

RAD7 RADON DETECTOR

User Manual



Owner _____

Serial # _____

SERVICE RECORD

Date Service

Date	Service

It is recommended that the unit be returned to DURRIDGE Co annually, for recalibration.

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WARNING



The mains plug for this instrument shall only be inserted in a socket outlet provided with a protective ground contact. Any interruption of the protective conductor may make the instrument dangerous.

Opening the cover of this instrument is likely to expose dangerous voltages. Disconnect the instrument from all voltage sources while it is being opened. Due to battery power, the instrument may still be dangerous.

Using this instrument in a manner not specified by the manufacturer may impair the protection provided by the instrument.

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INTRODUCTION

The RAD7 is a highly versatile instrument that can form the basis of a comprehensive radon measurement system. It may be used in many different modes for different purposes. This manual adopts a progressive approach, in which there is, first, a simple, step-by-step description of how to get readings for a) real-time monitoring, and b) sniffing. Next comes a more detailed description of the many features of the instrument and how to access them. The rest of the manual covers a whole range of topics, in somewhat arbitrary order. We recommend that, as soon as possible, you read the entire text, just so that you will have an idea of what there is. While you can start to make good measurements on the first day of ownership of the RAD7, it can take years to master the subtleties of radon and thoron behaviour, and to appreciate the full capabilities of the instrument.

We have tried to make the manual easy to use, with a useful table of contents. Please let us know how well we have succeeded. If there are some topics inadequately covered, please tell us. We will issue updates from time to time.

Points of special note

The RAD7 is a rugged and long-lasting piece of equipment. There are many units still in daily use that were sold nine years ago or more. However, it is a sophisticated, precision electronic device, and it is not hermetically sealed, so please treat it with respect. Please do not allow water, other liquids or dirt to get into the machine. If using it somewhere where it may get splashed, damaged, or exposed to rain, please protect it.

The batteries are lead-acid technology, like a car's. If left in a discharged state they will, like a car's, lose capacity. After running the RAD7 on its batteries please recharge them as soon as possible (by plugging in the unit and turning it on). With careful use, the batteries, like a car's will last five years or more.

Finally, there is one security feature that is sometimes inadvertently set by an inexperienced, though authorized, user; namely the key pad lockout. If the key pad ceases to function, and all you see is "DURRIDGE RAD7" on the display, just do the following: Hold down the ENTER and two arrow keys until you hear a beep, release the three keys and immediately push MENU. You should then be rewarded by "Test" on the display. If the tone was set to OFF, then you will not hear the beep, so hold the three keys down for three to four seconds, before releasing them and pushing MENU, - try hold-down times a little longer, or shorter, if, at first, you do not succeed.

1. GETTING STARTED: YOUR FIRST DAY WITH THE RAD7

1.1 Unpacking

First make sure you have everything you're supposed to have. Take the materials out of the packing boxes and see if you have all the items shown below or on the packing list enclosed with the shipment. If anything is missing, please call DURRIDGE immediately at (781) 687-9556.

- RAD7 monitor
- Power cords
- Shoulder strap & keys
- Printer
- 2 sets Velcro tabs
- 3 rolls printer paper
- Printer adapter
- 6 inlet filters
- 1 dust filter
- Vinyl tubing: 3 pieces 3' long
- Large drying tube
- 4 small drying tubes
- 5 lbs. desiccant (drying granules)
- CAPTURE CD
- Null-modem computer cable
- USB adapter
- Manual

1.2 General Safety Instructions

For your own safety and the proper operation of RAD7:

- DO NOT spill liquids onto the machine.
- DO NOT expose operating panel of machine to rain or any other excess moisture.
- DO NOT allow liquid to be sucked into inlet tube.

If you intend to use the instrument in a harsh environment, give it some protection. Even just a transparent plastic bag enclosing the RAD7 (but not the air sampling tube) can protect it from splashing mud and water. Allowing the dry air from the RAD7 outlet to exhaust into the interior of the bag will keep the RAD7 in a clean and dry environment.

If liquid does get into the machine, please disconnect the power cord, turn off the power switch, and return the RAD7 to DURRIDGE for repair.

Do not use your RAD7 if the instrument is damaged or malfunctioning. Please call, or email, the DURRIDGE service department, who will advise what to do about the problem.

Replace a frayed or damaged power cord immediately.

Electrical equipment may be hazardous if misused. Keep away from children.

Do not open or attempt to repair the machine. The detector has an internal high voltage supply that can generate more than 2,500 volts.

Warning: This machine is intended to be electrically grounded when externally powered. The power cord is equipped with a plug, to fit only into a grounding-type AC outlet.

The instrument is factory set to either 120 VAC or 240 VAC operation. The setting is indicated on the input power label.

The batteries are Gates Monobloc type 0819-0012, 6V 2.5Ah. There are two installed in the instrument. They are not user replaceable.

1.3 Taking a Look

The RAD7 Professional Electronic Radon Detector



1.4 Starting a Two-day Test

You will need the RAD7 and power cord, the Laboratory Drying Unit (the large tube of desiccant, with a screw cap at one end), an inlet filter (one of the six small filters supplied), the piece of tubing with a 5/16" ID segment at one end and a 1/8" ID segment at the other and the printer.

On first starting up, you will need to set the clock for your time zone (See Setup Clock, page 26). Switch on the RAD7, push [MENU], then push [→] twice. You will see Setup on the display. Push [ENTER], then push [→] ten times. You will see Setup Clock. Push [ENTER]. Use arrow keys to adjust hours, minutes, seconds, day, month and year, pushing [ENTER] to confirm each setting. Now we are ready to continue.

- a) Attach the filter to the tubing (push it into the end with the insert).
- b) Carefully remove both plastic caps from the Drying Unit (you will need them later, to reseal the unit). Attach the sleeved end of the tubing to the tube fitting, on the Drying Unit, farthest from the screw cap.
- c) Attache the filter to the Inlet port of the RAD7. The air sampling system is now set up for the measurement.
- d) Plug in the RAD7 and switch on.
- e) Push [MENU], [ENTER], then push [→] four times. You should see on the LCD display: Test Purge.
- f) Push [ENTER]. The pump should start.
- g) Set up the printer (insert paper and batteries - see manual).
- h) Place printer between green lines on face plate (See photo, page 10).
- i) After purging for some time (normally, at least five minutes), push [MENU], and [→] two times, you will see: Setup on the display.
- j) Push [ENTER] twice, then push either arrow key repeatedly until you see:
Protocol: 2-Day on the display. Push [ENTER].
- k) With Setup on the display, push [ENTER], then [→] seven times, to see Setup Format on the display. Push [ENTER] then use arrow keys to select Format: Short. Push [ENTER].
- l) Switch off the RAD7. Switch on the printer, now switch the RAD7 back on. The printer will print out something like the following:

```
DURRIDGE RAD7
Vers 2.5f 991128
Model 711
Serial 00512
Calib 21-MAY-08
```

```
Last used
  FRI 21-MAY-08  17:30
```

```
Current settings
  FRI 21-MAY-08  19:09
```

```
Protocol: 2-Day
Cycle: 01:00
Recycle: 48
Mode: Auto
Thoron: Off
Pump: Auto
Tone: Geiger
Format: Short
Units: pCi/L C
```

- m) Push [MENU], [ENTER], [→]. You should see on the LCD display: Test Start
- n) Push [ENTER]. The pump will start running. On the LCD display you will see something like:
0101 Live Sniff
00:59:37 00001

You are now monitoring the radon level right where you are. Every hour, the printer will print out a reading something like this:

```
0102 2.69 " 0.73 p Sniff
  FRI 21-MAY-08 19:41
  26.8 C RH: 7% B:7.06V
```

Where 0102 are the run (01) and cycle (02) numbers, 2.69 is the measured radon concentration, 0.73 is the STATISTICAL uncertainty (see page 41), p indicates the units (in this case pCi/L), and Sniff shows that, for this reading, only the Po-218 decays (see page 33) are being counted (after three hours, the mode changes automatically to Normal). The second line is clearly the date and time, while the third shows the temperature and humidity inside the measurement chamber, and the battery voltage. Medium and Long format settings print more information each cycle.

If you allow the RAD7 to complete a run, it will print out a summary of the entire run, including:

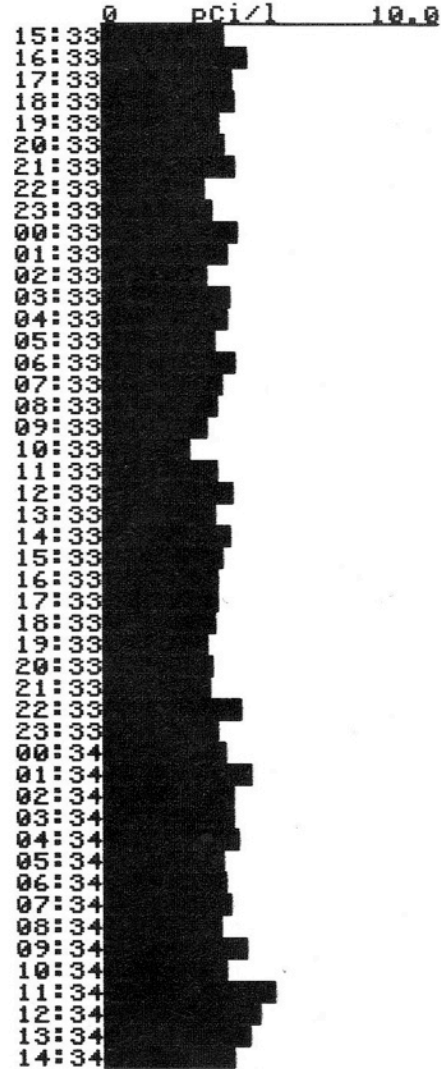
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1. Date and time
2. Machine serial number
3. Average value for the test
4. Bar chart of the individual readings, and
5. Cumulative alpha energy spectrum.

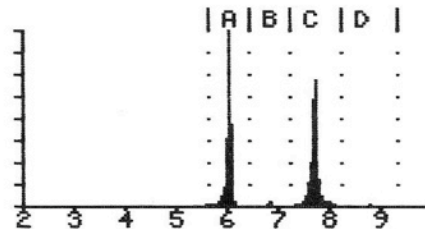
In the example shown it may be seen that the average level was 3.71 pCi/L, or 137 Bq/m³.

To terminate the run early, you may switch off the RAD7. The data collected, to the end of the last completed cycle, is automatically stored in the RAD7 memory, and available for later display, printing or download to a PC. If you wish to store the last, incomplete cycle data as well, use Test Save before switching off the RAD7. When you do this, the end-of-run printout does not take place. The summary is stored in memory and may be printed at any time, except that the cumulative spectrum, which would have been printed out at the end of the run, is lost.

```
Run 02
Begin 09-JAN-08 15:33
Serial 02094
Cycles = 048
Mean: 3.71 pCi/l
S.D.: 0.46 pCi/l
High: 5.13 pCi/l
Low: 2.55 pCi/l
```



Cumulative Run Spectrum



End-of-Run Printout

1.5 Starting a Sniff Test

Sniffing lets you make quick, qualitative surveys of radon and thoron levels. It may be used to search for radon entry points. There are some advantages in sniffing for both thoron (see page 33) and radon at the same time (see page 53), so that is the procedure described here.

You will need the same equipment as for the 2-day test, above, except that a small drying tube should be used, instead of the laboratory drying unit. Also, for portability, you may remove the external power from the RAD7, and run both the RAD7 and the printer on their batteries.

If you have not already done so, set the clock, as described above.

- a) Attach the filter to the tubing (push it into the end with the 1/8" ID segment).
- b) Carefully remove both plastic caps from the small drying tube (you will need them later, to reseal the unit). Attach the 5/16" ID end of the tubing to one end of the tube.
- c) Attache the filter to the Inlet port of the RAD7. Make sure it is firmly fit onto the inlet. The air sampling system is now set up for the measurement. While testing, you can use the small drying tube as a wand, to collect your air sample from the location of interest.
- d) Plug in the RAD7 and switch on.
- e) Push [MENU], [ENTER], then push [→] four times. You should see on the LCD display: Test Purge.
- f) Push [ENTER]. The pump should start.
- g) Set up the printer.
- h) Place printer between green lines on the face plate (See photo, page 10).
- I) After purging for a few minutes push [MENU], and [→] two times, you will see: Setup on the display.
- j) Push [ENTER] twice, then push either arrow key repeatedly until you see: Protocol: Thoron on the display. Push [ENTER]. (See page 24 for difference between Thoron and Sniff protocols).
- k) With Setup on the display, push [ENTER], then [→] seven times, to see Setup Format on the display. Push [ENTER] then use arrow keys to select Format: Short. Push [ENTER].

