RAD AQUA

Continuous Radon in Water Accessory for the RAD8

User Manual

DURRIDGE

Radon Capture & Analytics

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INTRODUCTION

The RAD Aqua is an accessory for the Durridge RAD8 Continuous Radon Monitor. It is a device to bring the radon concentration in a closed air loop into equilibrium with the radon concentration in a flow-through water supply. It consists of a spray chamber, called an “exchanger”, that brings the air and water into equilibrium. The radon in the air is monitored continuously by the RAD8.

The partition coefficient, which is the ratio of radon concentration in the water to that in the air at equilibrium, is determined by the temperature at the air/water interface. This temperature is measured with a temperature probe inserted into the exchanger. At typical room temperature the partition coefficient is about 1:4. That means there is a four-times-higher concentration of radon in the air than in the water, so there is, in effect, a gain of four times in the sensitivity of the system to radon in water, compared to radon in air.

It takes time for the water to deliver radon to the air loop and for the RAD8 to respond to the changed radon concentration. With optimum configuration the response time of the system may be reduced to less than half an hour.

CAUTION

Tap water and typical ocean water have sufficient dissolved gases to maintain the water level in the exchanger at an acceptable level. However, should the water level in the exchanger start to rise to an unacceptable height an air bleed may be added as described in Section 7.5.1. This will prevent water from being drawn into the desiccant and hence into the RAD8.

1 RAD AQUA SETUP

1.1 Exchanger Assembly

The RAD Aqua exchanger is supplied semi-assembled. First the chosen nozzles and other components should be installed in the head assembly then the base, trivet, cylinder, rod and head should be assembled together and held in place with the brass thumb screw.

1.1.1 Nozzles

The RAD Aqua is supplied with three pairs of alternative nozzles. These are the WL4, WL1 and WL0.25. We install one and include the other two in the accessories. At 20psi (138 Pascal) water pressure the published flow rates for each are:

WL4:	10.98	L/min.
WL1:	4.1	L/min
WL0.25:	0.68	L/min.

WL0.25 is intended for slow continuous monitoring where rapid changes are not expected and where conservation of water is a consideration. WL4 is intended for those applications where speed of response is a major goal. WL1 is a compromise between the two.

1.1.2 Temperature Probe

The Temperature Probe is inserted through the stem adapter. A little petroleum jelly may help it to slide into the correct position.

1.1.3 Air Return

The air return is sent, via the check valve, to the internal tubing that terminates halfway down the RAD Aqua cylinder. The actual length of that internal tubing is not critical. If it is very short air would be able to short-circuit the exchanger without passing through the spray. If it were too long it may terminate beneath the internal water surface and may lose air through the water outlet. It should be about halfway down the cylinder.

1.1.4 Tie Rod

Insert one end of the tie rod into the thread in the trivet. Place the cylinder in the trivet slots. Push the head assembly onto the rod. Attach and tighten the thumb screw to draw and hold the assembly together.

Fig. 1 RAD Aqua with Temperature Probe

1.2 Connections

1.2.1 Air Loop

Two pieces of tubing connect the RAD8 and Laboratory Drying Unit to the RAD Aqua air/water exchanger, as shown in Fig. 2 on the following page. These two pieces of tubing can be several tens of meters long. The standard tubing supplied with the RAD8/RAD Aqua is sufficient for a connection up to 12 feet (3.7 meters) between the exchanger and the RAD8.

Connect the Sample Out port of the RAD8 to the check-valve connected to the head assembly. For this, the 12 foot long, 3/16" ID tubing, with a 1/8" ID section at one end, may be used. The 1/8" end connects to the RAD8 Sample Out port, and the 3/16" end fits the check valve. Connect the other 3/16" hose connector on the head assembly to the Laboratory Drying Unit, at the screw cap end, with the tubing and sleeve provided.

Connect the other end of the Laboratory Drying Unit (there should be at least one inch of blue desiccant left at this end) to the air inlet filter (with 1/8" ID tubing at the filter end), which is then connect to on the RAD8's Sample In port.

