



# **RAD AQUA User Manual**

## **CONTINUOUS RADON-IN-WATER MONITORING**



DURRIDGE Company Inc.  
524 Boston Rd  
Billerica, MA 01821  
Tel: (978)-667-9556  
Fax: (978)-667-9557  
Service@durrIDGE.com  
www.durrIDGE.com

<b>INTRODUCTION</b>	<b>4</b>
<b>1. SETUP</b>	<b>5</b>
<b>1.1 EXCHANGER ASSEMBLY</b>	<b>5</b>
1.1.1 Nozzles	5
1.1.2 Temperature Probe	5
1.1.3 Air return	5
<i>Fig. 1 RAD AQUA</i>	5
1.1.4 Tie rod	5
<b>1.2 CONNECTIONS</b>	<b>5</b>
1.2.1 Air loop	5
<i>Fig. 2 RAD7/RAD AQUA Schematic</i>	6
1.2.2 DRYSTIK	6
1.2.3 RAD7 and Exchanger Location	6
1.2.4 Water Supply	7
1.2.5 Temperature Probe	7
<b>1.3 WATER FLOW</b>	<b>7</b>
1.3.1 Water Source	7
1.3.2. Water Level	7
<b>1.4. AIR FLOW</b>	<b>7</b>
1.4.1 Continuous Pumping	7
1.4.2 Pump on “Auto”	7
1.4.3 Mode set to “Auto”	8
<b>1.5. PROTOCOL</b>	<b>8</b>
1.5.1 RAD7 Protocol	8
1.5.2 RAD AQUA Protocol	8
1.5.3 User Protocol	8
<b>2. MEASUREMENT PROCEDURE</b>	<b>9</b>
<b>2.1 START UP</b>	<b>9</b>
2.1.1 Temperature Probe	9
2.1.2 Start Measurement	9
<b>2.2 SPEED OF RESPONSE</b>	<b>9</b>
2.2.1 Measurement in Progress	9
2.2.2 Influencing Factors	9
2.2.3 Water flow rate	9
2.2.4 Air flow rate	10
2.2.5 RAD7 Mode	10
<b>2.3 Long Term Measurement</b>	<b>10</b>
2.3.1 Desiccant	10
2.3.2 Memory	10

<b>3. DATA</b>	<b>11</b>
<b>3.1 DATA HANDLING</b>	<b>11</b>
3.1.1 Printer	11
3.1.2 Memory	11
3.1.3 RADLINK	11
3.1.4 CAPTURE for Windows or Mac	11
3.1.5 Temperature Data	11
3.1.6 Time Relationship	11
<b>3.2 DATA CONVERSION</b>	<b>12</b>
3.2.1 FRITZ von WEIGEL	12
3.2.2 CALCULATION	12
<b>4. THORON in WATER</b>	<b>13</b>
4.1 Why Thoron?	13
4.2 Measurement in Water	13
4.3 Thoron Sensitivity	13
4.3.1 Source to Exchanger	13
4.3.2 Exchanger to RAD7 method 1	13
4.3.3 Exchanger to RAD7 method 2	13
4.4 Speed of Response	14
<b>5. DRYSTIK</b>	<b>15</b>
5.1 Passive DRYSTIK	15
5.2 Active DRYSTIK	15
5.3 Effect on Response Time	15
5.4 Custom designed Active DRYSTIK	15
<b>6. CARE, MAINTENANCE and TROUBLESHOOTING</b>	<b>16</b>
6.1 RAD7	16
6.2 EXCHANGER	16
6.3 DESICCANT	16
6.4 RISING WATER LEVEL	16
6.5 AIR PATH INTEGRITY	16
<b>References and Bibliography</b>	<b>17</b>

## INTRODUCTION

The RAD AQUA is an accessory for the DURRIDGE RAD7 Electronic Radon Detector. 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 RAD7.

The partition coefficient, 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 coefficient is about 0.25. That means there is 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 RAD7 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 chapter 5. This will prevent water from being drawn into the desiccant and hence into the RAD7.

## 1. Setup

### 1. 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 -	4.1L/min
WL0.25 -	0.68L/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 probe is inserted through the stem adapter. A little petroleum jelly may help it to slide into position.

##### 1.1.3 Air return

The air return is sent, via the check valve, to the internal tubing that terminates halfway down the 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.