- l) Switch off the RAD7. Switch on the printer, now switch the RAD7 back on. The printer will print out something like the following:

```
DURRIDGE RAD7
Vers 2.5f 991128
Model 711
Serial 00512
Calib 21-MAY-08
```

```
Last used
      WED 23-MAY-08      17:30
```

```
Current settings
      FRI 25-MAY-08      19:09
```

```
Protocol: Thoron
Cycle: 00:05
Recycle: 00
Mode: Sniff
Thoron: On
Pump: Auto
Tone: Geiger
Format: Short
Units: pCi/L C
```

- m) Push [MENU], [ENTER], [→]. You should see on the LCD display: Test Start
- n) Push [ENTER]. The pump will start running. On the LCD display you will see something like:

```
0201          Live          Sniff
00:04:37          00001
```

You are now sniffing for thoron and radon. Every five minutes, the printer will print out a reading something like this:

```
0203  2.69 " 2.83    p  Sniff
      1.68 " 2.15    p  Thoron
      FRI 21-MAY-99 19:41
      26.8 EC RH: 7% B:7.06V
```

Where 0203 are the run (02) and cycle (03) numbers, 2.69 is the measured radon concentration, 2.83 is the STATISTICAL uncertainty (see page 41), p indicates the units (in this case pCi/L), and Sniff shows that, for this reading, only the Po-218 decays (see page 33) are being counted. The second line is the measured thoron concentration and uncertainty. The third line is now the date and time, while the fourth shows the temperature and humidity inside the

Chapter 1

measurement chamber, and the battery voltage. Medium and Long format settings print more information each cycle.

Note that the Po-218 has a 3-minute half life. After moving to a new location, it will take about 15 minutes for the count rate to reach equilibrium with the new radon concentration. So not until after the third 5-minute cycle will the reading indicate the new level. However, the thoron daughter, Po-216, has a very short half life (150 ms), so the response of the RAD7 to thoron is virtually instantaneous. For thoron, the first 5-minute cycle is as good as any other.

Thoron will only be found very close to radon entry points. That, together with its fast response, makes thoron sniffing an excellent sleuth for radon entry points.

To terminate the run any time, you may switch off the RAD7. The data collected, of completed cycles, is stored in the RAD7 memory, and available for later display, printing or downloading to a PC.

2. BASICS OF RAD7 OPERATION

2.1 Introduction

2.1.1 The Key Pad

The RAD7 is operated through a four-key menu-driven interface. These four keys allow you to look at the commands, select one, and then do it.

Menu Key

Press [MENU] and you see the menu prompt (>) and the word Test:

```
>Test
```

Arrow Keys

Press the forward and backward arrow keys to go through the available options. To advance quickly through the options, hold down the key so that it "auto-repeats."

The arrow keys allow you to move right and left through the various commands, looking for the action you want.

Enter Key

When you have decided on a certain menu option, you select it by pressing [ENTER]. The enter key tells the RAD7 that you have made your selection. You are telling it what you want it to do.

The enter key makes it happen.

2.1.2 Command List

The RAD7 command list has four command groups: Test, Data, Setup and Special. The Test group of commands controls the collection of new radon data. The Data group retrieves data from memory, outputs them, and gets rid of old, unwanted data. The Setup group prepares the RAD7 to operate according to your requirements. The Special group is a set of commands that are available when RADLINK, the remote control software, is loaded.

2.2 Test

The Test group of commands controls the collection of radon data and allows you to manipulate the current test (test-in-progress). You can start and stop data collection, save or clear the current test, or print the current test as it stands. (The Test commands do not allow access to stored data. You have to go to Data for that.)

2.2.1 Test Status

To see the status display, enter the Test Status command. Press [MENU], [ENTER], [ENTER]

On the LCD display, you will see:

```
0501      Idle      Sniff
00:30:00                                00000
```

On the upper left, you see the current run number/cycle number (0501 - run 05, cycle 01.).

The middle shows the detector status (Idle or Live), and the upper right gives the current test mode (Sniff, Normal or Grab). (Note that in Auto mode, the indication will change from Sniff to Normal after three hours of measurement.

Lower left shows the count-down timer (00:30:00 = 30 minutes) which counts down to zero when the detector is Live (i.e., a test is in progress). The lower right shows the total number of counts since the beginning of the current cycle.

The arrow keys may now be used to access additional status information.

Press → once, and you will see something like this:

```
Last reading:
0409  1.80 " 0.74    p
```

The lower left is the run number (2 digits) and cycle number (2 digits) of the last completed cycle stored to memory.

The lower right is the radon reading and statistical uncertainty, followed by "p", indicating

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picoCuries/liter, or "b" for Becquerels/cubic meter.

When a cycle ends, the information on this display is updated. If there have been no readings yet, the display will show

No readings yet.

Press → once again, and now you will see something like this:

24.8°C RH:3%
B: 6.36V P: 00mA

Top left is the internal temperature. (To change from Celsius to Fahrenheit, see Setup Units.)

Top right shows the internal Relative Humidity reading. When testing, maintain this value at 10% or less, by using the desiccant.

Bottom left is the battery voltage. This should range from about 6.00 to 7.10. A discharged battery (less than 6.00 V) should be recharged as soon as possible. A fully charged battery will rest at 6.40 to 6.50 V. During a recharge, the voltage will eventually rise above 7.00 V. At no time should this read higher than 7.20 V.

In the lower right is the pump current. This number should vary from 00mA (pump off) to 80mA. When the pump is running with a light load, the current will range from 40-70mA. When the pump is running with a heavy load (clogged filter or blocked hose), the current will go to 90mA or higher. Pump currents above 90mA are considered a sign of trouble. Try changing the filters and check for blockage.

Press → again, and you will see something like this:

HV: 2218V, 10%
L: 02 S: 0.21V

This is a display of diagnostic values. Ordinarily it will be of little interest to you.

The top line is the high voltage reading and duty cycle. The range of normal values is from 2000 to 2500V, and from 8% to 18%.

The lower left corner is the leakage current. At room temperature, this value will normally range from 0 to 10. Higher temperatures ordinarily

cause this value to rise. Excessive leakage current will result in "noise" in the lower energy end of the spectrum, and will also cause broadening of the alpha peaks.

The lower right corner is the signal voltage from the analog circuit. This number should be "stable"; that is, fluctuations should be no more than 0.05V from the average value.

Press → yet again, and you will see something like this:

w		cpm		+/-		%tot
A		6.0		4.3		48.8

This is the display for the A window data. You may press → to advance to B, C, D, etc.

The RAD7 records 8 windows (A - H) every time you make a measurement. They separate counts due to daughters of radon and thoron, and the background. Specific alpha particles end up in specific windows.

W: The window letter.

cpm: The counts per minute observed in the window.

+/-: The statistical uncertainty of the cpm value, also in units of cpm.

%tot: The number of counts in the window as a percentage of the total counts in the spectrum. This tells you quickly where the majority of the counts are: In the 3-minute radon peak (window A), or the long-lived radon peak (window C), etc.

As always, you press the [MENU] key to exit this display and return to the start of the menu.

2.2.1a Quick Save-and-Restart

This function allows the user to end a sniff test, store it to memory, and start up a new sniff test, all using a single key. It operates only from the SNIFF mode.

From the status display (showing the countdown timer), press the ENTER key once. The display will show:

Save and restart
? Yes

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Press the ENTER key once more to confirm your intention. To escape, push the MENU key or push an arrow key to select "No" and push ENTER.

2.2.2 Test Start and Test Stop

To start testing (or "counting"), after you have chosen the required setup, go to >Test Start by pressing [MENU], [ENTER], [→], and then [ENTER].

The display will indicate that counting has begun: Start counting.

One second later, the Status display will appear with the countdown timer in motion:

```
0501      Live      Sniff
00:29:37                00001
```

When the countdown reaches zero, the RAD7 will automatically calculate the radon concentration, store (or "save") the counts to memory, and clear the counters to begin a new cycle.

To interrupt the measurement, go to >Test Stop by pressing [MENU], [ENTER], [→], [ENTER].

The display will respond:

Stop counting

After one second, the display will go back to the top of the menu >Test.

You may wish to examine the Status display to verify that the status is Idle.

To resume testing from exactly the same point in the cycle where you stopped, select >Test Start as described above.

Note that Stop does not terminate the run, it is a pause. If you do not wish to resume testing from the same point, you should select either >Test Save or >Test Clear before continuing. This will terminate the suspended test, store it to memory (Save) or wipe it out (Clear), and clear the counters to begin a new run.

2.2.3 Test Save

The >Test Save command suspends counting and saves the suspended test (test-in-progress) to

memory as if it had reached completion. Test Save completes the current run, so any subsequent test data will be stored as a new run. The display momentarily shows the run and cycle number in the form of 0101 Saved. This command may be accessed whether the status is Live or Idle. It always leaves the status Idle.

You will find this command especially useful when you wish to move the instrument to another location without waiting for the countdown to reach zero, but without losing that last incomplete cycle. The calculated radon concentration from the incomplete cycle is still good.

2.2.4 Test Clear

The >Test Clear command causes counting to be suspended and the current run to be completed without saving the last (suspended) incomplete cycle. Subsequent test data will be stored as a new run. You must answer Yes to the question Are you sure? in order to activate this command.

This command may be accessed whether the status is Live or Idle. It always leaves the status Idle.

2.2.5 Test Purge

The >Test Purge command suspends counting and begins purging the detector. The pump begins running and the high voltage circuit turns off in order to clear the sample chamber of radon gas and daughters as quickly as possible. You must provide clean, desiccated, radon-free air to the inlet in order to push out any radon that was previously sampled. Outdoor air is usually adequate for this purpose.

As always, use the inlet filter and drying tube. Ten minutes is usually sufficient for bringing the background down after exposure to moderate amounts of radon.

In order to dry out the RAD7 without using up much desiccant, connect the hoses from the RAD7 to the drying unit, as a loop. When the pump runs, the same air will circulate repeatedly through the desiccant. This procedure will efficiently remove residual moisture from the RAD7. This does not introduce any fresh air, and so does not change the radon level in the instrument, but you can make a measurement of

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the background while it is set up in this configuration.

To end the purge, answer Yes to the question Stop purge? which appears on the display. Alternatively, you may push [MENU] to end the purge.

2.2.6 Test Lock

If you push [ENTER] when this is displayed, it will lock the key pad. The LCD display will just show:

DURRIDGE RAD7

Nobody will be able to unlock the key pad, unless they know the secret.

If the key pad was locked during a measurement, then the readings will continue as normal, with the RAD7 recording all the data, until the end of the run.

Switching the unit off, while locked, will stop the measurement, but the key pad will still be locked when the RAD7 is switched on again.

To unlock the key pad, hold the [ENTER] and both arrow keys down, all together, for 3 - 4 seconds, or until the unit beeps, then release the three keys and push [MENU] immediately.

2.2.7 Test Sleep

The >Test Sleep command allows you to turn off most of the electronic circuits, with the power switch on, in order to conserve battery charge. A fully charged RAD7 should be able to "sleep" for about one week on batteries alone. Press the menu key to "wake up" the RAD7.

The Sleep function was for older models that did not have the Real Time Clock (RTC) and Non-Volatile Memory (NVRAM) options. New and upgraded instruments may be shut down completely, power switch off, without losing any stored data or clock.

2.2.8 Test Print

The >Test Print command calculates results for an incomplete or suspended test cycle and prints them according to the print format that is currently set.

Spectrum output is available by selecting >Setup Format Long beforehand.

If you wish to abort printing, press the menu key. The run number and cycle number that ordinarily appear on printed data are replaced by 0000 to signify that the cycle is not completed.

2.2.9 Test Com

The >Test Com command outputs the results for an incomplete test cycle to the serial port.

If you wish to abort output, press the menu key. The run number and cycle number that ordinarily appear with the data are replaced by 0000 to signify that the cycle is not completed.

