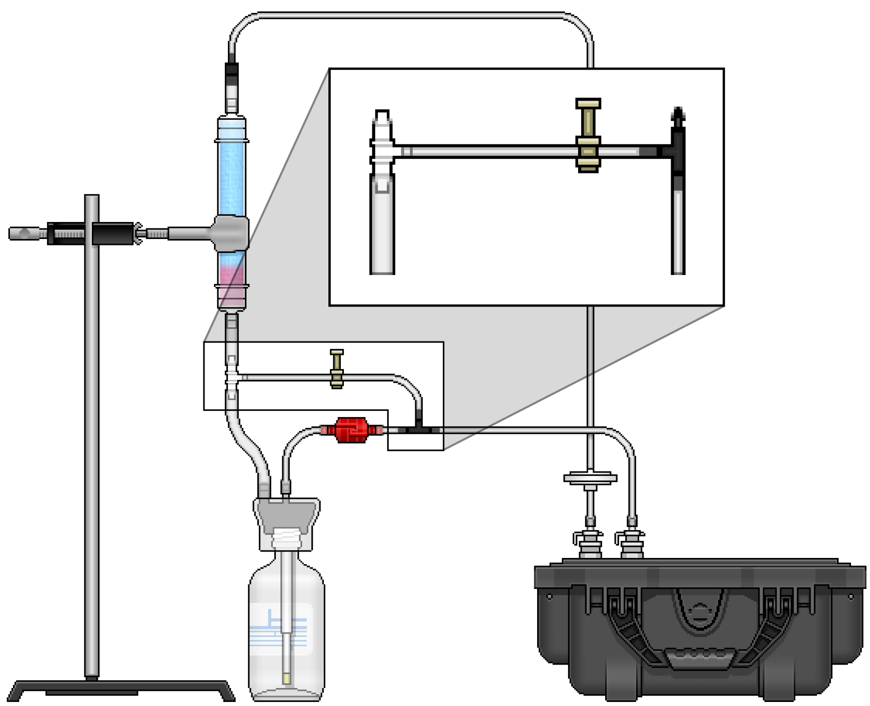


Fig. 8 RAD H_2O with Bypass Assembly

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 RAD8 unit may require periodic service beyond routine calibration, particularly the air pump. For help, contact service@durridge.com or visit www.durridge.com.

7 DEVIANT SETUPS

7.1 Passive Drystik (ADS-1)

Use of a 12” Passive Drystik is not really a deviant setup but rather a supplement to the standard setup. The Passive Drystik may be installed with the membrane tubing upstream of the desiccant and the purge line between the RAD8 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 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 RAD8/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. The preset ‘H_2O 40 ml’ protocol will give accurate readings of the radon in the water when 40 ml vials are used, and similarly ‘H_2O 250 ml’ protocol when 250 ml vials are used.

7.2 Laboratory Drying Unit

A large “Laboratory” Drying Unit, as used for regular radon-in-air monitoring, may be used with the RAD H_2O. However, it increases the volume of air in the system, and so reduces the concentration of radon in the loop after aeration of the sample. To accommodate the change in air-loop volume a multiplying factor of 1.69 must be applied to RAD H_2O readings taken with the H_2O 40 ml and H_2O 250 ml preset protocols. 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 510 pCi/l.

The multiplying factors for 40 ml vials and 250 ml vials are sufficiently close to the same that only one figure needs to be remembered. The precise factor for any setup depends also on the choice and length of tubing.

Durridge’s Capture software can calculate radon in water concentrations for a variety of deviant setups involving different drying unit sizes, tubing volumes, and other factors. Use the Test Parameters dialogue in Capture (File > Test Parameters > Big Bottle, then select a RAD H_2O preset from the drop-down menu) to see how the calculated radon-in-water value changes when you swap the Small Drying Tube for a Laboratory Drying Unit. See the Capture Manual on our website for more details.

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 Laboratory Drying Unit. It is necessary to purge this out of the system before the start of the next reading. To that end, the Laboratory Drying Unit and RAD8 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 the larger Laboratory Drying Unit installed instead of the Small Drying Tube the sensitivity is divided by a factor of 1.69. Thus the lower limit of detectability is multiplied by the same factor, and the uncertainty of any reading is increased by SQR(1.69) or by a factor of 1.3.