Fig. 1 RAD AQUA



##### 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.

#### 1.2 CONNECTIONS

##### 1.2.1 Air loop

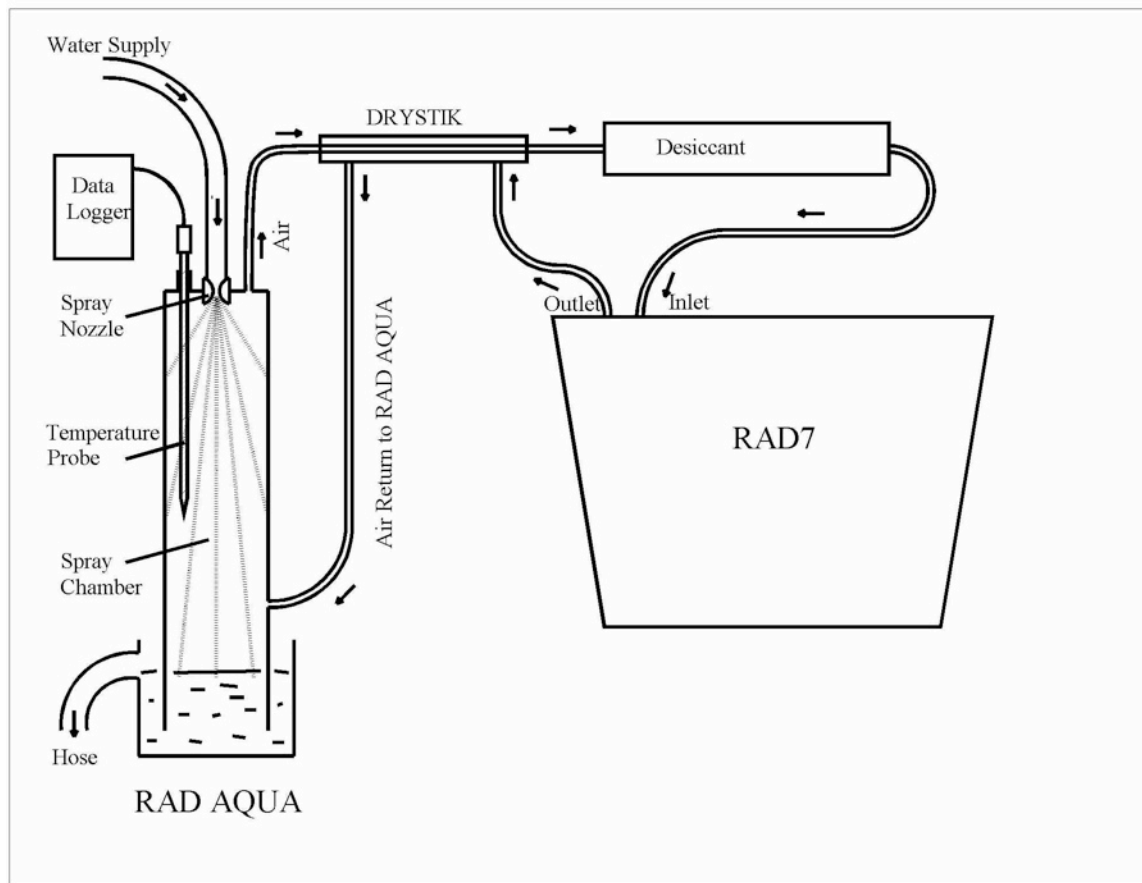
Two pieces of tubing connect the RAD7 and drying unit to the RAD AQUA air/water exchanger. These two pieces of tubing can be several tens of meters long. The standard tubing supplied with the RAD7/RAD AQUA is sufficient for a connection up to five feet between the exchanger and the RAD7.

## 1. Setup

Connect the OUTLET of the RAD7 to the check-valve connected to the head assembly. For this, the 5ft long, 3/16" ID tubing, with a 1/8" ID section at one end, may be used. The 1/8" end fits on the RAD7 outlet, 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 placed on the RAD7 INLET. The Luer taper ensures an airtight connection.

Fig. 2 RAD7/RAD AQUA Schematic



### 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 drying unit, and the outer sheath should be purged with dry air from the RAD7 outlet. See Fig. 2.