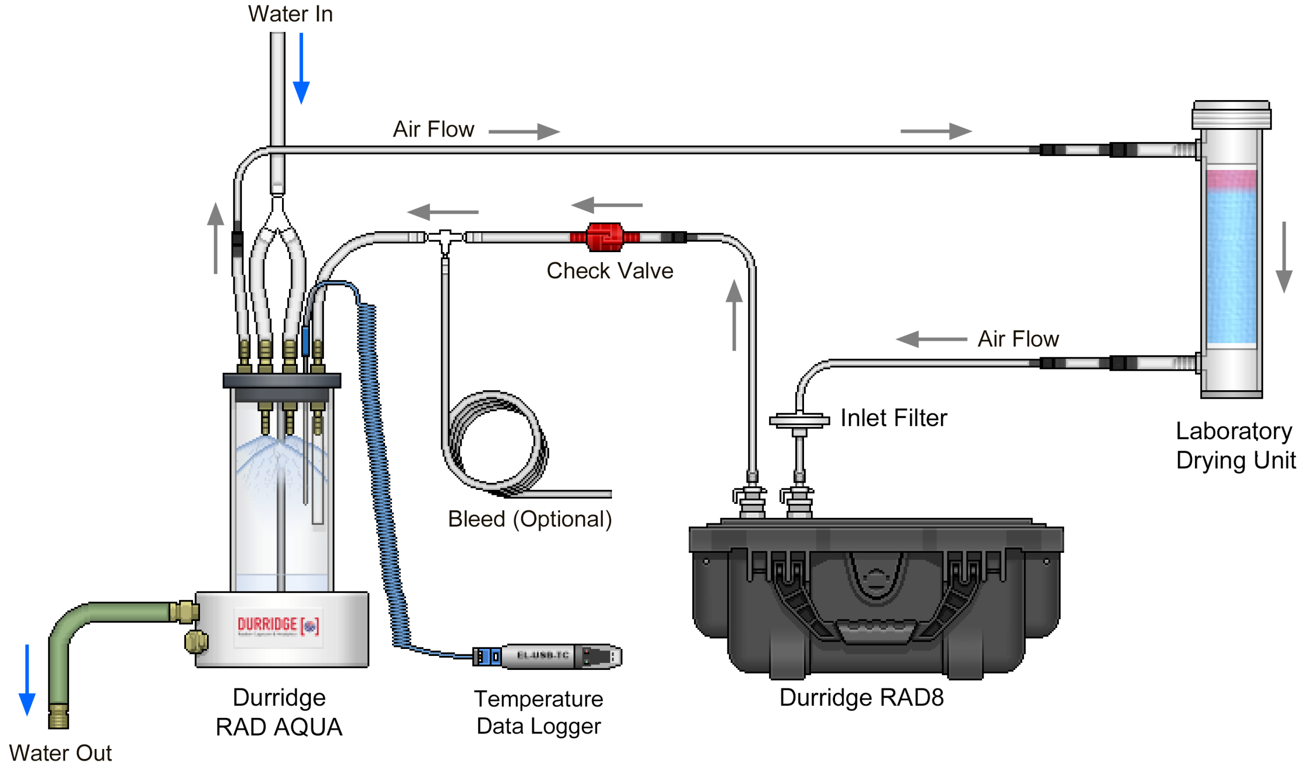

Fig. 2 RAD Aqua Standard Setup

1.2.2 Drystik

Please note that the above instructions are for use of the RAD Aqua without a Drystik humidity exchanger. A Drystik, if available, should be placed between the exchanger and the Laboratory Drying Unit. The outer sheath of the Drystik should be purged with dry air from the RAD8 Sample Out port. See Fig. 4 in Section 5. More details are provided in the Drystik user's manual.

1.2.3 Exchanger Location

The RAD Aqua exchanger unit may be placed upright in a sink, or higher than a boat's gunwales. Water will flow from the hose outlet, in the base of the exchanger. A garden hose may be connected to the exchanger base, to take the outflow, provided it runs downhill from the exchanger.

1.2.4 Water Supply

The water supply should be connected to the two large hose connectors in the head assembly. If the supply will be at high pressure, then clamps may be necessary around the water tubing, to hold the tubes on.

For a slow-response application, where water conservation is important, one nozzle can be sealed with a cap over the hose connector and water supplied only to the other one.

1.2.5 Temperature Probe

The Temperature Probe should be inserted down the stem adapter as far as it will go. A little Vaseline smeared on the shaft will help it go in more easily, and will also ensure an air-tight fitting. The probe should be plugged into the temperature data logger, which should be put in a plastic bag to protect it, once it has been launched.

1.3 Water Flow

1.3.1 Water Source

The water entering the instrument should come direct from the sampling point, below the surface, and should not have been exposed to any air-water interface en route. The water should be clean and free from debris. If necessary, it should be filtered (but not with charcoal, which would adsorb radon) before entering the exchanger. The preferred delivery system is a submerged pump, delivering the water at fairly low pressure, straight from the sampling point to the exchanger. Three sizes of spray nozzle are supplied. The choice will depend on the pump performance and the speed of response required.

1.3.2 Water Level

With the water flowing, a spray will be observed inside the body of the exchanger. Water will accumulate inside the base and overflow out through the hose connector(s). If the flow rate is very high it may be necessary to utilize both hose connectors. The water level may also start to rise too high inside the body of the exchanger. To correct this, either reduce the flow rate or purchase the optional 12” cylinder. A high water level inside the exchanger is no problem provided it is no more than 1/3 of the way up the exchanger and is stable.

If the water level rises slowly but continuously up the cylinder it will be due to the water source being completely without dissolved air. To correct this a bleed may be added to the return air path from the RAD8. It should be a long piece of tubing open at one end and connected with a T-connector to the tubing between the head assembly and the check valve. See Section 7.5.1 for details.

1.4 Air Flow

1.4.1 Continuous Pumping

If you set Pump Mode to 'On' when starting a test, then the pump will run continuously. Setting Analysis Mode to 'Rapid' will cause the RAD8 to count only polonium-218 decays (which are associated the 'A' Window in the RAD8 spectrum). In this operational mode, the system will have the fastest response time, but desiccant is consumed quickly.

1.4.2 Pump Set to 'Standard'

The pump, in Standard operation, pumps for two minutes in every five. Choose 'Standard' Pump Mode when you are less interested in measuring the fastest changes in radon concentration, and more interested in conserving desiccant. Setting the Analysis Mode to 'Auto' will cause the RAD8 to switch from 'Rapid' Analysis Mode to 'Precise' Analysis Mode after 3 hours, at which point the RAD8's sensitivity effectively doubles, because it begins accounting for decay events from both polonium-218 (the A Window) and polonium-214 (the C Window). This comes at the cost of an increase in the instrument's response time from ~15 minutes to ~2.5 hours.

For rapidly changing concentrations of radon in the water, a Cycle Time of 10 minutes with the Pump Mode set to 'Standard' and the Analysis Mode set to 'Rapid' may be a suitable compromise between desiccant usage and response time. Note that the RAD8 stores all data internally with 5-minute time resolution, allowing the Cycle Time to be changed freely after the measurement is complete using Durridge's Capture 8 Pro software. See the RAD8 and Capture manuals for more details.