7.3 Extended Cycle Time and Cycle Count

Both Cycle Time and Cycle Count may be increased to give more counts and hence higher sensitivity to the radon-in-water measurement. Do Start Test > Manual Config to set these parameters, from where they can be stored as a Custom Protocol for easy retrieval later. Sample Source should be set to 'H_2O 40 ml' or 'H_2O 250 ml' to ensure that the RAD8 displays the calculated radon-in-water activity concentration, rather than the measured radon-in-air concentration. Set Pre-Test Purge to 10 minutes to fully aerate the sample before counting begins. Set the Pump Mode to 'Standard', which will cause the pump to run for 2 minutes in every 5 during the counting period. This will periodically circulate dry air through the RAD8 and ensure that the humidity does not climb to unacceptably high levels.

To be able to circulate sample air through the desiccant and through the RAD8 without aerating the water sample any further, connect the included RAD H_2O Bypass Assembly as shown in Fig. 8 in the previous section. This will allow the the air flow to bypass the aerator as needed. The Bypass Valve must remain closed during the first ten minutes while the water sample is being aerated. It may be opened for later circulation of the air round the loop, to keep the RAD8 dry.

The final reading will be the same as for a standard RAD H_2O protocol except that it will be more precise. So no multiplying factor is required.

In extended measurements with the RAD H_2O, leak tightness becomes even more important than with the standard 20-minute counting time. Any leak will cause the readings to drop as time goes by. Keep an eye on the Chart screen, and consider checking all tubing connections (including re-greasing those on the Aerator Cap) if the rate of decrease is unacceptably high. Note that even with no air leakage at all, there will be a slow drop due to radioactive decay, which would cause the reading to drop to half of its initial value in 3.8 days (the radon half-life).

7.4 Active Drystik (ADS-2, ADS-3, ADS-3R)

If an Active Drystik is included in the air loop, the RAD8 pump must be switched Off and bypassed, and the Drystik pump used instead. The Active Drystik models ADS-2 and ADS-3 offer multiple air flow ports. The High Airflow port provides an air flow rate of approximately 1.5 L/min, and it will cause the aeration to proceed more rapidly than is possible with the RAD8 pump. But if the Drystik's Low Airflow output is used, the air flow rate will be much lower than the RAD8 pump speed; slightly under 0.2 L/min. It will therefore take at least 20 minutes (instead of ten) to aerate the sample.

Different models of Active Drystik have different internal volumes, and therefore increase the air loop volume by differing amounts. Check your model number, then use the Test Parameters dialogue (File > Test Parameters > Big Bottle, then select a RAD H_2O preset from the drop-down menu) to see how the calculated radon-in-water value changes when you add your Active Drystik into the setup (see the Capture Manual on our website for more details).

7.5 Large Water Samples

Properly aerating water samples larger than 250 ml requires separate hardware, specifically the Big Bottle System, and this involves the more complex procedure that was touched on in the previous section. The Big Bottle System facilitates the measurement of water samples as large as 2.5 liters. Please see the Durridge website [www.durridge.com] for details.

ACKNOWLEDGEMENTS

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. All responsibility for the content of this manual now rests with Durridge.

REFERENCES

Abdalla, S.A.T. "Measurement and Application of Radon in South African Aquifer and River Waters" Department of Physics, University of the Western Cape (February, 2009).

Abojassim, A.A. "Radon Concentrations Measurement for Drinking Water in Kufa City /Iraq Using Active Detecting Method," Advances in Physics Theories and Applications 26 (2013).

Al-Attiyah, K.H.H., and I.H. Kadhim. "Measurement and Study of Radioactive Radon Gas Concentrations in the Selected Samples of River Hilla / Iraq," Journal of Natural Sciences Research Vol. 3, No 14 (2013).

Altshuler, B., and B. Pasternack. "Statistical Measures of the Lower Limit of Detection in a Radioactivity Counter," Health Physics 9:293-298 (1963).

BEIR IV Committee. Health Effects of Radon and Other Alpha Emitters, National Academy Press, Washington, DC (1988).

Burkhart, J.F., et al. "A Comparison of Current Collection/Sampling Techniques for Waterborne Radon Analysis", 1991 Annual AARST National Fall Conference, II:255-271, Rockville, MD (October 1991).