### 1.2.3 RAD7 and Exchanger Location

Place the RAD7 on a clean, dry surface, preferably inside a laboratory. If it has to be located in a harsh environment, then it should be protected from the elements (especially water). A simple way to do this is to place the RAD7 inside a large transparent plastic bag, such as the one in which it was originally shipped. The bag opening should be gathered around the inlet and outlet

## 1. Setup

tubes, so that the instrument is inside a closed space, completely protected from the elements, while still allowing observation of the LCD and print-out, and operation of the key pad.

The 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 Hobo logger, which should be put in its own 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) 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 level may also start to rise too high inside the body of the exchanger. To correct, 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 RAD7. 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.

## 1.4. AIR FLOW

### 1.4.1 Continuous Pumping

If you choose "SETUP PUMP ON [ENTER]" and "SETUP MODE SNIFF [ENTER]", then the pump will run continuously, regardless of the length of the cycles, or status of the RAD7, and the RAD7 will count only 218-Po decays. In this operational mode, the system will have the fastest response time, but desiccant is quickly hydrated.

### 1.4.2 Pump on "Auto"

The pump, in auto operation, pumps for five minutes at the beginning of every cycle and then for one minute in every five. The length of each cycle is chosen by the user. Short cycle times will involve more pumping and speed up the response of the instrument, but will consume more desiccant. Longer cycle times will give better

## 1. Setup

statistical precision to the individual readings, and will conserve desiccant and memory space.

For rapidly changing concentrations of radon in the water, 10 minute cycles, with the PUMP on AUTO and MODE on SNIFF, may be a suitable compromise, though not giving fastest response.

### 1.4.3 Mode set to "Auto"

For very low concentrations, or when long-term monitoring is desired, long cycle times of an hour or longer, with the PUMP and MODE set to AUTO, may make good sense.

## 1.5. PROTOCOL

### 1.5.1 RAD7 Protocol

First, please read the RAD7 manual and learn how to use the instrument for measurement of radon in air. The RAD7 should normally be operated with AC (or, with 12V option, 12V) power applied, to keep the batteries in a fully charged condition.

### 1.5.2 RAD AQUA Protocol

Switch on RAD7. Push the MENU key. Go to:

SETUP CYCLE, push <ENTER>. Set the cycle time required (as discussed above).

SETUP RECYCLE to 00, for continuous operation.

SETUP MODE: For fast response, with moderate or high radon concentrations, choose SNIFF. For low concentrations, to gain better statistics, choose AUTO.

SETUP THORON: Choose OFF

SETUP PUMP: Choose ON or AUTO, depending on choice, see above

SETUP TONE: Choose what you like

SETUP FORMAT: Choose what you like, but LONG format with short cycle times uses a lot of paper. You will probably not need to use the printer at all, in the field.

SETUP UNITS: Your choice

SETUP SAVUSER: Push <ENTER>. When it says "Are you sure?" use arrow keys to change response to "Yes" and push <ENTER>.

### 1.5.3 User Protocol

You now have your personalized USER protocol saved. To recall your settings, go to SETUP PROTOCOL USER and push <ENTER>. To make a change, simply display the parameters to be changed, make your changes then, once more, go to SETUP SAVUSER and save them.

## 2. MEASUREMENT PROCEDURE

### 2.1 START UP

#### 2.1.1 Temperature Probe

Load the Boxcar software, provided, into a PC and connect the PC to the Hobo temperature logger with the serial cord provided. Run Boxcar. In the 'Launch' dialog window, set up the time interval required for the temperature measurements. The logger can store 8,000 readings, so it makes sense to use a good many of them in any measurement run. In other words, if a 10-hour experiment is planned, you could take a temperature reading every five seconds.

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, launch the logger, to make it start recording. Observe that the LED on the logger flashes periodically. Once the logger is launched, you may remove the serial cord from both the logger and the PC.

**Warning!** Make sure that previous temperature data has been downloaded before launching the logger. The launching process erases all previous data.

If 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. Switch on the RAD7 (have the printer switched on if you are using it. The RAD7 will then print a header for the data printout, including a review of the setup, before it gives you a 'Test' prompt.)

Provided that the RAD7 has been set up properly, see above, at the 'Test' prompt, push [ENTER] then the right arrow, to see 'Test Start' on the LCD, then push [ENTER] to start the test.

### 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 count rate being close to the equilibrium value. After that you need to accumulate sufficient counts for the precision desired. For example, 100 counts 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 RAD7 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 218-polonium.

#### 2.2.3 Water flow rate

At typical room temperature, the equilibrium 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 it would take four times the air volume just to deliver the radon. In practice the transfer is not complete so we may estimate that ten times the air volume is required.