2.3 Data

The Data group of commands retrieves data from memory, displays it, prints it, reports it graphically, and outputs it to the serial port. The Data group also includes commands for managing memory. The memory will hold the data for 1,000 cycles, in up to 100 runs

Many commands in the Data group require you to enter a two-digit run number after the command. The "default" run number (the one automatically set if you do nothing) is the run number of the last complete cycle of data stored. The arrow keys allow you to select any other run number.

2.3.1 Data Read

Select >Data Read followed by a two-digit run number, to examine radon readings from that particular run. For example, select >Data Read 01 to examine readings from run number 01, the first test in memory.

You will see something like this:

```
0101  23.3 " 1.54    p
      11:45 19-MAY-99
```

Line 1 is the run/cycle number followed by the radon concentration, uncertainty, and unit indicator. This example shows:

Run 01, Cycle 01, 23.3 " 1.54 pCi/L.

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Line 2 is the time (24-hour military time) and date the reading was completed.

Press [→] to advance to the next reading in memory; press the backward arrow to go back to the previous reading.

To quit examining data, press [ENTER] or [MENU].

Note that large numbers are presented in shorthand notation. The symbol "K" stands for 1,000 and "M" stands for 1,000,000. For example, 33K2 stands for 33,200.

2.3.2 Data Print

To print out a run of data from memory, select >Data Print followed by the two-digit run number. For example, to print the data from run number 05, select >Data Print 05.

If the printer format has been set to Short, the following printout will be made for each cycle of the run:

```
0501  2.69 " 2.83   p Sniff
      FRI 21-MAY-99 19:41
      26.8 EC RH: 7% B:7.06V
```

Line 1 is the run/cycle number, the radon concentration, the uncertainty, the units indicator (p=picoCuries per liter, B=Becquerels per cubic meter), and the mode indicator.

Line 2 is the date and time that the cycle was completed and stored to memory.

Line 3 is the temperature (in either "C" Celsius or "F" Fahrenheit), relative humidity (internal), and battery voltage at the time the cycle ended.

If the printer format has been set to Medium or Long, then you will see a printout like this for each cycle:

```
0501  2.69 " 2.83   p Sniff
      FRI 21-MAY-99 19:41
      26.8 EC RH: 7% B:7.06V
Total Counts:  42.
Livetime:      27.8min
A: 0.53"0.08   cpm      47.3%
B: 0.02"0.02   cpm      1.7%
C: 0.52"0.08   cpm      46.4%
```

```
D: 0.01"0.02   cpm      0.9%
O: 0.04"0.03   cpm      3.6%
```

Lines 1, 2 and 3 are the same as in Short format, as outlined above. Line 4 is the total number of counts detected during the cycle.

Line 5 is the livetime, the time that the detector was actively collecting data.

Lines 6 through 10 are the windows data for windows A, B, C, D, and O. (O is the consolidated window for "others", or counts that are not included in windows A through D.)

Each line of windows data contains the window letter (A, B, C, etc.) followed by the window's counts per minute (cpm), statistical uncertainty of the counts per minute, and percent of the total counts included within that window.

NOTE: The RAD7 does not store spectra from old cycles, so no spectra will print from memory even if the printer format is Long. If you need a spectrum, be sure you print while the test is still running.

If no data are available to print, the RAD7 will beep and display No tests stored.

To abort a printout, press the menu key, then press the printer paper advance button.

2.3.3 Data Com

The RAD7 has an RS232 port that can transfer data to your computer. Status must be Idle.

To send a run of data to the serial port, select >Data Com followed by the two-digit run number. When ready, push [ENTER].

The following message will appear on the display as the data is sent:

Data transfer ...

When the data transfer finishes, the RAD7 will beep.

To enable your PC to receive data, appropriate software should be running. A terminal emulation program, or CAPTURE, the data link software provided with the RAD7, may be used. See the

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chapter on Data Communication, Chapter 5, for more detail.

2.3.4 Data Summary

To print a summary report and time graph of a run's data, select >Data Summary followed by the two-digit run number. The following information will be printed:

```
Run 31
Begin 01-Jun-99 12:49
Serial 00500
Cycles = 048
Mean: 0.77 pCi/l
S.D.: 0.27 pCi/l
High: 1.41 pCi/l
Low: 0.20 pCi/l
```

where:

Line 1 is the run number.
Line 2 shows the date and time of the first reading.
Line 3 is the serial number of the instrument.
Line 4 is the number of completed cycles in the run.
Line 5 is the arithmetic mean (or "average") of the radon concentrations recorded.
Line 6 is the standard deviation of the readings taken during the run.
Lines 7 and 8 are the highest and lowest radon concentrations.

Following Line 8 is a bar graph of radon concentration through time. Time-of-day is printed along the left-hand edge of the graph. If there is only one cycle of data, the bar graph will not print.

This printout procedure has been programmed into several protocols. When you choose one of the pre-programmed protocols, this report is printed out automatically at the end of the run, together with a cumulative spectrum.

2.3.5 Data Free

To determine the amount of free memory available for storing new radon readings, select >Data Free, and push [ENTER].

For about two seconds, the display will look something like this:

910 cycles free.

The RAD7 can store up to 999 cycles of data. As the memory fills with data, the Data Free indicator decreases. If the Data Free indicator reaches 000, any subsequent attempt to store data to memory will result in a "memory full" error.

Keep your eye on this indicator to avoid embarrassment! When the amount of free memory gets uncomfortably low (i.e. 200 or less), consider deleting un-needed old data to open up space for new data. See Data Delete and Data Erase.

2.3.6 Data Delete

To delete an entire run of data, select >Data Delete followed by the two-digit run number.

The display will prompt you for confirmation:

```
Delete run 31?
No
```

Press → to find Yes, then press [ENTER] to delete the run's data from memory and free the space for new data. No other run's data will be affected.

After deletion of a run's data, any attempt to retrieve the data will result in a No tests stored message. The main purpose of the Data Delete command is to selectively free up memory space for new tests. Do not confuse Data Delete with Data Erase, which wipes out all runs of data from memory. See also Data Free, Data Renumber, and Data Erase.

2.3.7 Data Renumber

Select >Data Renumber to renumber remaining runs into consecutive order after deleting one or more runs. This allows you to free up run numbers for new runs to be added, which is necessary when the run number approaches 99.

Say you have used all 99 runs and you wish to clear out some space for new runs. Furthermore, you have decided that you no longer need the data from runs 01 to 10. Delete these runs using Data Delete. Now select >Data Renumber to renumber runs. Runs 11 to 99 become runs 01 to 89, leaving 90 to 99 free to take new data.

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The Data Renumber command does not free up memory space, only run numbers. The 999 cycle memory limit remains whether or not all 99 runs have been used.

2.3.8 Data Erase

Select >Data Erase only if you wish to completely wipe all data from the entire RAD7 memory. Data Erase deletes all runs and resets the current run/cycle number to 0101.

Select >Data Erase. The RAD7 will ask for confirmation:

Erase all Tests? No

Press → to find Yes. Press [ENTER] to complete the erasure. Use with caution!

2.4 Setup

The Setup group of commands configures the RAD7 to perform tests according to your needs. The RAD7 remembers all Setup parameters when it is turned off, so access the Setup commands only to change parameters.

Setup includes a 1-step >Setup Protocol command to configure the most frequently used parameters (Cycle time, Recycle number, Mode setting, and Pump setting) according to preset "protocols". These standard preset protocols include (None), Sniff, 1-day, 2-day, Weeks (that is, indefinite), User (which lets you preset your own), Grab, Wat-40 and Wat250 (for use with the RAD H₂O), and Thoron.

The special command >Setup SavUser defines the user protocol according to the current parameter settings.

2.4.1 Setup Protocol

Select >Setup Protocol to automatically load in a group of predefined Setup parameters under one of the standardized protocols, or the User protocol. If you do not wish to select a protocol, you may abort the command by pressing the menu key, and no parameters will be changed.

Table 2.4.1 Preset protocols

	Cycle	Re cycle	Mode	Thoron	Pump
Sniff	00:05	0	Sniff	Off	Auto
1-day	00:30	48	Auto	Off	Auto
2-day	01:00	48	Auto	Off	Auto
Weeks	02:00	0	Auto	Off	Auto
User	xxx	xxx	xxx	xxx	xxx
Grab	00:05	4	Sniff	Off	Grab
Wat-40	00:05	4	Wat-40	Off	Grab
Wat250	00:05	4	Wat250	Off	Grab
Thoron	00:05	0	Sniff	On	Auto

A Recycle number of 00 indicates indefinite test length. The test ends only if the operator intervenes, or if the RAD7 memory fills.

2.4.2 Setup Cycle

How long a test do you want, and how often do you want the RAD7 to take a reading (a cycle)? A typical radon test is made up of many cycles.

Select >Setup Cycle to adjust the Cycle time, or integration time, for a single radon reading. The Cycle time can be adjusted anywhere from two minutes to 24 hours. For continuous monitoring, the Cycle time is usually 30 minutes or longer. For radon sniffing, the Cycle time is usually 5 or 10 minutes. For thoron sniffing, the cycle time may be as little as 3 minutes.

Upon selection of >Setup Cycle, push [ENTER] and you will see something like this:

Cycle: 00:30

First, select the number of hours (00 to 23), and press [ENTER]. Then select the number of minutes (00 to 59) and press [ENTER].

Remember that a run includes many cycles in sequence, and the total duration of the radon test is determined by the Cycle time multiplied by the number of cycles, or Recycle number. To adjust the Recycle number, use the >Setup Recycle command.

2.4.3 Setup Recycle

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How long a test do you want, and how often do you want the RAD7 to take a reading (a cycle)? You determine the length of your test by choosing both the length and number of cycles. If you make a reading every 30 minutes, you will need 48 cycles to get a 24-hour test. In this case, 48 is the Recycle number.

Use >Setup Recycle to set the total number of cycles in a complete run. Multiply Cycle time by Recycle number to determine the total duration of the run.

Select >Setup Recycle. Push [ENTER] and you will see something like this:

Recycle: 48

Use the arrow keys to change the Recycle number, and press [ENTER] to complete the selection. Recycle number may be set from 00 to 99.

If 00 is selected, then the number of cycles is assumed to be infinite. Select 00 if you want the RAD7 to collect data indefinitely, or to go beyond the 99th cycle. After the 99th cycle, the RAD7 will then simply start a new run, and continue collecting data. Data collection will stop only when the operator intervenes, or when the memory completely fills up.

2.4.4 Setup Mode

Select >Setup Mode to change the RAD7 mode of operation. Five modes are available: Sniff, Auto, Wat-40, Wat-250, and Normal.

Sniff mode is used when you want to follow rapid changes of radon concentration. In Sniff mode, the RAD7 achieves rapid response to changing radon levels by focusing on the 3-minute polonium-218 alpha peak, calculating the radon concentration on the basis of this peak alone.

In Normal mode, the RAD7 achieves higher statistical precision by counting both polonium-218 and polonium-214 alpha peaks.

Auto mode automatically switches from Sniff mode to Normal mode after three hours of continuous measurement. This allows time for the equilibrium of the longer-lived radon daughter isotopes. The earliest part of the run will have the

benefit of the Sniff mode's quick response, while the latter parts of the run will benefit from the Normal mode's superior statistical precision.

We recommend that the Auto mode be used for all screening tests and any tests to measure the average concentration over a period of time. With the Auto mode there is no need to throw away the first three hours of data, or to calculate adjustments to correct for disequilibrium. The mean concentration reported in the run summary should accurately reflect the actual mean. Sniff mode should be used where the goal is to follow, and measure, rapid changes in the radon concentration.

Wat-40 and Wat250 make calculations of the radon concentration in 40 ml and 250 ml water samples, respectively. They require the RAD H₂O water accessory kit to aerate the water under the controlled conditions necessary for these calculations.

2.4.5 Setup Thoron

Select >Setup Thoron. Push [ENTER] and you will see:

Thoron: Off

Use the arrow keys to toggle between On and Off, and press [ENTER] to complete the selection.

With Thoron On, the calculated thoron concentration will be printed during continuous data logging, or in subsequent printing of data. Also, if the pump is in Auto mode, it will be directed to pump continuously during the thoron measurement.