1.4.3 Analysis Mode Set to 'Auto'

For very low concentrations, or when long-term monitoring is desired, long Cycle Times of an hour or longer may make good sense. Under these conditions the Pump Mode should be set to 'Standard' and the Analysis Mode should be set to 'Auto'. As with the Cycle Time, the Analysis Mode can be changed freely between 'Rapid', 'Precise' and 'Auto' after the measurement, using Capture 8 Pro.

1.5 Protocol

1.5.1 RAD8 Protocol

First, please read the RAD8 manual and learn how to use the instrument with the Preset Protocols used for the measurement of radon in air. Then familiarize yourself with the process of setting up a custom protocol and specifying individual test parameters.

1.5.2 RAD Aqua Protocol

Set up a Custom Protocol for your RAD Aqua measurements by choosing `Start Test` and then `Manual Config`. (see the RAD8 manual for more details). Assign the following configuration parameters:

Cycle Count: Choose a number for a fixed-length measurement, or set to zero to let the measurement run until it is manually stopped.

Cycle Time: Use the 10-minute Cycle Time suggested above, or choose your own to suit your needs.

Pump Mode: Choose 'On' or 'Standard' (see above).

Pre-Test Pump: Starting the water flow and choosing an appropriate pre-test pumping time ensures that air-water equilibrium is established before the measurement begins.

Analysis Mode: Usually set to 'Rapid'. Or, for long-term continuous monitoring, choose 'Auto'. See above.

Sample Source: Choose 'Standard'

Thoron Display: Check the box to display the calculated thoron reading on the Test Status → Summary screen. When measuring thoron in water using RAD Aqua, Durridge recommends setting Pump Mode to 'On' in order to maximize thoron sensitivity. See Chapter 4 for more details.

1.5.3 Custom Protocol

After setting the above parameters in the Manual Config menu, choose `Save As` to create a new Custom Protocol with the desired settings. This Custom Protocol can be recalled later from the Custom Protocols menu.

2 MEASURMENT PROCEDURE

2.1 Start Up

2.1.1 Temperature Probe

Load the temperature logger software and connect the temperature logger to the PC. Configure the logger to take temperature readings at frequent intervals (these may be far more frequent that the RAD8 test Cycles.)

Choose the second (external) temperature sensor. Connect the temperature probe to the logger and note that when you hold the probe the indicated temperature rises.

When everything is set, begin recording. The logger's LED may flash periodically. Once the logger has begun running, you may remove the data cable from both the logger and the PC.

Warning: make sure that previous temperature data has been downloaded before launching the logger. The launching process may erase previous data.

If you have not already done so, insert the probe into the RAD Aqua.

2.1.2 Start Measurement

Start the water flowing. Note that, after a few seconds, water starts to flow out of the outlet hose.

Under the Start Test menu, recall the Custom Protocol that you created in Section 1.5.3, or configure a new one using Manual Config. Name the Test, then choose Start Test to begin the measurement.

2.2 Speed of Response

2.2.1 Measurement in Progress

The instrument is now measuring the radon in the water. With high concentrations and short Cycle Times, and depending on the air and water flow rates, it will take half an hour or more before there is much of a reading, and maybe fifty minutes before you can rely on the polonium-218 (A Window) count rate being close to the equilibrium value. After that you need to accumulate sufficient counts for the precision desired. For example, 100 counts at equilibrium would give a reading with a standard deviation of 10%. At very low concentrations, it may take hours, and averaging over many cycles, to reach a sufficiently precise value.

2.2.2 Influencing Factors

There are two processes requiring time. One is for the air in the closed loop to approach equilibrium with the water, and the other is for the RAD8 to respond to the changed radon concentration in the air loop. The first is primarily controlled by the water flow rate and the second is determined by the half-life of the first daughter of radon, namely polonium-218.

2.2.3 Water Flow Rate

At typical room temperature, the partition coefficient for radon in air and water is about 4:1. That is the concentration of radon in air at equilibrium with water will be four times higher than the concentration in the water. If the water were able to give up all its radon to the air in the RAD Aqua spray chamber, then it would take a water volume of four times the air volume just to deliver enough radon to establish air-water equilibrium. In practice the transfer is not complete so we may estimate that ten times the air volume is required.

Considering the volumes of the RAD8's internal air path, the Laboratory Drying Unit and the RAD Aqua's spray chamber, we can conservatively estimate the volume of the air loop to be around 2 litres (though this depends somewhat on the length of external tubing used, and on the water level inside the spray chamber). Therefore about 20 litres of water is needed to deliver the radon to the air loop before it can reach equilibrium. A water flow rate of V L/min will take at least 20/V minutes to deliver the radon.

2.2.4 Air Flow Rate

Though important for thoron (see below), the air flow rate is less critical to the radon response time. For maximum speed of response, the air should keep circulating around the loop so that the air in the exchanger is continually being replenished with air from the measurement chamber of the RAD8. Thus the shortfall from equilibrium and hence the efficiency of transfer is maximized. To achieve this, Pump Mode may be set to 'On', see 1.4.1 and 1.5.2 above.

For a more relaxed operation, the pump may be set to Standard, which will preserve the desiccant and increase the life expectancy of the pump. Air will remain stationary in the RAD Aqua for three minutes before moving through the desiccant and into the RAD8. While in the RAD Aqua, the stationary air may approach equilibrium with the water thus inhibiting further radon transfer from the water to the air. It will be about 8 minutes before that parcel of air returns to the RAD Aqua. We can therefore estimate that the response time of the system will be increased by about 8 minutes if Pump Mode is set to 'Auto'.

Having Pump Mode set to 'Auto' would normally be associated with having the RAD8 Cycle Time of 30 minutes or longer. So an extra 8 minutes on the response time will not be excessive.