Considering the volume of the RAD7, the drying unit and the RAD AQUA, we can conservatively estimate the volume of the air loop to be of the order 4 litres. Therefore about 40 litres of water is needed to deliver the radon to the air loop before it can reach equilibrium. A water flow rate

## 2. Measurement Procedure

of V L/min will take at least 40/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 RAD7. Thus the shortfall from equilibrium and hence the efficiency of transfer is maximized. To achieve this the pump 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 AUTO, which will preserve the desiccant and increase the life expectancy of the pump. Air will remain stationary in the RAD AQUA for four minutes before moving to the desiccant where it waits another four minutes before entering the RAD7. 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 15 to 20 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 20 minutes if the pump is set to AUTO

Having the pump on AUTO would normally be associated with having the RAD7 cycle time of 30 minutes or longer. So an extra 15 to 20 minutes on the response time will not be excessive.

### 2.2.5 RAD7 Mode

In AUTO (the default) mode, the RAD7 will automatically switch from SNIFF mode to NORMAL mode after three hours into the run. This is to take advantage of the additional counts provided by the 214-Po 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 mode for the RAD7 is appropriate. The RAD7's response time will be a couple of hours or so. The RAD AQUA can be running with a low water flow rate and the RAD7 pump can be on AUTO also.

For fast response, however, it is essential to force the RAD7 to stay in SNIFF mode (Setup, Mode, Sniff [ENTER]). It will then always count only the 218-Po decays, giving it a 13-minute, 95% response time.

## 2.3 LONG TERM MEASUREMENT

### 2.3.1 Desiccant

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 remaining length of blue (dry) desiccant is less than one inch, the desiccant should be replaced. Please see the RAD7 manual on desiccant regeneration. If the desiccant is not replaced, and the humidity in the instrument rises above about 20%, then the sensitivity drops off and the reading is lower than the true value.

### 2.3.2 Memory

The capacity of the internal memory of the RAD7 is 1,000 records or cycles. If each cycle is half an hour, that would be data for 500 hours, or just over 20 days. Every time the desiccant is changed, therefore, all the stored data should be downloaded to a PC, backed up, and erased from the RAD7 memory.

## 3. DATA

### 3.1 DATA HANDLING

#### 3.1.1 Printer

The IR printer will print out data in short, medium or long format - see RAD7 manual. In long format, there will be a spectrum printed at the end of every cycle.

#### 3.1.2 Memory

The internal memory of the RAD7 stores the date and time, the radon concentration, live time, total count and percentage in each of the main energy windows, as well as a host of other parameters, for every cycle - see RAD7 manual. These data can be downloaded to a PC at any time, during or after a run, with CAPTURE software, supplied.

#### 3.1.3 RADLINK

RADLINK, remote control software installed in the RAD7, enables a PC to control the RAD7 remotely, to grab any or all of the data, and to divert what would have been sent to the IR printer to the PC instead - see RAD7 manual. These, as with all other commands, may be invoked from a terminal program or any other program that can communicate through the serial port of the PC.

The PC must be connected to the RAD7 with a null-modem cable, as supplied with the RAD7. If the PC does not have an RS232 serial port the Keyspan USB/RS232 adaptor, as supplied, should be used. It is advisable to go to the Keyspan web site (<[www.keyspan.com](http://www.keyspan.com)>) to download the latest driver for the adaptor and the operating system of the PC.

#### 3.1.4 CAPTURE for Windows or Mac

The latest version of CAPTURE may be downloaded from the DURRIDGE web site (<[www.durridge.com](http://www.durridge.com)>). Go to the downloads page and click on the beta site link. In CAPTURE, choose a useful destination file name

for the new data file, e.g. RAD7 serial number plus date, choose the appropriate serial port and a fast baud rate, say 9600 baud or 19200 baud. On the RAD7 set the same baud rate (Special Set Baud, 9600 or 19200) then go to Special ComAll but do not press [ENTER] YET. In CAPTURE, click "download data". Then return to the RAD7 and push [ENTER]. If everything has been set up correctly you will see data appearing on the PC screen. When the transfer is finished CAPTURE will parse the data and then display a graph of the entire data set. Individual segments may be selected with the cursor lines and zoomed in by double clicking between the cursor lines.

Once the data is downloaded, and backed up securely, you should erase the RAD7 memory, to avoid any accumulation of data eventually filling the memory so preventing storage of future data.