Note that the thoron calculation assumes a standard setup for the measurement. A small drying tube, three feet of vinyl tubing, and the inlet filter, should be used. Typically, the small drying tube is held in the hand, and used as a wand. If the laboratory drying unit is used instead of the small drying tube, it creates additional sampling delay, which allows more of the thoron to decay before reaching the RAD7, reducing the sensitivity of the measurement to about half that of the standard setup.

The only difference between Sniff protocol and Thoron protocol is that this setting, 'Setup

Thoron', is Off in Sniff protocol and On in Thoron protocol (See Setup Protocol, page 22).

2.4.6 Setup Pump

Select >Setup Pump to change the Pump setting. Four settings are available: Auto, On, Grab, and Off.

Auto means that the RAD7 switches the pump on and off according to a predetermined pattern that allows for sufficient sampling of air while conserving battery charge and pump wear.

In Auto pump setting, the pump always switches on for 4 minutes at the beginning of a new test cycle to ensure a good initial sample. If the humidity in the sample cell remains above 10%, then the pump stays on to allow the cell to dry out. Then the pump runs for just one minute in every five, until the end of the cycle.

On means the pump is always on, whether the RAD7 is counting (Live) or not (Idle).

Grab initiates a standard grab sampling sequence at the beginning of a run. When you start a new run with the pump set to Grab, the pump will run for exactly 5 minutes. This is followed by a five-minute equilibrium delay, after which the counting period begins. The pump does not run at all during the counting period. As usual, you can determine the length of the count period by multiplying the cycle time by the recycle number. The total time to complete a test is the pump sample time (5 minutes) plus the delay period (5 minutes) plus the count period. Note that the Grab, Wat-40 and Wat250 protocols, under >Setup Protocol, above, all use this pump setting.

Off means the pump is always off.

Use Auto pump setting for routine radon testing. The RAD7 has been factory calibrated with the pump in this setting.

2.4.7 Setup Tone

Select >Setup Tone to choose the audible tone type. Three settings are available: Off, Chime, and Geiger. Off means the beeper remains quiet. Chime means the beeper will sound only at the end of a cycle, and is otherwise silent. Geiger means the beeper will emit a chirp whenever a

particle is detected, much like the familiar Geiger counter. But unlike a Geiger counter, the pitch of the chirp depends on the energy of the alpha particle. A trained ear can distinguish "old" radon from "new" radon by the sound of the chirps. The thoron beep is the highest pitch. In the Geiger setting, anyone will recognize a radon "gusher" by the rapid-fire chirping the RAD7 produces.

2.4.8 Setup Format

Select >Setup Format to change the way data are printed out. Four settings are available: Short, Medium, Long, and Off.

Short causes the RAD7 to print results in an abbreviated form. Three lines of printed text contain a cycle's most important data: the run/cycle number, radon concentration and uncertainty, units and mode, time and date, temperature, relative humidity (internal), and battery voltage.

Medium and Long printouts include seven additional lines of data: total counts, livetime, and counts per minute for five alpha energy windows. These seven lines are the raw data from which the radon concentrations shown in the first line of the printout are calculated.

The Long format, when printing from a test in progress (Live) includes a graph of the alpha energy spectrum. Since spectra cannot be saved to long-term memory, the spectrum will not be printed when retrieving past data.

Off means that no data will print out at the end of each cycle, but the summary and cumulative spectrum will print at the end of the run (if the printer is set up, switched on and has external power).

2.4.9 Setup Units

Select >Setup Units to change the measurement units with which the RAD7 reports radon concentration and temperature. First, enter the radon concentration unit (pCi/L = picoCuries per liter, Bq/m³ = Becquerels per cubic meter, cpm = counts per minute, #cnts = number of raw counts). Next, enter the temperature unit (_F = degrees Fahrenheit, _C = degrees Celsius or Centigrade).

PicoCurie is the favored unit of radon activity in the U.S., while Becquerel is the favored unit in

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Europe and Canada. 1 pCi/L equals 37 Bq/m³. "Counts per minute" is the direct output of the RAD7 while "number of raw counts" is the raw direct output. With livetime, mode, and calibration factor, one can convert from any of these units to any other, but it is usually easier to let the RAD7 do the work.

The choice is retroactive. Change the unit using the >Setup Units command, then print out the same data. Everything will print as before, but in the new units.

2.4.10 Setup Savuser

Select >Setup SavUser to program the special User protocol according to the present Setup parameters. You must answer Yes, and push [ENTER], to confirm that you wish to change the User protocol. The purpose of this command is to give you an opportunity to customize a protocol according to a set of favorite parameters. Thereafter, it's a cinch to return to the same set of parameters; simply select >Setup Protocol User.

The User protocol has many possible applications. One RAD7 owner uses her instrument for 3-day screening tests. To make the setup easy, she programs the User protocol with the parameters for a 72-hour screening test.

To do this, she first sets up all the parameters as she wants them. She enters 2 hour for the Cycle time, 36 for the Recycle number, Auto for the Mode setting, Off for thoron, and Auto for the Pump setting.

Finally, to program the User protocol with these values, she selects >Setup SavUser and answers Yes to the confirmation question. After that, she can easily return to the 72-hour protocol by selecting >Setup Protocol User, any time she wishes.

2.4.11 Setup Clock

Use >Setup Clock to change time zones, go in or out of daylight savings time, or to synchronize the RAD7 clock with another clock. The Real Time Clock (RTC) will maintain time-of-day and calendar date for as long as 10 years, and is accurate to within one minute per month at room temperature.

Select >Setup Clock to set the time and date

of the RAD7 clock. You will see:

Time: 15:05:34

The arrow keys change the numbers. Holding an arrow key down will cause the numbers to change quickly. The cursor (blinking square) will start on the hour. Set the correct number with the arrow keys, then push [ENTER] to confirm. Do the same for the minutes and seconds.

Next you should see:

Date: 13-AUG-91

The cursor then moves on to date, month and year, in turn. Press [ENTER] after each figure is set.

2.4.12 Setup Review

The >Setup Review command allows you to display and print a listing of the current instrument settings, including Date and Time, Protocol, CycleTime, Recycle, Mode, Thoron, Pump, Tone, Format and Units. Thus you can check that the instrument is set up properly, and confirm this, in hard copy, right on the data printout.

2.5 *Special*

Unless you have RADLINK, the remote control software, installed in the RAD7, you will see:

Not installed.

Install? No

Use the arrow keys to toggle between Yes and No. If you confirm Yes, the RAD7 will sit, waiting for a data string at the RS232 port. To recover, push [MENU]. Note that this facility is normally not used for installation, because RADLINK, if purchased with the RAD7, or as part of a calibration and upgrade, will be installed at the factory.

If RADLINK is installed already, then >Special opens a menu of special commands available from the keypad of the RAD7. All the commands, both standard and special, will also be accessible from a remote PC, either directly, or by modem connection.

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The following command set are those available with RADLINK version 0252. Earlier versions will have a subset of these.

2.5.1 Special Ident

Output the RAD7 identification sequence, including firmware version, hardware model number, unit serial number, and last calibration date.

2.5.2 Special SPrOn

Re-direct subsequent output from the infra-red printer to the serial port. In other words, everything that would ordinarily be printed will shoot out the serial port, but nothing will be printed, even when you say "Print". One reason to use this might be to move the data very quickly into a computer without waiting for the (slow) infra-red printer link. You can cancel the re-direction order and restore the use to the infra-red printer with the "Special SPrOff" command. When you turn off the RAD7 and turn it on again, it always restores output to the infra-red printer.

Note that the spectra that would be printed on the infra-red printer are not sent to the serial port by Special SPrOn.

2.5.3 Special SPrOff

Cancel the printer to serial port re-direction, so that output can go to the printer again.

2.5.4 Special SetBaud

Set the serial port bit rate. The following standard speeds are available: 300, 600, 1200, 2400, 4800, 9600, and 19,200 bps. The other communication settings are always 8 bit, no parity, and 1 stop bit. The RAD7 remembers the serial port speed when you power down. Note that at the highest serial speed settings the RAD7 may not be able to keep up with incoming character strings unless the characters are "paced". An "echo-wait" strategy will avoid this problem. Also note that the RAD7 recognizes XOFF/XON flow control protocol when sending data.

2.5.5 Special Status

Gives a snapshot of the RAD7 status page, including run and cycle numbers, countdown timer, last reading, temperature, humidity, and so on. This is basically the same information that you can get with "Test Status", but it gives the data in one shot and does not continue to update every second.

2.5.6 Special Start

Same as "Test Start"(see ¶2.2.2 Test Start), but does not go into a continuously updating status display.

2.5.7 Special Stop

Same as "Test Stop"(see ¶2.2.2 Test Stop).

2.5.8 Special Comspec

Output the current test data, including the counts in all 200 alpha energy bins. These counts can be imported into a spreadsheet program and displayed as a graph of the energy spectrum.

2.5.9 Special ComAll

(Version 0244/940221 or later) - Output complete set of RAD7 test data (up to 1000 readings) to the serial port in comma delimited format.

2.5.10 Special SPrAll

Output complete set of RAD7 test data (up to 1000 readings) to the serial port in standard, readable 24 column printer format, without affecting the infra-red printer.

2.5.11 Special S-Load

Used to load special software into the RAD7 through the serial port.

2.5.12 Special Version

Output the special extension version number.

2.5.13 Special Model

Output the RAD7 hardware version number.

2.5.14 Special Serial

Output the RAD7 unit serial number.

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2.5.15 Special Beep

The RAD7 gives an audible beep tone. Does not make any sound if the tone setting is "Off".

2.5.16 Special Relays

Access the RELAYS set of commands. At the end of every cycle, if the function is enabled, the RAD7 will set or reset two external relays according to the individually set thresholds and the measured radon level. The commands consist of 'relay1', 'relay2', 'enable', and 'disable'. Use the arrow keys to scroll between these commands. Relay1 permits the user to set a level, above which the RAD7 will turn on relay1, and below which it will turn the relay off. Relay2 does the same for the second relay. 'Enable' causes the function to go into effect. Note that the command to the relays is sent after the RAD7 has finished printing data at the end of the cycle. 'Disable' stops the RAD7 from sending any commands to the relays.

2.6 Infrared Printer

The RAD7 uses an infrared link to print to the HP printer supplied. The printer should be placed on the face plate, between the green lines as indicated. The print mechanism uses thermal technology. Only thermal paper will work. Detailed instructions are provided in the HP printer manual.

It should be noted that the printer has a time-out sleep control, which puts the printer out of action after ten minutes with nothing to print. This function is there to save batteries, and is automatically disabled if external power is supplied continuously.

Without batteries, external power will allow the printer to work normally, except that batteries are needed to print, properly, the bar chart of the run summary.

If the printer is placed in position and switched on before switching on the RAD7, it will print out identity information and a review of the setup, before the RAD7 goes to >Test. It is good practice to do this if the measurement data are to

be printed out, because it automatically provides a header for the data printout, with instrument identity and setup:

```
DURRIDGE RAD7
Vers 2.5f 991128
Model 711
Serial 00512
Calib 21-MAY-99
Last used
    FRI 21-MAY-99 17:30

Current settings
    FRI 21-MAY-99 19:09

Protocol: 2-Day
Cycle: 00:60
Recycle: 48
Mode: Auto
Thoron: Off
Pump: Auto
Tone: Geiger
Format: Short
Units: pCi/L EC
```

At the end of every cycle, the printer will print the data of that cycle, according to the format setting.

In short format, it prints:

```
0102 2.69 " 0.73 p Sniff
    FRI 21-MAY-99 19:41
    26.8 EC RH: 7% B:7.06V
```

With the run and cycle number, radon level, two-sigma uncertainty, units and mode in the top row, date and time in the second, and temperature, humidity and battery voltage in the third.