2.2.5 RAD8 Analysis Mode

With Analysis Mode set to 'Auto', the RAD8 will automatically switch from Rapid to Precise Analysis Mode after three hours into the run. This is to take advantage of the additional counts provided by the polonium-214 decays that will, by then, have approached equilibrium with the (steady) radon concentration in the measurement chamber.

For slow, long-term measurements with long Cycle Times, 'Auto' Analysis Mode for the RAD8 is appropriate. After the switch to Precise Analysis Mode occurs, the RAD8's response time will be roughly 2.5 hours. The RAD Aqua can be running with a low water flow rate and the RAD8 Pump Mode can be set to 'Standard'.

For fast response, however, the RAD8's Analysis Mode should be set to 'Rapid'. It will then always use only the polonium-218 (A Window) counts when calculating the displayed radon concentration, giving it a 13-minute 95% response time. Analysis Mode can be freely changed when viewing the data with Durridge's Capture 8 Pro software.

2.3 Long-Term Measurement

As set up above, the system will continue making measurements indefinitely. There are, however, various resources that are being used up in the process, and which must be replenished. The most obvious is the desiccant. A new, or regenerated, Laboratory Drying Unit will normally last for about ten days of continuous use in a temperate climate. In this application, however, it is receiving saturated air and, therefore, will be hydrated more quickly. When the width of the remaining strip of blue (dry) desiccant is less than one inch, the desiccant should be replaced. Please see the RAD8 manual for detailed instructions on desiccant regeneration. If the desiccant is not replaced, and the humidity in the instrument begins to rise, then the sensitivity drops off and the reading is lower than the true value.

3 DATA

3.1 Data Handling

3.1.1 RAD8 Memory

The RAD8's 16GB of onboard flash memory is sufficient to store millions of data records. However it is a good idea to back up important data regularly, using Durridge's Capture software. Capture 8 Pro users have the option to upload RAD8 data to Durridge's Capture Cloud platform. This can be done via the Capture software, or directly from the RAD8 via local Wi-Fi network (choose `System Settings → Data Upload → Cloud Upload`). Advanced users also have the option to set up automatic data transmission to an FTP server of their choosing (`System Settings → Data Upload → FTP Upload`).

3.1.2 Capture Software for Windows and macOS

Data recorded to the RAD8 may be downloaded and graphed using Durridge's Capture software, which is available from the Durridge website [www.durridge.com/software/capture/].

To view RAD Aqua data in Capture, connect the RAD8 to the computer using the included USB cable, or via Wi-Fi. (To connect the RAD8 via Wi-Fi, open Capture's main program window and choose Connect Device → Connect RAD8. Set the Connection Type to Network, specify the RAD8's unique IP address, and make sure the Interface is set to RAD8 Built-In Wi-Fi.) Download the RAD8 data, then obtain the temperature logger data as explained in Section 3.1.3. After the radon data is opened in a Graph Window, select the data points comprising the RAD Aqua test, and open the Test Parameters Window. Set the Radon Measurement Method to RAD Aqua as shown in Fig. 3 on the following page. Next specify the water temperature source as instructed. The water temperature information is used by Capture to calculate the radon in water concentrations. For detailed instructions, please see the RAD Aqua information in the Capture user's manual, which is available from the Durridge website.

3.1.3 Temperature Data

To obtain the water temperature data, connect the Temperature Logger to the computer and run its software to download the data. The program will take a moment to download the entire memory of the logger, and then display it as a graph. You should save it to your hard drive before doing anything else. You can then export it to a comma-delimited .TXT file for use with Capture, or for incorporating into a spreadsheet or database program.

Alternatively, the Temperature Logger data can be read directly into Capture using the controls in the Test Parameters Window; see the instructions in the Capture user's manual for details.

Warning! Make sure that the Temperature Logger data is properly downloaded and saved to the computer before starting the logger again. Restarting the logger operations may erase its previous data.

3.1.4 Time Relationship

A water temperature reading is made at the moment in time indicated with the reading. A radon reading, in contrast, is the average value taken over the Cycle whose end occurred at the time indicated. More precisely, in Rapid Analysis Mode, taking into account the polonium-218 half-life, a Cycle whose end occurred about 5 minutes before the time indicated. For constant radon and temperature values this is of no consequence, but if the temperature was changing quickly then the temperature readings during the course of the radon cycle, and for five minutes before, should be averaged to give the average temperature at the air water interface when the radon being measured was leaving the water. This is handled automatically by the Capture software.

3.2 Data Conversion Formulas

3.2.1 Fritz Weigel Formula

The RAD8 gives an accurate reading of the radon concentration in the air. With the RAD Aqua, this air reaches equilibrium with the water in the exchanger. To convert the air concentration to water concentration, the air concentration must be multiplied by the air-water partition coefficient, which is given by the Fritz Weigel equation (Weigel, 1978):

$$a = 0.105 + 0.405 * \exp(-0.0502*T)$$

where T is the temperature in degrees Celsius.

At room temperature, a is around 0.25, giving, at equilibrium, a four-to-one ratio of radon in air to water. The Fritz Weigel formula is applied automatically in Capture when the Water Type is set to Fresh Water in the Test Parameters Window, as shown in Fig. 3, below.

3.2.2 Schubert et al. Formula

If the Water Type is set to Saline Water in Capture's Test Parameters Window, the radon in water concentration is calculated using the Schubert et al. formula, which is a function of both water temperature and salinity. (See Schubert et al., 2012.)

The Test Parameters Window provides a field for specifying the salinity of the water, in parts per thousand. Note that this formula is suitable for water samples with any degree of salinity, including zero. When the salinity value is set to zero, it produces results that are nearly identical to those produced by the Fritz Weigel formula.