#### 3.1.5 Temperature Data

To download the temperature data, hook up the temperature logger to the PC, run Boxcar once more, and READ, or DOWNLOAD the data. The program will take a few minutes to download the entire memory, and then display it as a graph. You should save it to your hard drive before doing anything else. You can also export it to an .XLS or .TXT file for incorporating into a spreadsheet or database program. We recommend that you back up your data onto different media as soon as possible.

**Warning!** Make sure that the data is properly downloaded and backed up before launching the logger again. Launching it will erase all previous data.

#### 3.1.6 Time Relationship

A 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 SNIFF mode, taking into account the 218-Po 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 fast, 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.

### 3.2 DATA CONVERSION

#### 3.2.1 FRITZ von WEIGEL

The RAD7 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 partition, or equilibrium, coefficient, given by the Fritz Weigel equation (Weigel, 1978):

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

where T is the temperature in deg C.

### 3. Data

At room temperature, a is around 0.25, giving, at equilibrium, a four-to-one ratio of radon in air to water.

#### 3.2.2 CALCULATION

The RAD7 radon data is stored in the RAD7 and the water temperature data is stored in the Hobo temperature logger. Currently it is necessary to download the RAD7 data into a PC with CAPTURE or other program and to download the Hobo data with Boxcar, as supplied with the RAD AQUA. The water radon concentration must then be calculated manually according to the Fritz Weigel equation. CAPTURE automatically gives the average radon concentration of the selected data between the cursor lines, but the temperature needs to be assessed separately and entered into the equation above to determine the partition ratio.

CAPTURE PRO will be able to download both the Hobo and RAD7 data and process the two sets automatically to give the radon concentration in the water directly. This will be made available from DURRIDGE in due course.

## 4. THORON in WATER

### 4.1 WHY THORON?

Thoron,  $^{220}\text{Rn}$ , an isotope of  $^{222}\text{Rn}$  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 RAD7 as quick as possible.

### 4.3 THORON SENSITIVITY

Sample is lost by decay while in the water en route to the exchanger and then again in the air en route to the RAD7.

#### 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 litre 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 RAD7 method 1

The RAD7 pump will typically generate an air flow rate of around 0.9 L/min. The volume of the air above the water spray in the chamber will be about 0.5L, the laboratory drying unit is about 1L as is also the RAD7 itself. An estimate, therefore of about 2.5L of air is required to be pumped for a thoron atom in the exchanger to reach the RAD7. At 900ml/min this will take a little less than 3 minutes. The thoron will have decayed through about three half lives between leaving the sampling point and being detected in the RAD7. In addition, the transfer from the water to the air will not be complete and the returning air from the RAD7 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 10% 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 RAD7 pump, a separate pump may be used to circulate air round the loop much faster than the RAD7 pump. However, the RAD7 cannot tolerate an air flow rate higher than 3L per minute. The RAD7, therefore, 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 RAD7.

With a circulating air flow rate of, say, 10L/min the delay from the exchanger to the RAD7 tap will be about 0.2 minutes and from the tap to the RAD7 chamber about 1 minute. So now, the total time delay from sampling point to entry into the

#### 4.Thoron

RAD7 will be no more than 1.5 minutes so reducing the attenuation due to radioactive decay of the thoron to no more than 70%.

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 RAD7 to thoron.

The first daughter of thoron,  $^{216}\text{Po}$ , has a half life of just 150mS. Thus in 0.5 seconds the RAD7 window B,  $^{216}\text{Po}$ , count rate will have nearly reached equilibrium with the thoron in the chamber. So the speed of response of the RAD7 to thoron is limited not be the half life of the polonium daughter but by the time it takes to get 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 RAD7 is only about 1.5 minutes.

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, such as shown in the schematic, fig.2, may be installed in the RAD AQUA system without modifying any other part of the system or the operating conditions. The inner membrane tube goes between the exchanger and the desiccant while the outer sheath is purged by dry air from the RAD7 outlet. The two flows should be in opposite directions along the DRYSTIK. A 12" DRYSTIK will increase the life of the desiccant by a factor of about five. A 48" DRYSTIK will increase the life by about 10 times.

#### 5.2 ACTIVE DRYSTIK

In active configuration, there is a pump upstream and a needle valve downstream of the inner membrane tube. This increases the pressure inside the tube which increases its efficiency.