Medium format adds:

```
Total Counts: 357.
Livetime:      28.2 min
A. 5.74"0.98 cpm    45.4%
B. 0.32"0.29 cpm    2.5%
C. 6.13"1.01 cpm    48.5%
D. 0.00"0.14 cpm    0.0%
O: 0.46"0.34 cpm    3.7%
```

Where the lifetime is the actual time spent waiting for an event, slightly less than the elapsed time. The windows, A, B, C, D, and all the rest, O,

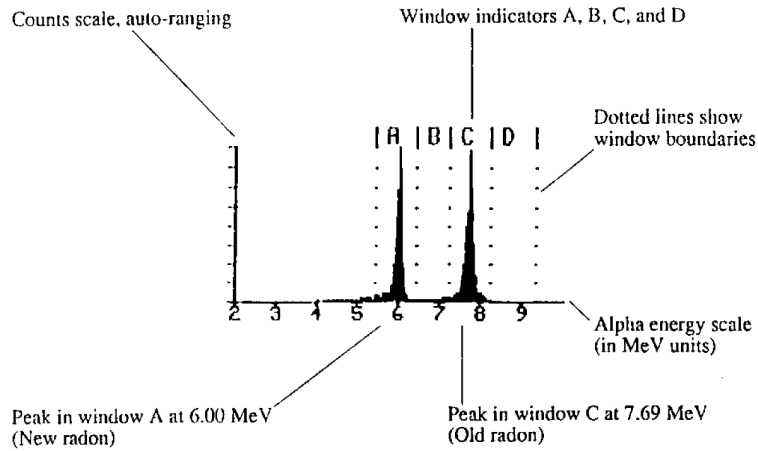
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correspond to the different alpha energies in the spectrum.

Long format adds, to the short and medium formats, a printed spectrum of the alpha energies, see figure 3:

At the end of a run, the printer will print a summary, see figure 2 in chapter 1. It will include an average of the radon concentrations, the high value, low value and standard deviation. These

are followed by a bar chart, showing the variation of radon concentration from cycle to cycle throughout the run. Finally, it prints a cumulative spectrum, see figure 6, showing the distribution of energy of all the alpha decays counted during the run. This spectrum is very informative. It gives a good indication of the condition of the instrument and the quality of the measurement. It is a useful habit to look at the cumulative spectrum from time to time, just to be sure that it has not changed in character.



Alpha

Energy

Spectrum

3. BASICS OF RAD7 TECHNOLOGY: HOW IT WORKS

3.1 Introduction

This chapter deals with a number of fundamental facts concerning radon and thoron, their measurement in general and their measurement, specifically, with the RAD7. It is not necessary to master the underlying physics to become proficient in the use of the instrument, but some understanding of what is happening is helpful.

It is recommended that the user read the whole of the manual, including this chapter, on first acquiring the instrument, and then again after gaining some experience in the field.

3.2 Radon Decay Chain

When the earth was formed, billions of years ago, there were probably many radioactive elements included in the mix of material that became the earth. Three, of interest, have survived to this day, namely uranium-235, uranium-238, and thorium-232. Each has a half life measured in billions of years, and each stands at the top of a natural radioactive decay chain.

A radioactive element is unstable. At some indeterminate moment, it will change to another element, emitting some form of radiation in the process. While it is impossible to predict exactly when the transformation of an individual atom will take place, we have a very good measure of the probability of decay, within a given time slot. If we started with a very large number of atoms of a radioactive element, we know quite precisely how long it would take before half those atoms had decayed (though we could not identify the decaying atoms individually, beforehand). This time interval is called the half-life of that particular element.

A natural radioactive transformation is accompanied by the emission of one or more of alpha, beta or gamma radiation. An alpha particle is the nucleus of a helium atom. It has two protons and two neutrons. Thus an 'alpha decay' will reduce the atomic number by two and reduce the atomic weight by four. A beta particle is an electron, with its negative charge. Thus a beta

decay will increase the atomic number by one and leave the atomic weight unchanged. A gamma ray is just a packet of energy, so a gamma decay by itself would leave both the atomic number and atomic weight unchanged.

A decay chain is a series of distinct transformations. A uranium-235 nucleus goes through a series of 11 transformations to become stable lead-207. A thorium-232 nucleus goes through 10 transformations to become stable lead-208. And a uranium-238 nucleus goes through 14 transformations to become stable lead-206.

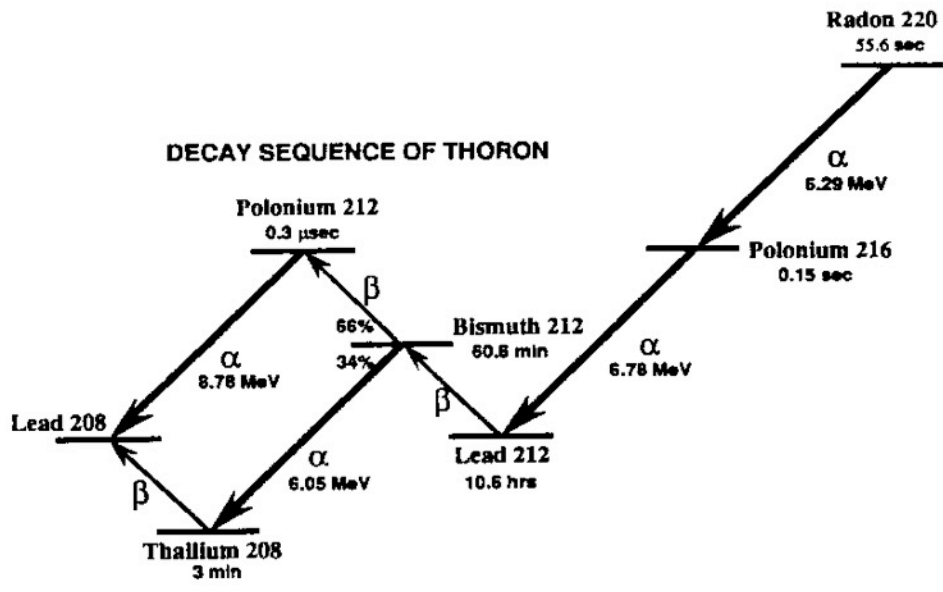
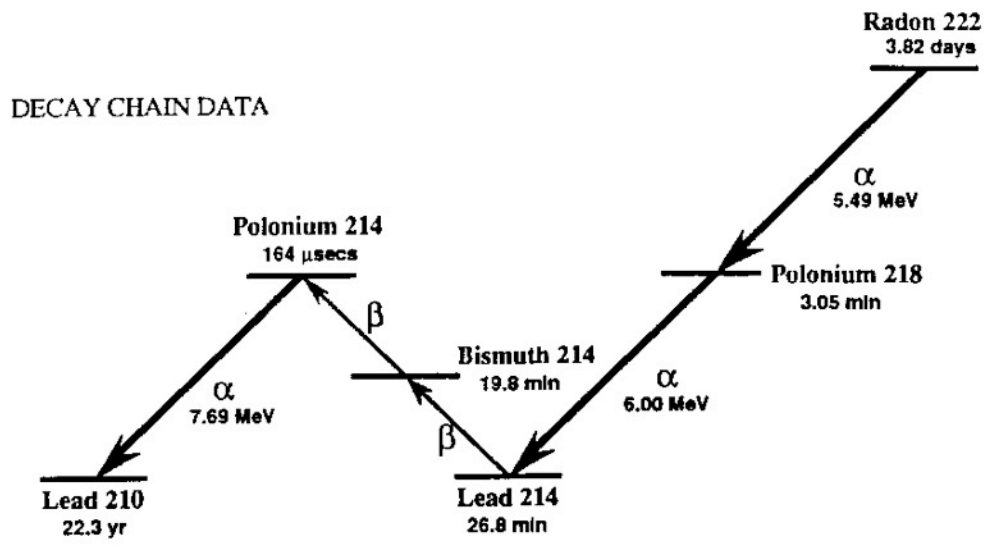
All three of these natural decay chains include isotopes of radon. Radon-219, or "actinon", is a link in the uranium-235 chain. You will probably never encounter actinon in indoor air, due to its scarcity and short half-life. Radon-220, or "thoron", is part of the thorium-232 decay chain. You will sometimes encounter thoron in indoor air, particularly near radon entry points, and, more often, in soil gas. Radon-222, or familiar "radon", is part of the uranium-238 decay chain. You will almost always be able to detect radon-222 in indoor air, outdoor air, and soil gas.

The radon isotope is the first element, in each of the decay chains, that is not a metal. It is, in fact, an inert, or "noble", gas. So it can escape any chemical compound its parent (radium) was in, and diffuse into the air.

To focus on these inert gases, the thoron and radon decay chains, shown below, are those parts of the thorium-232 and uranium-238 decay chains that include just these radioactive gases and their short-lived progeny.

It may be noted that only alpha decays change the atomic weight, and then only in steps of four. Thus the atomic weights of all the members of the radon-220, thoron, decay chain are divisible by four, while none of the radon-222 are.

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Radon and Thoron decay chains

3.2.1 Radon-222 (Radon)

Every nucleus of radon-222 eventually decays through the sequence polonium-218, lead-214, bismuth-214, polonium-214, and lead-210. With each transformation along this path the nucleus emits characteristic radiations: alpha particles, beta particles, or gamma rays, or combinations of these. The RAD7 was designed to detect alpha particles only, so we will emphasize alpha radiation.

Radon-222 is an inert gaseous alpha-emitter that does not stick to or react with any materials. It has a half-life of 3.82 days. A particular radon nucleus may decay at any time, but it is most likely to decay between now and 8 days (two half-lives) from now. When the radon nucleus decays, it releases an alpha particle with 5.49 MeV of energy, and the nucleus transforms to polonium-218. The polonium nucleus can never go back to radon again. Polonium atoms are metals and tend to stick to surfaces they come in contact with, e.g., a dust particle in the air, or a wall, or the inside of your lung!

Polonium-218 nuclei have a short half-life, only 3.05 minutes, which means that most of them will decay within 6 minutes of their formation. The average polonium-218 nucleus lives for only 4.40 minutes before it decays (1.443 times the half-life gives the mean life). Like radon, polonium-218 emits an alpha particle when it decays, but with an energy of 6.00 MeV rather than radon's 5.49 MeV.

When polonium-218 decays, it transforms to lead-214, also a radioactive solid. But lead-214 has a half-life of 26.8 minutes, and it emits beta radiation rather than alpha radiation. When lead-214 decays, it becomes bismuth-214, also a radioactive solid and a beta emitter. Bismuth-214 has a half-life of 19.8 minutes, and transforms to polonium-214 when it decays.

Polonium-214 is a bit different. It has a half-life of only 164 microseconds (0.000164 seconds) and it emits a 7.69 MeV alpha particle when it decays. When polonium-214 decays, it becomes lead-210, which has a half-life of 22.3 years. This means that an average lead-210 nucleus takes 1.443 times 22.3 years, or 32.2 years, to decay. Because of its long half-life, we usually ignore lead-210 as a factor in radon measurement, though it

adversely affects the background of some instruments (not the RAD7).

Lead-210 eventually undergoes beta decay to Bismuth-210 which quickly (5 days half-life) undergoes a further beta decay to Polonium-210. Polonium-210 has a half-life of 138 days and decays with a 5.30 MeV alpha particle to Lead-206, which is stable. The 5.30 MeV alpha particle from Polonium-210 creates unwanted background in most radon monitors, but not in the RAD7.

3.2.2 Radon-220 (Thoron)

Similarly to radon-222, every radon-220 (thoron) nucleus eventually decays through a sequence of 5 transformations to Lead-208. The main distinction is the very different half-lives involved.

Thoron has a half-life of only 55.6 seconds. It emits a 6.29 MeV alpha particle and transforms to polonium-216, which in turn has only a 0.15 second half-life before emitting a 6.78 MeV alpha particle and transforming to Lead-212.

Lead-212 hangs around for a long time, with a half-life of 10.6 hours. It transforms by beta decay to bismuth-212, which, in turn, has a half-life of 60.6 min.

Bismuth-212 has a 2:1 split, with two thirds transforming by beta decay to polonium-212 and one third transforming by 6.05 MeV alpha decay to thallium-208. The polonium-212 decays immediately to lead-208, emitting an 8.78 MeV alpha particle in the process, while the thallium-208, with a half-life of 3 min, undergoes a beta decay to the same destination, lead-208.

3.3 Continuous Monitors

There are several types of continuous radon monitors on the market. Nearly all of these are designed to detect alpha radiation, but not beta or gamma radiation. Why? Because it is very difficult to build a portable detector of beta or gamma radiation that has both low background and high sensitivity.

Three types of alpha particle detectors are presently used in electronic radon monitors:

1. Scintillation cells or "Lucas cells"
2. Ion chambers
3. Solid state alpha detectors.

Each of these types has advantages and disadvantages relative to the others. All of these types can be used for low background alpha particle counting.