Burnett, W.C., et al. "Using high-resolution in situ radon measurements to determine groundwater discharge at a remote location: Tonle Sap Lake, Cambodia," Journal of Radioanalytical and Nuclear Chemistry 296(1):97-103 (April, 2005).

Burnett W.C. et al. “Radon as a Tracer of Submarine Groundwater Discharge…”, Continental Shelf Research 26: 862-873 (2006).

Burnett, W.C., and N. Dimova. "A Radon-Based Mass Balance Model for Assessing Groundwater Inflows to Lakes," Global Environmental Studies 55-66 (2012).

Burnett, W.C., R.N. Peterson, I.R. Santos, and R.W. Hicks. "Use of automated radon measurements for rapid assessment of groundwater flow into Florida streams," Journal of Hydrology 380(3-4):298-304 (January 30, 2010).

Caulfield, C. Multiple Exposures: Chronicles of the Radiation Age, University of Chicago Press (1989).

Cothern, C.R., and P.A. Rebers, editors. Radon, Radium, and Uranium in Drinking Water, Lewis Publishers, Chelsea, MI (1990).

Crawford-Brown, D.J. "Analysis of the Health Risk from Ingested Radon," Chapter 2 in Cothern and Rebers (1990).

Dimova, N.T. "Using Radon Isotopes for Studying Hydrological Processes in Marine and Aquatic Systems," Electronic Theses, Treatises and Dissertation, Florida State University (December 2, 2009).

Dimova, N.T., et al. "Application of radon-222 to investigate groundwater discharge into small shallow lakes," Journal of Hydrology 486:112-122 (April 12, 2013).

Duggal, V., A. Rani, and R. Mehra. "In situ measurements of radon levels in groundwater in Northern Rajasthan, India," Advances in Applied Science Research 3(6):3825-3830 (2012).

Dulaiova, H. "Multiple Isotopic Tracers for Study of Coastal Hydrological Processes," Electronic Theses, Treatises and Dissertation, Florida State University (June 28, 2005).

El-Gamal, A.A., R.N. Peterson, and W.C. Burnett. "Detecting Freshwater Inputs via Groundwater Discharge to Marina Lagoon, Mediterranean Coast, Egypt," Estuaries and Coasts 35(6):1486-1499 (November, 2012).

El-Taher, A. "Measurement of radon concentration and their annual effective dose exposure in groundwater from Qassim area, Saudi Arabia," Journal of Environmental Science and Technology ISSN 1994-7887 (2012).

Federal Register. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule," (40 CFR Parts 141 and 142), 56(138):33050- 33127 (July 18, 1991).

Federal Register. "Interim Primary Drinking Water Regulations; Promulgation of Regulations on Radionuclides," (40 CFR Part 141), 41(133):28402-28405 (July 9, 1976).

Frame, P.W. "Natural Radioactivity in Curative Devices and Spas," Health Physics 61(6) (supplement):s80-s82 (1991).

Francesco, S.D., et al. "Radon hazard in shallow groundwaters: Amplification and long term variability induced by rainfall," Science of The Total Environment 408(4):779-789 (January 15, 2010).

Garcia-Solsona, E., et al. "An assessment of karstic submarine groundwater and associated nutrient discharge to a Mediterranean coastal area (Balearic Islands, Spain) using radium isotopes," Biogeochemistry 97(2-3):211-229 (March, 2010).

Gilfedder, B.G., H. Hofmann, and I. Cartwright. "Novel Instruments for in Situ Continuous Rn-222 Measurement in Groundwater and the Application to River Bank Infiltration," Environ. Sci. Technol. 47(2):993–1000 (2013).

Goldin, A.S. "Evaluation of Internal Control Measurements in Radio-assay," Health Physics 47(3):361-374 (1984).

Hahn, P.B., and S.H. Pia. Determination of Radon in Drinking Water by Liquid Scintillation Counting, Method 913.0, U.S. EPA EMSL Radioanalysis Branch (May 1991).

Henschel, D.B. Radon Reduction Techniques for Detached Houses: Technical Guidance, 2nd Edition, U.S. EPA, EPA/625/5-87/019 (revised January 1988).

Hess, C.T., et al. "Radon Transferred from Drinking Water into House Air," Chapter 5 in Cothern and Rebers (1990).

Hess, C.T., and S.M. Beasley. "Setting up a Laboratory for Radon in Water Measurements," Chapter 13 in Cothern and Rebers (1990).