A typical setup has the RAD7 pump set to OFF (Setup, Pump, Off [ENTER]), the DRYSTIK pump running continuously and the needle valve adjusted to give a flow rate of about 0.2 L/min.

With this configuration even a 12" DRYSTIK will make the desiccant last almost indefinitely. A 144" Active DRYSTIK will bring the relative

humidity in the RAD7 down below 10% even without any desiccant in the air path.

#### 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 round 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 DESIGNED ACTIVE DRYSTIK

The 0.2 L/min of the DURRIDGE-supplied active DRYSTIK arises because it matches the average flow rate of a RAD7 in AUTO mode and also matches the performance of the installed pump at a pressure of 44 PSI (3 atmospheres). With appropriate choice of pump and needle valve, an active DRYSTIK can be produced that will maintain a 44 PSI pressure inside the inner membrane tubing and a flow rate of 1L/min or even more, to restore the speed of response of the system while virtually eliminating the need to replace the desiccant periodically.

## 6. CARE, MAINTENANCE and TROUBLESHOOTING

### 6.1 RAD7

Water, particularly salt water, is hostile to electronic instruments. Please keep the RAD7 in a relatively clean and dry environment. One way is to enclose the instrument in a large, transparent plastic bag, see 1.2.3 above. Should it ever be seriously splashed with salt water, please return it to DURRIDGE immediately, for a thorough examination and cleaning.

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

It is useful to look at a cumulative spectrum periodically. This may be obtained by having the printer on and allowing the RAD7 to complete a run. The "Recycle" number may be set to the current cycle number (Setup, Recycle, NN [ENTER]). When the RAD7 reaches the end of the current cycle it will then print out the end of run summary including the cumulative spectrum. Look to see that the peaks are clean and in the normal position.

### 6.2 EXCHANGER

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.

### 6.3 DESICCANT

Please see the RAD7 manual for care and regeneration of the desiccant. Regenerated desiccant, after a few regenerations, loses most of its indicating ability (due, we believe, to migration of the cobalt chloride to the interior of

the calcium sulphate crystals). One way to 'indicate' the status is, every time you refill the laboratory drying unit with regenerated desiccant, you first add half an inch or so of new, blue desiccant, out of the jar. This way, you can always tell if the unit is still working, as the new desiccant will only turn pink when the rest of the desiccant, upstream, has become hydrated.

### 6.4 RISING WATER LEVEL

Should water rise inside the exchanger there is a danger that it may be sucked out into the desiccant and RAD7. This may occur because of the water supply having no dissolved gas and absorbing air from the exchanger. To prevent this, a bleed consisting of a long, small bore piece of tubing may be connected, with a T-connector, to the return air supply downstream of the check valve.

Rising foam, due to some forms of pollution in the water, may also be treated with a bleed as in the above paragraph. Should that not prevent the foam 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 RAD7 system.

### 6.5 AIR PATH INTEGRITY

As whenever 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 of the laboratory drying unit) in the air loop, particularly upstream of the RAD7. In the event of unexpectedly low radon values, check the air path for integrity.

**References and Bibliography**

In chronological order

Weigel, F, 1978. *Chemiker Zeitung*, 102 (1978) 287

Burnett, W.C., G. Kim, and D. Lane-Smith, 2001. A continuous radon monitor for assessment of radon in coastal ocean waters. *Journal of Radioanalytical and Nuclear Chemistry*, 249, 167-172.

Burnett, W.C., J. Chanton, J. Christoff, E. Kontar, S. Krupa, M. Lambert, W. Moore, D. O'Rourke, R. Paulsen, C. Smith, L. Smith, and M. Taniguchi, 2002. Assessing methodologies for measuring groundwater discharge to the ocean. *EOS*, 83, 117-123.

Lambert, M.J. and W.C. Burnett, 2003. Submarine groundwater discharge estimates at a Florida coastal site based on continuous radon measurements. *Biogeochemistry*, 66, 55-73.

Chanton, J.P., W.C. Burnett, M. Taniguchi, H. Dulaiova, and D.R. Corbett, 2003. Seepage rate variability derived by Atlantic tidal height. *Biogeochemistry*, 66, 187-202.

Burnett, W.C. and H. Dulaiova, 2003. Estimating the dynamics of groundwater input into the coastal zone via continuous radon-222 measurements. *Journal Environmental Radioactivity*, 69, 21-35.