The DURRIDGE RAD7 uses a solid state alpha detector. A solid state detector is a semiconductor material (usually silicon) that converts alpha radiation directly to an electrical signal. One important advantage of solid state devices is ruggedness. Another advantage is the ability to electronically determine the energy of each alpha particle. This makes it possible to tell exactly which isotope (polonium-218, polonium-214, etc.) produced the radiation, so that you can immediately distinguish old radon from new radon, radon from thoron, and signal from noise. This technique, known as alpha spectrometry, is a tremendous advantage in sniffing, or grab-sampling, applications. Very few instruments other than the RAD7 are able to do this.

A distinction should be made between true, real-time continuous monitors, and other instruments and devices. With a continuous monitor, you are able to observe the variation of radon level during the period of the measurement. This can sometimes show big swings in radon concentration and may allow you to infer the presence of processes influencing the level. For good data, it is important that there be sufficient counts to provide statistically precise readings. Devices which give just a single, average reading, or whose precision is inadequate except after a long measurement time, are not, in this sense, continuous monitors.

Another important parameter is background. This is the reading given by the instrument when there is no radon in the air sample. For low level continuous monitoring, it is necessary that the background be extremely low and stable. Because of the high quality alpha detector, and unique, real-time spectral analysis, the RAD7 background is vanishingly small, and is immune to the buildup of lead-210, which plagues other instruments.

3.4 *Sniffers*

Sniffing means taking quick, spot readings. Thus you can get a rough idea of the radon level, without waiting for a full, 48-hour, EPA protocol test. The technique is often used to locate radon entry points in a building.

Any fast-response, continuous radon monitor, with a pump, can be used for sniffing. However, there are some factors to consider: One is the rate of recovery after exposure to high radon levels. When the sniffer finds a radon gusher, the whole radon decay chain builds up inside the instrument, and the various daughters become well populated. If the sniffer now moves to a low level region, it will take many hours for the lead/bismuth/polonium-214 daughters to decay away. In the RAD7 this doesn't matter, because, in Sniff mode, it looks only at the polonium-218 decays, and ignores the polonium-214 decays left over from previous sniffs. The polonium-218 has a three-minute half life, so the RAD7, sniffing for radon, has a 15 minute response time to both sudden increases and sudden decreases in level.

Unique to the RAD7 is the ability to sniff for thoron. Polonium-216 has a 150 ms half life, so the instrument response is virtually instantaneous. The only delay is the time required to put the air sample into the measurement chamber, which is about 45 seconds.

Another factor, when sniffing, is the vulnerability (of other instruments) to lead-210 buildup. Only with the RAD7 can you continue to sample high levels, without having to worry about increasing the background.

3.5 *Working Level*

Radon concentrations are determined by measuring the radioactivity of the radon or by measuring the radioactivity of the radon decay products. Instruments that measure radon decay products in the air are called "working level" monitors. Working level monitors sample air through a fine filter and then analyze the filter for radioactivity. The radon progeny are metal and they stick to the filter and are counted by a working level instrument. Radon-222, an inert gas, passes through the filter, so it is not counted

in such an instrument. Therefore, a working level instrument measures the radon progeny concentration (polonium-218, etc.), in the air, but not the radon gas concentration.

The RAD7, on the other hand, measures radon gas concentration. Radon daughters do not have any effect on the measurement. The RAD7 pulls samples of air through a fine inlet filter, which excludes the progeny, into a chamber for analysis. The radon in the RAD7 chamber decays, producing detectable alpha emitting progeny, particularly the polonium isotopes. Though the RAD7 detects progeny radiation internally, the only measurement it makes is of radon gas concentration.

In short, the RAD7 does not measure radon daughter concentrations (working levels), only radon gas concentrations.

3.6 *RAD7 Solid-State Detector*

The RAD7 's internal sample cell is a 0.7 liter hemisphere, coated on the inside with an electrical conductor. A solid-state, Ion-implanted, Planar, Silicon alpha detector is at the center of the hemisphere. The high voltage power circuit charges the inside conductor to a potential of 2000 to 2500 volts, relative to the detector, creating an electric field throughout the volume of the cell. The electric field propels positively charged particles onto the detector.

A radon-222 nucleus that decays within the cell leaves its transformed nucleus, polonium-218, as a positively charged ion. The electric field within the cell drives this positively charged ion to the detector, to which it sticks. When the short-lived polonium-218 nucleus decays upon the detector's active surface, its alpha particle has a 50% probability of entering the detector and producing an electrical signal proportional in strength to the energy of the alpha particle. Subsequent decays of the same nucleus produce beta particles, which are not detected, or alpha particles of different energy. Different isotopes have different alpha energies, and produce different strength signals in the detector.

The RAD7 amplifies, filters, and sorts the signals according to their strength. In Sniff mode, the

RAD7 uses only the polonium-218 signal to determine radon concentration, and the polonium-216 signal to determine thoron concentration, ignoring the subsequent and longer-lived radon daughters. In this way, the RAD7 achieves fast response to changes in radon concentration, and fast recovery from high concentrations.

3.7 *RAD7 Spectrum*

The RAD7 spectrum, see figure 6, is a scale of alpha energies from 0 to 10 MeV. Of particular interest are the radon and thoron daughters that produce alpha particles in the range of 6 to 9 MeV.

When the radon and thoron daughters, deposited on the surface of the detector, decay, they emit alpha particles of characteristic energy directly into the solid state detector. The detector produces an electrical signal. Electronic circuits amplify and condition the signal, then convert it to digital form. The RAD7 's microprocessor picks up the signal and stores it in a special place in its memory according to the energy of the particle. The accumulations of many signals results in a spectrum.

The RAD7 divides the spectrum's 0 to 10 MeV energy scale into a series of 200 individual counters, each representing a 0.05 MeV channel. Whenever the RAD7 detects an alpha particle, it increments one of these 200 counters by one. Every so often, the RAD7 manipulates, condenses, prints out and stores data to long-term memory. Then it resets all 200 counters to zero, and begins the process anew.

The idealized spectrum of a 6.00 MeV alpha emitter looks like a single needle-thin spike at exactly 6.00 MeV.

Although the RAD7 approaches this ideal, the actual spectrum shows a broadened peak centered at near 6.00 MeV with a characteristic "tail" that stretches into lower energy channels. Electronic noise in the detector and amplifier causes the peaks to widen, while alpha particles that enter the detector at glancing angles cause the tail. Higher than normal operating temperatures tend

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to increase electronic noise, and so increase the width of the peaks.

A combination of different alpha emitters appears on the spectrum as a series of different peaks. For example, a combination of equal amounts of Po218 and Po214 (as would occur in the case of radon daughter equilibrium) appears as twin alpha peaks. One peak (Po218) is centered at 6.00 MeV, while the other (Po214) is centered at 7.69 MeV.

Example spectrum b, section 3.13, is the characteristic signature of radon at equilibrium with its alpha emitting daughters. We would expect to see a spectrum like this after several hours at a constant radon level. The 5.49 MeV alpha particle directly emitted by radon-222 does not appear on the RAD7 spectrum, because it was created in the air, not on the surface of the detector. The radon-222 atom is inert and electrically neutral, and cannot be attracted to the solid state detector. Only after it decays to polonium-218 does the atom become positively charged and is thus driven to the detector surface.

The RAD7 spectrum shows radon daughters, but not radon itself. Do not confuse the RAD7's spectrum with that of a working level instrument. The alpha peaks may appear the same, but the RAD7 is really measuring radon gas, not working level.

3.8 Windows

The RAD7 groups the spectrum's 200 channels into 8 separate "windows" or energy ranges. Window A, for example, covers the energy range of 5.40 to 6.40 MeV. So window A includes the 6.00 MeV alpha particle from polonium-218. The first step toward converting raw spectral data to radon measurement is to add up all the counts in each window and divide by the detector "liveness" or duration of active data collection. The RAD7 microprocessor does this task and stores the results to memory in this form. You can recall and print window data from past measurements. The RAD7 adds windows E, F, G, and H together to form window O (for "other") before storing the data to memory. Spectrum printouts clearly mark windows A, B, C, and D with dotted lines.

Each window's function:

- A. Radon Sniffer Mode counts. The total counts of alpha particles from the 3-minute, 6.00 MeV, Po218 decay.
- B. Thoron 1 Window. The total counts in the region of the 0.15 second, 6.78 MeV decay of Po216. This window lies between windows A and C of the radon groups and may have some counts from spill-over from adjacent windows.
- C. Radon Po214 counts. The total counts of the 7.69 MeV alpha particles from the decay of the great-great granddaughter of radon, which has an effective half-life of nearly an hour.
- D. Thoron 2 Window. The total counts in the region of the effective 8.78 MeV decay of Po212, which has a half-life of about 10 hours.
- E. High Energy Window. A diagnostics window that normally has close to zero counts. If the counts in this window are a large fraction of the counts in A or B or C or D, the RAD7 is probably not working properly.
- F. Low Noise counts. A diagnostics window that gives the total counts in the first 10 channels. The count rate in Window F is a measure of the noise in the system. The counts may be high if the RAD7 is operated at very high temperatures.
- G. Medium Noise counts. A diagnostics window that gives the total count in the region around channels 30 to 40. Window G normally has few counts, even when Window F shows a high count rate.
- H. High Noise or Po210 Window. The total counts in the region of the 5.31 MeV alpha particle due to Po210 (polonium-210), the granddaughter of Pb210 (lead-210). Since lead-210 (22 year half-life) results from the decay of the radon progeny we measure, this isotope will build up on the detector's sensitive surface through sustained measurement of very high radon concentrations, or many years of normal use. This window is not used in calculating radon levels, so the RAD7 will function well even with this isotope present, and the background will not be affected..

O. Composite window for "Others". The RAD7 groups windows E, F, G, and H together to form the composite window O. Window O catches all the counts that did not go into the major windows A, B, C, and D. If window O consistently receives more than 30% of the total counts, you should inspect the spectrum printout for signs of trouble.

3.9 *Isotope Equilibrium*

Take a RAD7 that is completely clean, with no radon or daughters inside. What does the detector see? Close to nothing. Less than one alpha count per hour, due to unavoidable contamination of the materials of the instrument's construction. That is the instrument's intrinsic background. It is ignored by most people as of no consequence. Intrinsic background may add 0.01 pCi/L to a typical measurement, far below the radon concentration of outdoor air (usually 0.10 to 1.00 pCi/L).

Now introduce some radon into the RAD7. What do you see? At first, maybe nothing. But within a few minutes, you begin to get counts in the A window. The RAD7 chirps merrily with each count. That's polonium-218, a result of the decay of radon-222 within the RAD7 sample chamber.

For the first 5 minutes or so, the count rate increases, then begins to approach a steady level. After about 10 minutes, we say that the polonium-218 daughter has reached close to equilibrium with the radon-222 parent.

Equilibrium is when the activity of the daughter stabilizes, neither increasing or decreasing. At this point, nearly all of the counts land in window A, and you see a single peak in the spectrum printout.

But the total count rate is still increasing, more slowly now. You begin to see counts appear in window C. Just a few, but more and more of them over the course of the next hour or two. After 3 hours or so, we reach full equilibrium, when the activities of all the daughters stabilize. Now the spectrum shows the characteristic twin peaks: polonium-218 in window A and polonium-214 in window C. The peaks are of almost identical size.

Now flush the RAD7 with fresh, radon-free air. The count rate in window A immediately begins to drop, just as fast as it rose when you first put the radon in. Without radon inside the RAD7, there is no source to replace the polonium-218 that decays. So the polonium-218 disappears with its characteristic half-life of 3.05 minutes.

After 3.05 minutes, the count rate in window A is half of what it was before. After 6.10 minutes, the count rate is half of that, or one-quarter of what it was before. You get the picture. After 10 minutes, there are hardly any counts at all in window A. Not so for window C, however. The spectrum still shows a single strong peak in window C.

The peak in Window C takes hours to disappear. After half an hour, the count rate in window C has not even halved. Polonium-214 may have a very short half-life, but its parents, lead-214 and bismuth-214, certainly don't. One has a half-life of 26.8 minutes, and the other has a half-life of 19.8 minutes. And they are sequential, which makes matters worse.