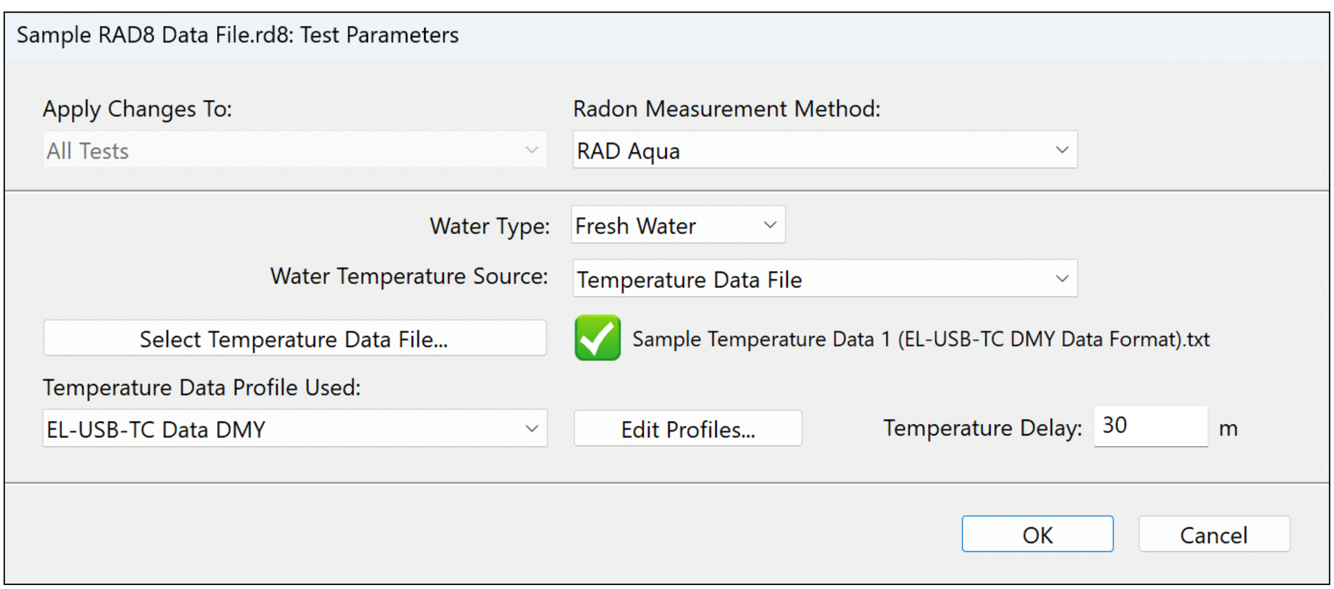

Fig. 3 The Capture RAD8 Test Parameters Window

4 THORON IN WATER

4.1 Why Thoron?

Thoron (radon-220) an isotope of radon, has a 55.6-second half-life. As a result, almost everywhere, it is not to be found. Close to a thoron source, however, the water will still have measurable thoron as it will be still be young and not have had time for it all to have decayed away.

Thoron coexists with radon in the soil. Ground water entering the ocean will therefore bring thoron as well as radon with it. Around submarine springs, therefore, there may be thoron in detectable amounts and this may be used to locate the springs (Burnett et al., 2007).

4.2 Measurement in Water

Because of its short half-life, the measurement of thoron in water is fraught with difficulties.

First, the concentration in the water will vary significantly from point to point and from time to time depending on the position of the sampling point relative to the position of the source and the water flow between the source and the sampling point.

Second, during the process of getting the thoron atoms into the measuring device, the thoron will be decaying, thus reducing the size of the sample. An estimate of the time taken for this process is required in order to apply a correction to the reading.

However, if using thoron as a tracer, a knowledge of the absolute sensitivity is not so important as minimizing the lower limit of detection. This may be done by making the transfer of thoron atoms into the RAD8 as quick as possible.

4.3 Thoron Sensitivity

Sample loss occurs by decay while in the water en route to the exchanger and then again in the air en route to the RAD8.

4.3.1 Source to Exchanger

The time delay in the water can be made small by having a high water flow rate and a short, small diameter hose. If the hose is no more than 3m long, with an internal diameter of no more than 8mm, say, the hose volume will not exceed 0.15 L and a water flow rate of, say, 4 L/min will mean a time delay for the thoron to reach the exchanger of no more than 2.5 seconds.

4.3.2 Exchanger to RAD8 Method 1

The volume of the air above the water spray in the chamber will be about 0.6 L and the Laboratory Drying Unit has a free air volume of around 0.5 L. Adding an extra 0.1 L for tubing, we arrive at an estimate of about 1.2 L for the volume of air required to be pumped for a thoron atom in the exchanger to reach the RAD8. The RAD8 pump will typically generate an air flow rate of 0.6 L/min. Therefore, this will take around 2 minutes. The thoron will have decayed through about two half lives between leaving the sampling point and being detected in the RAD8, so only around 25% of the original concentration will remain. In addition, the transfer from the water to the air will not be complete and the returning air from the RAD8 will have lost almost all its thoron, so there is another factor to be multiplied in. All in all, we may estimate that we see no more than 15% of what would have been seen had there been no thoron decay during acquisition.

4.3.3 Exchanger to RAD7 Method 2

Instead of using the RAD8 pump, a separate pump may be used to circulate air round the loop much faster. The RAD8 can tolerate air flow rates at least as high as 6 L/min. For higher air flow rates, the RAD8 should be connected to tap into the fast recirculating air loop, using its own pump to do so, with the main air flow bypassing the RAD8.