Dulaiova, H., R. Peterson, W.C. Burnett, and D. Lane-Smith, 2005. A multi-detector continuous monitor for assessment of  $^{222}\text{Rn}$  in the coastal ocean. *Journal of Radioanalytical and Nuclear Chemistry*, 263(2), 361-365.

Dulaiova, H. and W.C. Burnett, 2006. Radon loss across the water-air interface estimated from  $^{222}\text{Rn}$ - $^{224}\text{Ra}$ . *Geophysical Research Letters*, 33, L05606, doi:10.1029/2005GL025023.

Burnett, W.C. and H. Dulaiova, 2006. Radon as a tracer of submarine groundwater discharge into a boat basin in Donnalucata, Sicily. *Continental Shelf Research*, 26, 862-873.

Dulaiova, H., W.C. Burnett, G. Wattayakorn, and P. Sojisuporn, 2006. Are groundwater inputs into river-dominated areas important? The Chao Phraya River – Gulf of Thailand. *Limnology and Oceanography*, 51, 2232-2247.

Povinec, P.P., P.K. Aggarwal, A. Aureli, W.C. Burnett, E.A. Kontar, K.M. Kulkarni, W.S. Moore, R. Rjar, M. Taniguchi, and 11 others. 2006. Characterization of submarine groundwater discharge offshore south-eastern Sicily. *Journal Environmental Radioactivity*, 89, 81-101.

Burnett, W.C., P.K. Aggarwal, H. Bokuniewicz, J.E. Cable, M.A. Charette, E. Kontar, S. Krupa, K.M. Kulkarni, A. Loveless, W.S. Moore, J.A. Oberdorfer, J. Oliveira, N. Ozyurt, P. Povinec, A.M.G. Privitera, R. Rajar, R.T. Ramessur, J. Scholten, T. Stieglitz, M. Taniguchi, J.V. Turner, 2006. Quantifying submarine groundwater discharge in the coastal zone via multiple methods. *Science of the Total Environment*, 367, 498-543.

Dulaiova, H., W.C. Burnett, J.P. Chanton, W.S. Moore, H.J. Bokuniewicz, M.A. Charette, and E. Sholkovitz, 2006. Assessment of groundwater discharges into West Neck Bay, New York, via natural tracers. *Continental Shelf Research*, 26, 1971-1983.

## References and Bibliography

- Swarzenski, P. W., W.C. Burnett, W.J. Greenwood, B. Herut, R. Peterson, N. Dimova, Y. Shalem, Y. Yechieli, and Y. Weinstein, 2006. Combined time-series resistivity and geochemical tracer techniques to examine submarine groundwater discharge at Dor Beach, Israel. Geophysical Research Letters, 33, L24405, doi:10.1029/2006GL028282.
- Burnett, W.C., H. Dulaiova, C. Stringer, and R. Peterson, 2006. Submarine groundwater discharge: its measurement and influence on the coastal zone. Journal of Coastal Research, Spec. Issue 39, 35-38.
- Peterson R.N., W.C. Burnett, C.R. Glenn, and A.J. Johnson, 2007. A box model to quantify groundwater discharge along the Kona coast of Hawaii using natural tracers. International Association of Hydrological Sciences (IAHS) Publ. 312, "A New Focus on Groundwater-Seawater Interactions," (ed. W. Sanford, C. Langevin, M. Polemio, and P. Povinec), 142-149.
- Weinstein, Y., Y. Shalem, W.C. Burnett, P.W. Swarzenski, and B. Herut, 2007. Temporal variability of Submarine Groundwater Discharge: assessments via radon and seep meters, the southern Carmel Coast, Israel. International Association of Hydrological Sciences (IAHS) Publ. 312, "A New Focus on Groundwater-Seawater Interactions," (ed. W. Sanford, C. Langevin, M. Polemio, and P. Povinec), 125-133.
- Dulaiova, H. and W.C. Burnett, 2007. Evaluation of the flushing rates of Apalachicola Bay, Florida via natural geochemical tracers. Marine Chemistry, doi: 10.1016/j.marchem.2007.09.001.
- Burnett, W.C., N. Dimova, H. Dulaiova, D. Lane-Smith, B. Parsa, and Z. Szabo, 2007. Measuring thoron ( $^{220}\text{Rn}$ ) in natural waters. Book chapter in "Environmental Radiochemical Analysis III" (ed. P. Warwick), Royal Society of Chemistry, RSC Publishing, Cambridge, 24-37.
- Weinstein, Y., W.C. Burnett, P.W. Swarzenski, Y. Shalem, Y. Yechieli, and B. Herut, 2007. Role of aquifer heterogeneity in fresh groundwater discharge and seawater recycling: an example from the Carmel coast, Israel. Journal of Geophysical Research - Oceans, 112, C12016, doi: 10.1029/2007JC004112.
- Burnett, W.C., R. Peterson, W.S. Moore, and J. de Oliveira, 2008. Radon and radium isotopes as tracers of submarine groundwater discharge – results from the Ubatuba, Brazil SGD assessment intercomparison. Estuarine, Coastal and Shelf Science, 76, 501-511.
- Charette, M.A., W.S. Moore, and W.C. Burnett, 2008. Uranium- and thorium-series nuclides as tracers of submarine groundwater discharge. Chapter 5 In: "U-Th Series Nuclides in Aquatic Systems," (eds. S. Krishnaswami and J. Kirk Cochran), Elsevier, Amsterdam, 155-191.
- Santos, I.R., F. Niencheski; W. Burnett; R. Peterson; J. Chanton, C.F. Andrade; I.B. Milani; A. Schmidt; and K. Knoeller, 2008. Tracing anthropogenically-driven groundwater discharge into a coastal lagoon from southern Brazil. Journal of Hydrology, 353(3-4), 275-293, DOI: 210.1016/j.jhydrol.2008.1002.1010.