After you completely remove the radon, it may be a good 3 or more hours before the counts really die down in window C. We call window C the "old radon" window, since it represents counts from radon that was present in the RAD7 an hour or more before.

The effects of time in windows B and D, is similar, but much more pronounced. There is no delay in the RAD7 to polonium-216, so the count rate in window B is always in equilibrium with the thoron gas in the measurement chamber. In contrast, there is a 10-hour half life in the decay chain down to polonium-212, so it will take days for window D to reach equilibrium. Window D is, therefore, not counted when sniffing for thoron.

Note however, that for every 66 counts in window D, there will be 34 counts in window A. This is because of the two-way split from Bismuth-212. So, in calculating radon concentration, the RAD7 corrects the counts in window A for any thoron daughters that show in window D.

3.10 Modes: Sniff and Auto

"Old" radon daughters can be a real pain in the neck if you can't tell them apart from "new" radon. Most radon monitors don't help you at all here, but the RAD7 does. Waiting around for equilibrium is also a trial if it means sitting around for more than 2 hours. It is possible to calculate your way out of that problem, but the "old" radon always comes back to bite you. With the RAD7, the solution is simple and painless. Put the RAD7 in Sniff mode.

Sniff mode means that the RAD7 calculates radon concentration from the data in window A only. It ignores window C. Now the instrument responds to changes almost instantaneously. Hit a "hot spot?" No problem. In Sniff mode, you can purge the sample chamber and, in 10 minutes, you're ready to measure low levels again with reasonable accuracy. You can move from point to point in minutes, looking for radon entry points in foundation cracks or test holes.

For continuous monitoring in one location over many hours, normal mode is the way to go. Normal mode means that the RAD7 uses both radon peaks, A and C, to calculate concentration. With double the count rate, you increase the precision of the measurement. In indoor environments, the radon concentrations rarely fluctuate quickly enough to justify using Sniff mode for continuous monitoring.

The best of both worlds is provided by Auto mode. Here, the RAD7 starts a test run in Sniff mode, and then, after three hours, switches automatically to Normal mode. In this way, the first few cycles give readings without any bias from either "old" radon daughters left on the detector, or the slow build-up to reach equilibrium in window C, while the rest of the readings benefit from the higher precision given by twice the number of counts in each cycle.

For real-time monitoring, you are always better off to leave the mode in AUTO. The RAD7 is up to speed quickly, and is not influenced by old measurements. The final average of the run is therefore more accurate and more reliable.

3.11 Background

"Background" in a radon detector refers to spurious counts that occur even in the absence of radon. Background can arise from the properties of the instrument or its components, other forms of radiation in the instrument's environment, or contamination of the instrument.

The RAD7's design makes it much less susceptible to background than other radon monitors, but one should still be aware of background in the RAD7 to avoid mistakes. The following list gives possible sources of background in the RAD7:

3.11.1 Short-lived Radon and Thoron Daughters.

These are by far the most important components to background in the RAD7. Radon and thoron daughters that normally build up on the RAD7's solid state alpha detector continue to produce alpha counts for some time after the radon and thoron gases have been removed from the instrument. These lingering daughters can greatly confuse the result when you try to measure a low radon sample immediately after a high radon sample.

Many radon detectors require that you wait for the daughters to decay away (about three hours) before counting another sample. With the RAD7, however, you can go from high to low concentrations in a matter of minutes by counting in SNIFF mode, since the RAD7 distinguishes the different alpha-emitting daughters by their alpha energy. The resulting measurement responds with a 3.05 minute half-life. Thus, 10 minutes after the radon has been removed from the instrument, the background will have been reduced by more than 90% and you can count a new sample.

Thoron daughters are worse behaved than radon daughters. One thoron daughter, Lead-212, has a half-life of 10.6 hours, so that, with other radon monitors, if you build up huge amounts of this daughter, you may have to wait one to two days before using your radon instrument again. The RAD7's ability to distinguish daughters by their alpha energy almost always makes it possible to continue working.

3.11.2 Adsorbed Radon Gas.

Radon atoms can adsorb on or absorb into internal surfaces of the RAD7, on the inside of tubing or on desiccant granules. This radon can stay behind after you purge the instrument, then desorb (or out-gas) from these surfaces and enter the sample cell volume. This effect is ordinarily negligible since only a small fraction of the radon ever becomes adsorbed. But at very high radon concentrations (over 1000 pCi/L), even a small fraction can be significant, and you can expect to see some lingering radon after purging the instrument.

The best solution is to purge for 10 minutes every few hours until the count rate goes down. Even in the worst possible case, the radon must decay with a 3.82 day half-life, so you will eventually be able to use the instrument again.

3.11.3 Intrinsic Background.

Due to very low concentrations of alpha emitting contaminants in the materials of the RAD7's construction, you can expect to get as much as one count every two hours (0.009 cpm) without any radon present. This count rate, corresponding to about 0.02 pCi/L, is low enough to neglect when doing routine indoor radon work. But for very low-leveled outdoor radon levels, or special clean room applications, this background may be significant. With painstaking technique, and long-term monitoring, it can be measured. Very low level readings can then be corrected for background, bringing the detection threshold of the instrument down below 0.02 pCi/L.

3.11.4 Long-lived Radon Daughters.

After many years of use at elevated radon levels, your RAD7's detector will accumulate lead-210, an isotope with a 22-year half-life. Though lead-210 is itself a beta emitter, one of its daughters is polonium-210, which produces a 5.3 MeV alpha particle. The RAD7 is able to distinguish this isotope by its energy, and exclude it from all calculations. We do not expect lead-210 buildup to contribute significantly to background in the RAD7, even after years of ordinary use.

3.11.5 Contamination by Radon, or Thoron, Producing Solids.

If radon- or thoron-producing solids, such as radium-226 or thorium-228, become trapped in inlet hoses or filters, they may emanate radon or thoron gas that will be carried through the filters and into the instrument. Certain dusty soils may contain enough of these isotopes to make this scenario possible. If you suspect this kind of contamination, please call DURRIDGE. We would like to discuss your experience with you and help you solve your problem.

3.11.6 Other Alpha Emitters.

As long as you filter the incoming air stream, there is little or no possibility for contamination of the instrument with other alpha emitters. Virtually all solids will be stopped by the inlet filters. The only naturally-occurring alpha-emitting gas other than radon and thoron is radon-219, or "actinon." Actinon, which has a very short half-life (less than four seconds), results from the decay of naturally-occurring uranium-235. But since uranium-235 is so much less abundant than uranium-238 (the ancestor of radon-222), we do not expect to ever see actinon in significant quantities apart from even more significant quantities of radon.

3.11.7 Beta and Gamma Emitters.

The RAD7's solid state alpha particle detector is almost completely insensitive to beta or gamma radiation, so there will be no interference from beta-emitting gases or from gamma radiation fields. The most likely effect of high levels of beta or gamma radiation will probably be an increase in detector leakage current and increased alpha peak width. Typical environmental levels of beta and gamma emitters have absolutely no effect on the RAD7.

3.12 Precision & Accuracy

"Precision" means exactness of measurement with regard to reliability, consistency and repeatability. "Accuracy" means exactness of measurement with regard to conformity to a measurement standard. An accurate instrument is necessarily

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precise, but a precise instrument can be inaccurate (due to mis-calibration, for example).

As long as the operator follows consistent procedures, counting statistics will dominate the RAD7's precision. Environmental factors have proven to be much less significant over normal ranges of operation. Aside from precision, the most important factor in RAD7 accuracy is calibration.

DURRIDGE calibrates all instruments to a "master" instrument with a calibration precision of about " 2%. The master instrument has been calibrated by way of inter-comparison with radon chambers run by the U.S. EPA and the U.S. Department of Energy. We estimate the accuracy of the master instrument to be within " 4%, based on inter-comparison results. We estimate the overall calibration accuracy of your RAD7 to be

about " 5%. We look forward to new developments in calibration standardization and traceability, which we expect to help improve calibration accuracy.

The table below summarizes the precision of the RAD7 according to the contribution of counting statistics. Counting statistics depend on sensitivity (calibration factor) and background count rate. The RAD7's intrinsic, or "fixed," background count rate is so low as to be a negligible contributor to precision, for the range of radon concentrations covered by the table. Environmental and other factors may affect precision by as much as " 2%. The uncertainty values reported by the RAD7 are estimates of precision based on counting statistics alone, and are two-sigma values, as are the values in the following table.

Table: 3.12 Typical RAD7 precision based on counting statistics only.

Normal Mode with sensitivity 0.500 cpm/pCi/L. Table values are two-sigma uncertainty (or 95% confidence interval) in units of pCi/L (percent).

	1 pCi/L	4 pCi/L	20 pCi/L	100 pCi/L
1 hr	0.37 (37%)	0.73 (32%)	1.64 (8.2%)	3.65 (3.7%)
2 hr	0.26 (26%)	0.52 (13%)	1.15 (5.8%)	2.58 (2.6%)
6 hr	0.15 (15%)	0.30 (7.4%)	0.67 (3.4%)	1.49 (1.5%)
24 hr	0.07 (7.4%)	0.15 (3.8%)	0.33 (1.7%)	0.74 (0.7%)
48 hr	0.05 (5.3%)	0.10 (2.6%)	0.23 (1.2%)	0.53 (0.5%)
72 hr	0.04 (4.3%)	0.09 (2.1%)	0.19 (1.0%)	0.43 (0.4%)

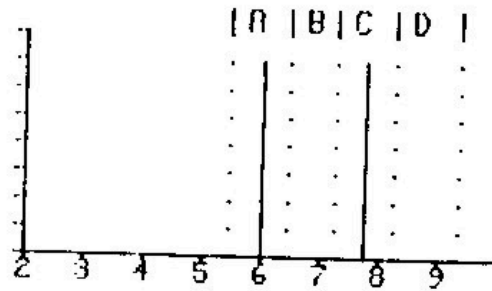
3.13 Spectrum Examples

3.13.1 Operational Radon Spectra

I. Idealized radon in equilibrium

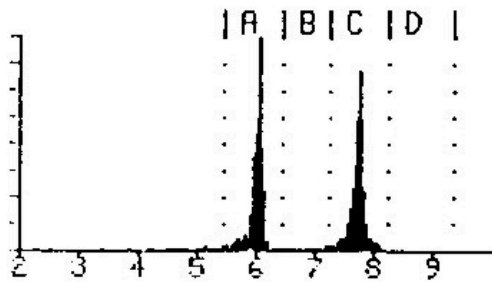
This is what you would see if both the detector and electronics reached theoretical perfection. At full equilibrium, both peaks are at the same height.

A	6.00 MeV	Po218
C	7.69 MeV	Po214



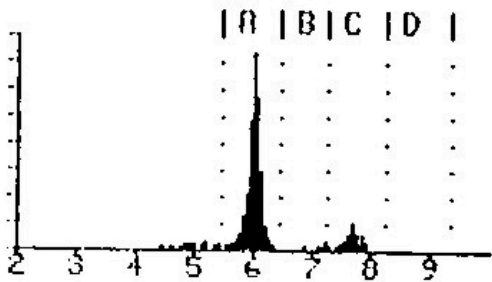
II. Radon in full equilibrium

After more than three hours at a constant radon level. The count rate in window C is about the same as in window A.



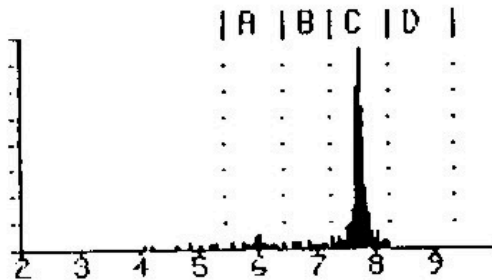
III. New radon

The RAD7 spectrum after less than one hour of exposure to radon. The peak in window C is just beginning to grow in, but its count rate is still much less than in window A.

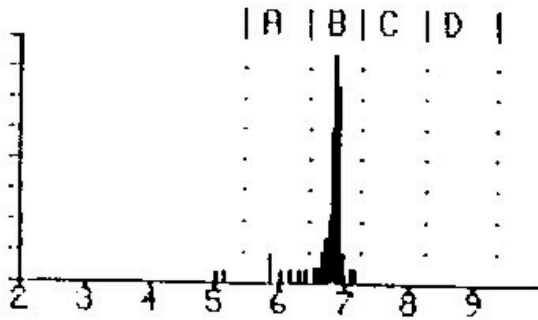


IV. Old radon

The RAD7 spectrum after purging the instrument with radon-free air for more than 10 minutes, following exposure to radon.