With a circulating air flow rate of, say, 6 L/min the delay from the exchanger to the RAD8 tap will be about 20 seconds and from the tap to the RAD8 chamber about 45 seconds. So now, the total time delay from sampling point to entry into the RAD8 will be around 1 minute, so reducing the attenuation due to radioactive decay of the thoron to around 50%.

Furthermore, with the external pump, the time for air to circulate once round the loop will be reduced to a fraction of a minute. The thoron concentration in the recirculated air will now be significant, giving a better chance for the air leaving the exchanger to be closer to equilibrium with the water.

4.4 Speed of Response

There is another advantage to using thoron as a tracer to locate submarine springs. That is the almost instantaneous response of the RAD8 to thoron.

The first daughter of thoron, polonium-216, has a half-life of just 150 ms. Thus in 0.5 seconds the RAD8 Window B (polonium-216), count rate will have nearly reached equilibrium with the thoron in the chamber. So the speed of response of the RAD8 to thoron is limited not by the half-life of the polonium daughter but by the time it takes to pump the sample into the measurement chamber.

We have seen that with the highest sensitivity configuration, using a separate pump to circulate air round the loop, the total time for thoron to go from the sampling point to the RAD8 is only about 1 minute.

A boat carrying the system, therefore, moving slowly, will see the thoron count rate increase within a minute or two of passing over a submarine spring and drop again shortly thereafter.

5 DRYSTIK

5.1 Passive Drystik

A passive Drystik may be installed in the RAD Aqua system without modifying any other part of the system or the operating conditions. The inner membrane tube and then the Laboratory Drying Unit go between the Pump Out and Detector In ports on the RAD8 front panel, while the outer sheath is purged by dry air from the RAD8 outlet traveling in the opposite direction and returning to the RAD Aqua. A 12" passive Drystik will increase the life of the desiccant by a factor of about five.

5.2 Active Drystik

Durridge's Active Drystik models include a pump upstream of the inner membrane tube, and a needle valve downstream of the tube. This increases the pressure inside the tube, which increases its efficiency.

A typical setup has the RAD8 pump bypassed, the Drystik pump running continuously, and the Adjustable Airflow needle valve adjusted to give a flow rate of about 0.2 L/min, though flow rates up to around 2 L/min are achievable.

When using an active Drystik, a Small Drying Tube or larger Laboratory Drying Unit full of desiccant can be added to keep the air sample in the RAD8 as dry as possible. It should be inserted between the Drystik air outlet and the inlet filter on the RAD8's Detector In port, as shown in Fig. 4 on the following page. The desiccant will last for a very long time, and the drying tube will add only a small amount of extra volume to the air loop, maintaining a fast response.

5.3 Effect on Response Time

With a flow rate of only 0.2 L/min it will take about 20 minutes for the air in the loop to go around once. This will make thoron detection impossible and also add an extra 10 or 15 minutes to the response time for radon. For long-term studies the slower response is generally not important, whereas the frequency of replacing the desiccant may be. So an active Drystik may be of considerable benefit.

5.4 Custom Drystik Settings

The standard 0.2 L/min flow rate of the Durridge Drystik is typically used because it matches the average flow rate of a RAD8 in Standard mode, and it also matches the performance of the installed pump at a pressure of 44 PSI (3 atmospheres). Durridge's Active Drystik models can be set to maintain a 44 PSI pressure inside the inner membrane tubing and a flow rate of up to 2 L/min, to restore the speed of response of the system while virtually eliminating the need to periodically replace the desiccant. See the Drystik user's manual for details.