## References and Bibliography

165. Peterson, R.N., W.C. Burnett, M. Taniguchi, J. Chen, I.R. Santos, and S. Misra, 2008. Determination of transport rates in the Yellow River-Bohai Sea mixing zone via natural geochemical tracers. Continental Shelf Research, 28 (19), 2700-2707.
167. Povinec, P.P., H. Bokuniewicz, W.C. Burnett, J. Cable, M. Charette, W.S. Moore, J.A. Oberdorfer, J. de Oliveira, R.N. Peterson, T. Stieglitz, and M. Taniguchi, 2008. Isotope tracing of submarine groundwater discharge offshore Ubatuba, Brazil: Results of the IAEA-UNESCO SGD project. Journal of Environmental Radioactivity, 99, 1596–1610.
- Peterson, R.N., W.C. Burnett, M. Taniguchi, J. Chen, I.R. Santos, and T. Ishitobi, 2008. Radon and radium isotope assessment of submarine groundwater discharge in the Yellow River Delta, China. Journal Geophysical Research - Oceans, 113, C09021, doi: 10.1029/2008JC004776.
- Burnett W.C., R.N. Peterson, M. Taniguchi, G. Wattayakorn, S. Chanyotha, and F. Siringan, 2009. Importance of groundwater discharge in developing urban centers of Southeast Asia. In: “From Headwaters to the Ocean: Hydrological Change and Watershed Management,” (eds. M. Taniguchi, Y. Fukushima, W.C. Burnett, M. Haigh and Y. Umezawa), Taylor & Francis, London, 289-294.
- Burnett, W.C., S. Chanyotha, G. Wattayakorn, M. Taniguchi, Y. Umezawa, and T. Ishitobi, 2009. Groundwater as a pathway of nutrient contamination in Bangkok, Thailand. Science of the Total Environment, in press.
- Peterson, R.N., W.C. Burnett, C.R. Glenn, and A.G. Johnson, 2009. Quantification of point-source groundwater discharges from the shoreline of the Big Island, Hawaii. Limnology and Oceanography, 54, 890-904.
- Santos, Isaac R., N. Dimova, R. Peterson, B. Mwashote, J.P. Chanton, and W.C. Burnett, 2009. Extended time series measurements of submarine groundwater discharge tracers ( $^{222}\text{Rn}$  and  $\text{CH}_4$ ) at a coastal site in Florida. Marine Chemistry, 113, 137-147.
- Santos, I.R., W.C. Burnett, J. Chanton, N. Dimova, R.N. Peterson, 2009. Land or ocean? Assessing the driving forces of submarine groundwater discharge at coastal site in the Gulf of Mexico. Journal of Geophysical Research - Oceans, 73, 1325-1339.
- Burnett, W.C., R.N. Peterson, I.R. Santos, R.W. Hicks, 2009. Use of automated radon measurements for rapid assessment of groundwater flow into Florida streams. Journal of Hydrology, submitted.