Hunkeler, D., et al. "Can 222Rn be sued as a partitioning tracer to detect mineral oil contaminations," Tracer Hydrology 97 (1997).

Johns, F.B., et al. Radiochemical Analytical Procedures for analysis of Environmental Samples, U.S. EPA, EMSL-LV-0539-17 (March 1979).

Khan, M.A. "Radon based Geo-Environmental Investigation of Karak Trough and its Adjoining Areas, District Karak, Khyber Pakhtunkhwa, Pakistan," National Centre of Excellence in Geology, University of Peshawar, Pakistan (2013).

Khattakm, N.U., et al. "Radon concentration in drinking water sources of the Main Campus of the University of Peshawar and surrounding areas, Khyber Pakhtunkhwa, Pakistan," Journal of Radioanalytical and Nuclear Chemistry 290(2):493-505 (November, 2011).

Kinner, N.E., et al. "Effects of Sampling Technique, Storage, Cocktails, Sources of Variation, and Extraction on the Liquid Scintillation Technique for Radon in Water," Environ. Sci. Tech. 25:1165-1171 (1991).

Krieger, H.L., and E.L. Whittaker. Prescribed Procedures for Measurement of Radioactivity in Drinking Water, U.S. EPA EMSL, (August 1980).

Kumar, A., et al. "Earthquake precursory studies at Amritsar Punjab, India using radon measurement techniques," International Journal of Physical Sciences 7(42):5669-5677 (November 9, 2012).

Kumar, A., A. Kumar, and S. Singh. "Analysis of Radium and Radon in the Environmental Samples and some physico-chemical properties of drinking water samples belonging to some areas of Rajasthan and Delhi, India," Advances in Applied Science Research 3(5):2900-2905 (2012).

Lane-Smith D.R. et al. Continuous Radon-222 Measurements in the Coastal Zone, Sea Technology Magazine, October 2002.

Lee J.M. and Guebuem Kimm, "A simple and rapid method for analyzing radon in costal and ground waters using a radon-in-air monitor", Journal of Environmental Radioactivity 89: 219-228, (2006).

Lowry, J.D., et al. "Point of Entry Removal of Radon from Drinking Water," Journal AWWA 79(4):162-169 (April 1987).

Lowry, J.D. "Measuring Low Radon Levels in Drinking Water Supplies," Journal AWWA 83(4):149-153 (April 1991).

McHone, N.W., M.A. Thomas, and A.J. Siniscalchi. "Temporal Variations in Bedrock Well Water Radon and Radium, and Water Radon's Effect on Indoor Air Radon," International Symposium on Radon and Radon Reduction Technology, Volume 5, Minneapolis, MN (September 1992).

Mehra, R., K. Badhan, and R.G.Sonkawade. "Radon Activity Measurements in Drinking Water and in Indoors of Dwellings, Using RAD7," Tenth Radiation Physics & Protection Conference (November 27-30, 2010).

Mehra R., and P. Bala. "Assessment of radiation hazards due to the concentration of natural radionuclides in the environment," Environmental Earth Sciences 71(2):901-909 (January, 2014).

Milvy, P. and C.R. Cothern. "Scientific Background for the Development of Regulations for Radionuclides in Drinking Water," Chapter 1 in Cothern and Rebers (1990).

National Council on Radiation Protection. Ionizing Radiation Exposure of the Population of the United States, NCRP Report No. 93, Bethesda, MD (September 1987).

Németh, Cs., et al. "Measurements of radon, thoron and their progeny in Gifu prefecture, Japan," Journal of Radioanalytical and Nuclear Chemistry 267(1):9-12 (December 1, 2005).

North East Environmental Products, Inc. "Shallow Tray Low Profile Air Strippers," and "VOC and Radon Removal from Water," (pamphlets), NEEP, 17 Technology Drive, West Lebanon, NH 03734 (1992).

Papatheodorou, S., Yao, W., Vieira, C. L. Z., Li, L., Wylie, B. J., Schwartz, J., & Koutrakis, P. (2021). Residential radon exposure and hypertensive disorders of pregnancy in Massachusetts, USA: A cohort study. Environment International, 146, 106285. https://doi.org/10.1016/j.envint.2020.106285

Prichard, H.M., and T.F. Gesell. "Rapid Measurements of 222-Rn Concentrations in Water with a Commercial Liquid Scintillation Counter," Health Physics 33(6):577-581, (December 1977).