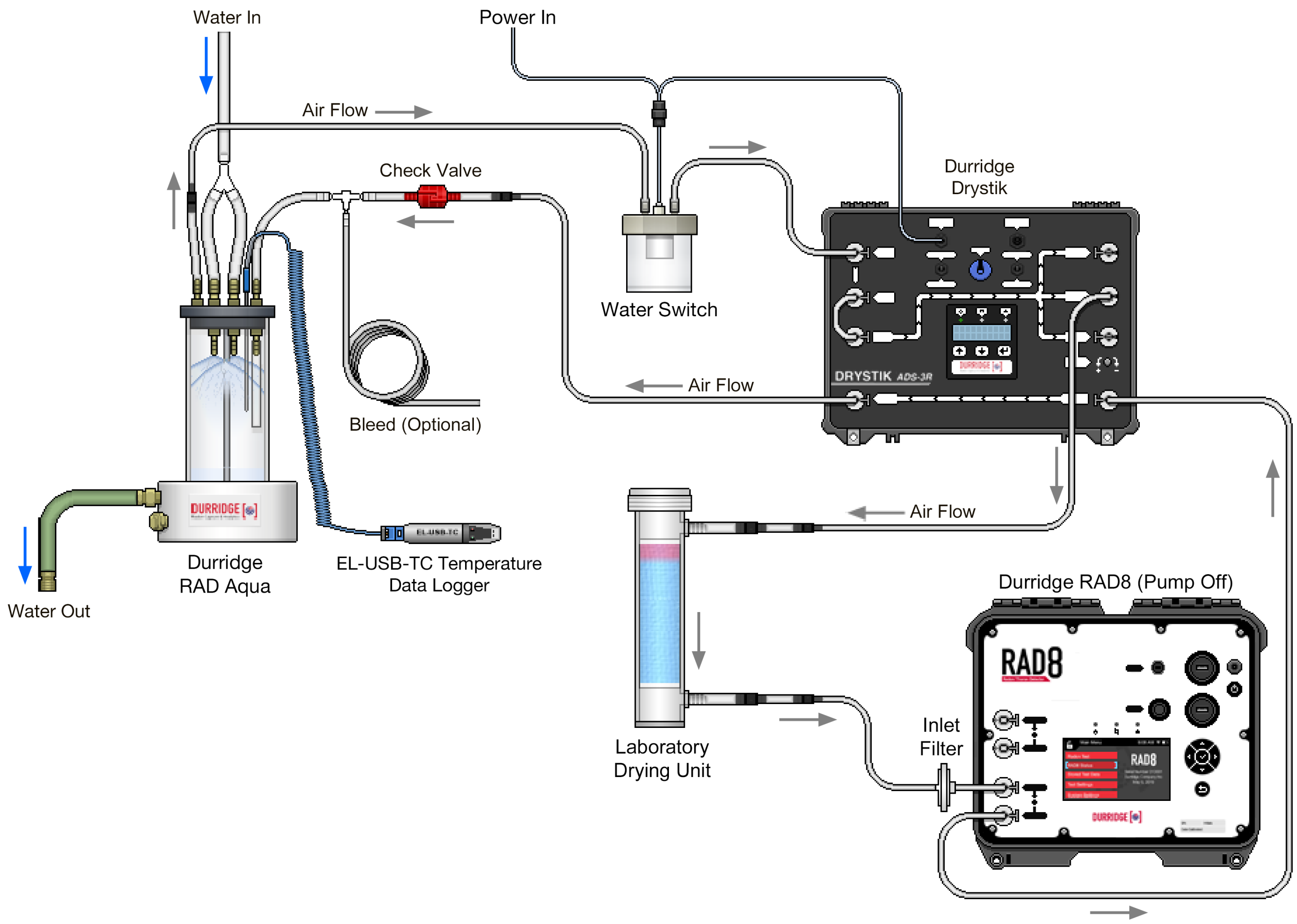

Fig. 4 RAD Aqua configuration with Active Drystik and Water Switch

6 BOATING

The RAD Aqua was originally designed to serve the needs of oceanographers making surveys, by boat, of coastal zones and lakes. In this application there are a number of considerations.

6.1 Response Time

If the boat is moving, which it usually is, the speed of response of the system translates to the spatial resolution of the data. Roughly speaking, the minimum distance that can be separated in terms of radon concentration is the 95% response time, to a step change in radon, times the boat velocity. It behooves one, therefore, to minimize the response time in order to have reasonable spatial resolution at a boat speed that is not too slow.

By going through the spray chamber the water is, in effect, delivering radon to the air loop. As discussed earlier, if V is the total volume of the air loop, it needs 10 to 20 times that volume of water to pass through the exchanger to deliver sufficient radon to the air for the reading to approach close to equilibrium. After equilibrium is reached, sufficient counting time then has to pass for the reading to achieve the desired precision. Call T1 the time to reach equilibrium and T2 the counting time needed to reach the desired precision. For a given setup and flow rates, T1 will be a constant. T2 will be a function of the radon concentration.

6.1.1 Minimizing T1 With Increased Water Flow Rate

Use the fastest pump that is consistent with power availability. A Rule 360 bilge pump draws less than 2.2 A at 12 V. It delivers 4.8 L/min, unobstructed flow, to 2ft above the water surface, and 2.4 L/min through two W1 nozzles mounted in a RAD Aqua. For many purposes, this pump rate is adequate and the power requirement is quite modest. A 45 AH car battery can run the pump for two 8-hour days of surveying and have energy to spare.

However, for fastest possible response time, the RAD Aqua can handle flow rates up to 10 L/min or more, through two W4 nozzles. But the power needed increases significantly. The Rule 3700 delivers 6 L/min through a W4 nozzle, but it draws over 15 A. One 8-hour run would completely discharge a 120 AH battery.

6.1.2 Minimizing T1 With Reduced Air Volume

A basic RAD Aqua setup has a RAD8, a spray chamber and a drying unit. The spray chamber and the RAD8 are each around 0.6 L in volume. The Laboratory Drying Unit is about 0.5 L. Tubing volume can be minimized by avoiding unnecessarily long lengths of tubing and using small ID tubing where possible. This setup would have an air volume, V, of about 1.7 L.

An Active Drystik, which efficiently removes humidity from the air even when there is no desiccant in the circuit, has only a small air path volume. It can replace the Laboratory Drying Unit. For optimum drying efficiency a Small Drying Tube can be inserted between the Drystik and the RAD8. This setup would have an air volume, V, of about 1.2 L.

With a Rule 360 water pump and W1 nozzles, 10 times V of water (the approximate amount required to reach air-water radon equilibrium) would be delivered in 7 or 5 minutes for the two cases above, respectively. Conservatively, the response time to reach equilibrium may be taken to be 10 minutes in either case.

6.1.4 Minimizing T2 With Multiple RAD8s and One RAD Aqua

Several RAD8s may be deployed in parallel, all accessing one RAD Aqua. In analyzing the data uncertainty, the counts of all the RAD8s are summed. Thus three RAD8s will reduce the time to reach a given precision by a factor of three. On the other hand, each RAD8 adds 0.6 L to the air-loop volume, thus potentially increasing T1.

For example, with a radon concentration of 2.5 pCi/L in the water, three RAD8s with one Laboratory Drying Unit, one RAD Aqua and a Rule 360 water pump, the counting time to reach about 20% two-sigma uncertainty (100 'A' Window counts) will be about 9 minutes (reduced from 25 minutes with only one RAD8). On the other hand, there is an extra 1.2 L in the air loop, requiring an extra 12 - 24 L of water to be pumped before air-water equilibrium is reached. With the Rule 360 that would take an extra 5 - 10 minutes, reducing the advantage of the three pumps to only 6 to 11 minutes. But with the Rule 3700, the extra 12 to 24 L of water would take only 2 - 4 minutes to deliver, thus preserving almost all the 16-minute gain of the multiple counting technique.

6.1.5 Minimizing T2 With Multiple RAD8s and Multiple RAD Aquas

If each RAD8 has its own RAD Aqua and bilge pump, adding another complete system will not change T1, but will reduce T2. A compromise of adding another bilge pump and RAD Aqua for every two RAD8s may best meet a user's need for fastest response on the one hand and minimum power requirements on the other.

6.2 Pump Position

In a stationary boat it is simple to hang a bilge pump over the side to the depth of interest. But when the boat is moving there is a lateral force on the pump that may force it towards the stern and consequently bring it closer to the surface.

6.2.1 Positioning Equipment

A long tether, running from the near the bow, will stop the pump from swinging to the stern, when the boat is under way. If the pump is heavy enough, or if a weight is added, this tether may be enough. Another tether, from the near the stern, will support the pump when the boat is stationary.

A stiff pole could be used, with the tether, to keep the pump at a fixed depth, regardless of the boat speed.

7 CARE, MAINTENANCE, AND TROUBLESHOOTING

7.1 Water Catastrophe

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

Keep the RAD8 upright. This will prevent water from touching the 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, connect an external pump to the Sample In port, to blow air through the instrument. When water ceases to be blown out of the Sample Out port, put desiccant upstream of the RAD8 to dry out the air path. This may take several hours.

Once there is no visible water in or on the instrument, it can be put in an oven at 50°C for a few hours to dry out completely. Additionally, desiccated air can be passed through the air path until the air leaving the RAD8 drops below 10% RH. After this treatment the RAD8 can be booted up once more, and you can use the RAD8's internal RH sensor to measure how dry the air path is. At this point the instrument should be returned to Durridge for service.

7.2 RAD8 Care

Water, particularly salt water, is hostile to electronic instruments. Whilst the RAD8 is IP67-rated against water and dust ingress, keeping its front panel as clean and dry as possible will help to prevent premature aging. As mentioned above, care should also be taken to avoid drawing liquid water or dusty air into the sample path.

The instrument should, in any case, be returned to Durridge every year for recalibration.

It is useful to look at a cumulative spectrum periodically (`Test Status → Spectrum`). Check to see that the alpha energy peaks are well-separated, no broader than usual, and well-positioned in the centre of their respective spectrum windows.

7.3 Exchanger Care

The exchanger should be kept as clean as possible in the circumstances. Sea water, if carrying any solid matter, should be filtered. The spray nozzle should be examined for build-up of deposits, and cleaned if necessary.

7.4 Desiccant Regeneration

Please see the RAD8 manual for information on the care and regeneration of the desiccant. Regenerated desiccant, after a few regenerations, loses most of its indicating ability (due to migration of the cobalt chloride to the interior of the calcium sulphate grains). One way to 'indicate' the status is, every time you refill the Laboratory Drying Unit with regenerated desiccant, first add half an inch or so of new, blue desiccant, out of the jar. If you then make sure to always use the lower fitting as the air outlet, you can always tell if the unit is still working, as the new desiccant at the bottom will only turn pink when the rest of the desiccant, upstream, has become hydrated.

7.5 RAD Aqua Troubleshooting

7.5.1 Rising Water Level in Spray Chamber

There are several things that can cause the spray chamber to fill with water. Each is described below.

The air return tubing inside the spray chamber may be too long. The open end should be about half way between the spray nozzle opening and the water level in the base. If the tubing is too long, disassemble the RAD Aqua (simply remove the knurled nut and pull the assembly apart) and cut off the extra tubing length. A tubing length of two inches (5 centimeters) is sufficient, and if necessary it can be made shorter.

Another cause of the spray chamber filling with water is the depletion of dissolved gases. This can cause air to be lost from the air loop. A bleed inserted between the check valve and the spray chamber air connection, with approximately 1 m of tubing, will replace any air that is removed and will establish the air pressure inside the chamber at atmospheric pressure. (The bleed is visible in Figure 2, in Section 1.2.1.)

Another reason the spray chamber may fill with water if that system's air loop is not closed, or it has a significant leak. This may cause the air pump to remove air from the spray chamber without replacing it. Verify that the closed air loop has no open connections or leaks.

7.5.2 Foam in Spray Chamber

Rising foam, due to some forms of pollution in the water, may also be treated with a bleed as described in the previous section. If that does not prevent the foam from rising too far, the intensity of the spray and flow velocity of the water will need to be reduced. This will slow down the speed of response of the RAD Aqua and RAD8 system.

7.5.3 Air Path Integrity

When drawing a sample from a remote location, air path integrity is essential to prevent dilution of the sample with ambient air. Always make sure that there are no loose connections or leaky fittings (such as the screw cap or ribbed fittings of the Laboratory Drying Unit) in the air loop, particularly upstream of the RAD8. In the event of unexpectedly low radon values, check the air path for integrity.

7.5.4 Poor Spray Formation

If the spray pattern is degraded, with no or inadequate spray curtain, the response time of the RAD Aqua will be increased, though the eventual equilibrium for radon will not be affected (Thoron equilibrium will be seriously affected because the additional time to reach equilibrium allows more of the thoron to decay.)

One cause of a poor spray is a pump of insufficient strength. Be advised however that larger pumps may cause other problems related to the supply of power.

If a bigger pump is not an option, another way to increase the flow velocity to generate a better spray is to switch to smaller nozzles. Disassemble the RAD Aqua, and replace the nozzles with smaller ones. Note, however, that doing so may negatively impact response time.

7.5.5 Water Overflowing from Base

Where possible, place the RAD Aqua somewhere that overflowing water doesn't matter. It is also advisable to screw the drain hose onto the lower base outlet. The top outlet may be opened and if permitted, water may be allowed to spill from the outlet directly.

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