Prichard, H.M. "The Transfer of Radon from Domestic Water to Indoor Air," Journal AWWA 79(4):159-161 (April 1987).

Ricardo, C.P., et al. "Pumping Time Required To Obtain Tube Well Water Samples With Aquifer Characteristic Radon Concentrations," International Nuclear Atlantic Conference - INAC (2011).

Rydell, S., B. Keene, and J. Lowry. "Granulated Activated Carbon Water Treatment and Potential Radiation Hazards," Journal NEWWA :234-248, (December 1989).

Rydell, S. and B. Keene. "CARBDOSE" (computer program for IBM-PC), U.S. EPA Region 1, Boston,

MA (1991).

Schmidt, A., et al. "The contribution of groundwater discharge to the overall water budget of Boreal lakes in Alberta/Canada estimated from a radon mass balance," Hydrol. Earth Syst. Sci. Discuss 6:4989-5018 (2009).

Schubert, M., Paschke, A., Lieberman, E., & Burnett, W. C. (2012). Air–Water Partitioning of 222Rn and its Dependence on Water Temperature and Salinity. Environmental Science & Technology, 46(7), 3905–3911. https://doi.org/10.1021/es204680n

Sharma, N., R. Sharma, and H.S. Virk. "Environmental radioactivity: A case study of Punjab, India," Advances in Applied Science Research 2(3):186-190 (2011).

Sharma, N., R.K. Sharma. "Survey of radon concentration in drinking water samples of Hoshiarpur and Ropar districts of Punjab, India," Advances in Applied Science Research 4(3):226-231 (2013).

Singh, S. et al. "Measurement of Radon concentration in ground water from some areas along the foot-hills of North-West Himalaya in Punjab," ANNO LXIV - N.4 (2009).

Singh, S., et al. "Radon Monitoring in Soil Gas and Ground Water for Earthquake Prediction Studies in North West Himalayas, India," Terr. Atoms. Ocean. Sci. 21(4):685-695 (August, 2010).

Somashekar, R.K., and P. Ravikumar. "Radon concentration in groundwater of Varahi and Markandeya river basins, Karnataka State, India," Journal of Radioanalytical and Nuclear Chemistry 285(2):343-351 (May 1, 2010).

Stringer, C.E. "Assessment of Groundwater Discharge to Lake Barco Via Radon Tracing," Electronic Theses, Treatises and Dissertation, Florida State University (March 29, 2004).

Su, N., et al. "Natural Radon and Radium Isotopes for Assessing Groundwater Discharge into Little Lagoon, AL: Implications for Harmful Algal Blooms," Estuaries and Coasts (November, 2013).

U.S. EPA Eastern Environmental Radiation Facility. Radon in Water Sampling Program, EPA/EERF-Manual-78-1 (1978).

U.S. EPA Office of Drinking Water. Reducing Your Exposure to Radon, 570/9-91-600 (June 1991).

U.S. EPA Office of Drinking Water. Radionuclides in Drinking Water Factsheet, 570/9-91-700 (June 1991).

Vitz, E. "Toward a Standard Method for Determining Waterborne Radon," Health Physics 60(6):817-829 (June 1991).

Weigel, F. "Radon," Chemiker Zeitung 102:287 (1978).

Whittaker, E.L., J.D. Akridge, and J. Giovino. Two Test Procedures for Radon in Drinking Water: Interlaboratory Collaborative Study, U.S. EPA EMSL EPA/600/2-87/082 (March 1989).

Winz, R. "Tracing Groundwater Inputs into Anacostia Seep Habitats Using Radon," Fall 2012/Spring 2013 Honors Capstones (September 25, 2013).

Yakut, H., et al. "Measurement of 222Rn Concentration in Drinking Water in Sakarya, Turkey," Radiat Prot Dosimetry (2013).

Zabadi, H.Al., et al. "Exposure assessment of radon in the drinking water supplies: a descriptive study in Palestine," BMC Research Notes 5:29 (2012).

Durridge Company Inc.
900 Technology Park Drive
Billerica, MA 01821

Telephone:	(978)-667-9556
Fax:	(978)-667-9557
Web:	www.durridge.com
Email:	service@durridge.com

Revision 2025-06-17