3.13.2 Thoron Spectra



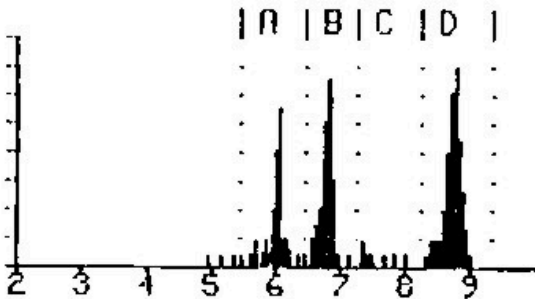
V. New thoron

The RAD7 spectrum while continuously sampling thoron laden air

B 6.78 MeV Po216

VI. Thoron in equilibrium

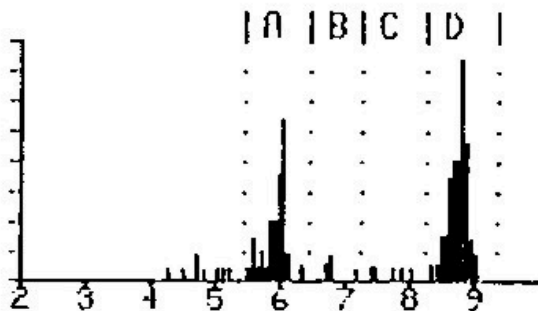
The spectrum after continuously sampling thoron laden air for more than 12 hours. The count rate in window A should be about half the count rate in window D



A 6.05 MeV Bi212
 B 6.78 MeV Po216
 D 8.78 MeV Po212

VII. Old thoron

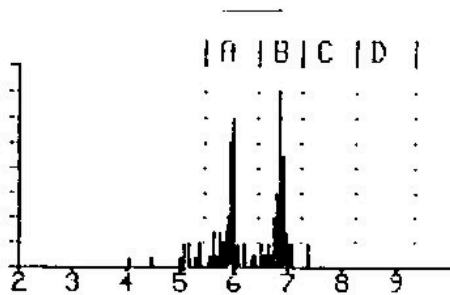
The spectrum after discontinuing a lengthy sampling of thoron laden air. The thoron peak, B, disappears immediately. The remaining two peaks decay together with a 10.6 hour half-life. The count rate in window A should be about half the count rate in window D.



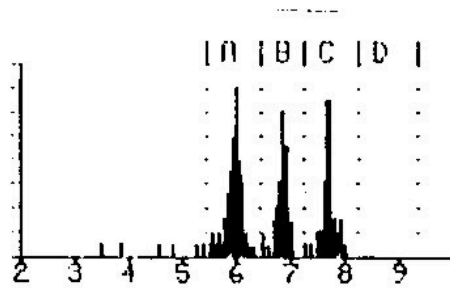
3.13.3 Combination Spectra

Radon and thoron spectra can add together to form combination spectra. Peaks in window B and/or D come from thoron, while a peak in window C comes from radon. The peak in window A is usually entirely from radon, but if there is a peak in window D, then there will be a contribution of about half the D count rate to the peak in window A.

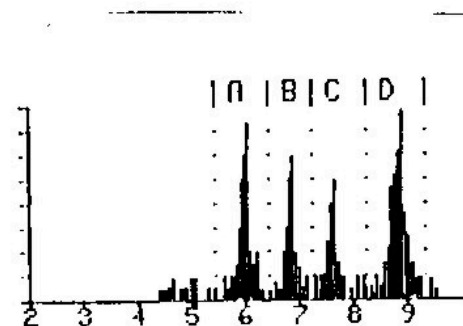
The RAD7 takes this into account, and always adjusts the window A count rate to correct for the Bi212 count, before calculating the radon concentration. The spectra below have comparable amounts of radon and thoron, but you will usually see one of the two much stronger than the other.



VIII. New radon with new thoron.



I. Equilibrium radon with new thoron

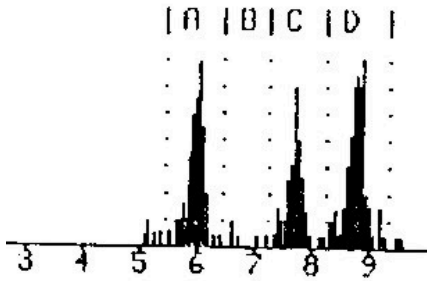


I. Equilibrium radon with equilibrium thoron.

The count rate in window A is roughly the rate of window C plus half the rate of window D.

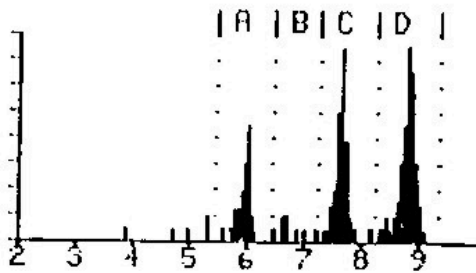
A	6.00 MeV	Po218
	+6.05 MeV	Bi212
B	6.78 MeV	Po216
C	7.69 MeV	Po214
D	8.78 MeV	Po212

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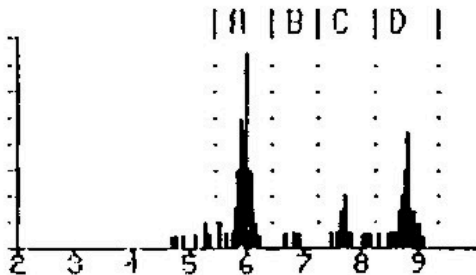
b. Equilibrium radon with old thoron

The count rate of A is roughly the rate of window C plus half the rate of window D.



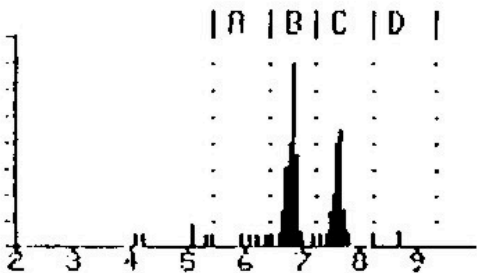
c. Old radon with old thoron.

Looks like spectrum k; but the count rate in window A is no more than about half the count rate of window D.



d. New radon with old thoron.

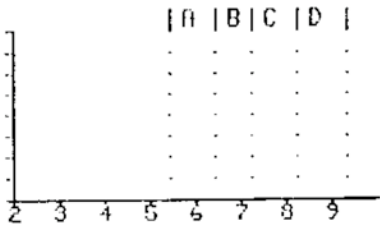
Looks like spectrum g; old thoron, but the count rate of window A is significantly more than half the count rate of window D.



e. New thoron with old radon.

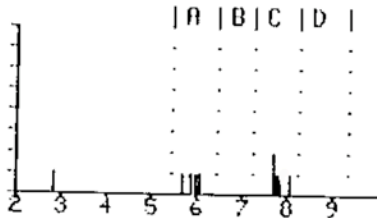
3.13.4 Pathological Spectra

If any of the following occur, and an external cause is not identified, the user should contact DURRIDGE immediately. Email to service@durridge.com would be a good way to initiate the contact.



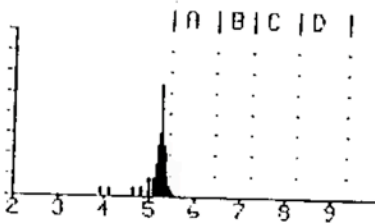
No counts.

Try a longer counting time. If there is not a single count in an hour, that is clear indication of instrument malfunction.



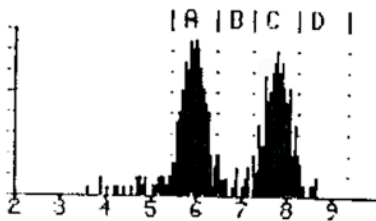
f. Few counts.

Normal for low radon levels and short counting times. Abnormally low counts could be caused by disruption of the air flow, or by malfunction in the high voltage circuit.



g. Lead-210/polonium-210.

A persistent peak at 5.3 MeV will develop from many years of regular use, or from sustained exposure to very high radon levels. It results from the buildup of lead-210 on the detector surface. Lead-210 has a 22 year half-life. It is not a problem for the RAD7 because the peak is outside window A, and thus does not contribute to the background.

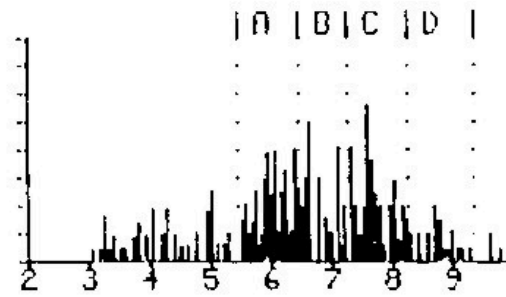


h. Wide alpha peaks.

Typically caused by electronic noise in the system. May be associated with vibration, with high operating temperature, or with degradation of the surface barrier detectors used in older model RAD7's, built by NITON prior to 1996.

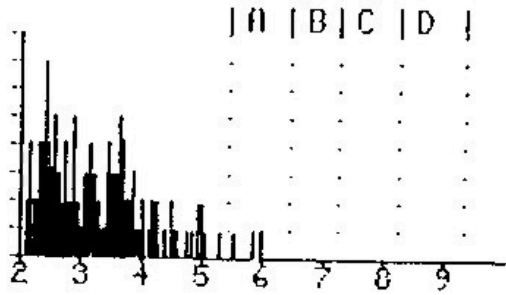
i. Smearred spectrum.

Alpha peaks cannot be discerned by the eye.
Severe electronic noise.



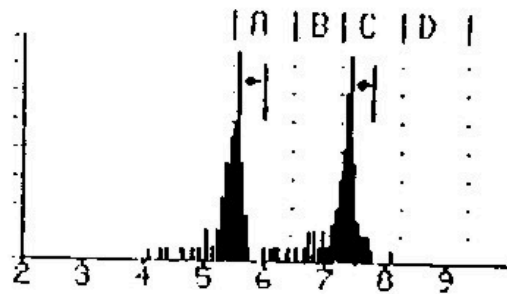
j. Low energy noise.

Independent of radon or thoron, such electronic noise may be intermittent or be associated with vibration.



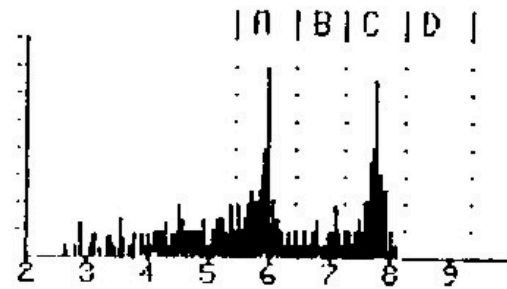
k. Shifted peaks.

Peaks appear normal, but are shifted in position. Shows a malfunction of the RAD7, which should be returned to DURRIDGE for service without delay.



ii. Heavy tails on alpha peaks.

The peaks are narrow, but have unusually thick tails. This may be caused by electronic noise, or by malfunction of the alpha detector.



4. USING THE *RAD7*: GOOD OPERATING PROCEDURES

4.1 Introduction

The different ways of using the *RAD7* may be arranged in six categories:

- a) continuous monitoring of radon in air,
- b) sniffing for radon and/or thoron,
- c) testing air grab samples,
- d) measuring radon in water,
- e) testing soil gas, and
- f) measuring radon and thoron emission from objects and surfaces.

While all six are discussed, it is primarily a) and d) that require standard operating procedures. The other applications tend to be more interactive, and individuals will develop protocols which work best for them.

4.2 Continuous Monitoring

4.2.1 Preparation

The *RAD7* batteries should be fully charged so that, even if there is a power cut, the test will be completed. Similarly, there should be more than sufficient active desiccant in the Laboratory Drying Unit.

For an EPA protocol test, the house should be fully closed from 12 hours before the start of the test. This means that ALL doors and windows should be shut tight. No air exchange system, or ventilation fans, may be running.

In winter it is not difficult to satisfy the requirement. Continued operation of the furnace is permitted. Closed house conditions are usually maintained anyway, to save heating costs. Doors may be opened momentarily, for access, but should otherwise remain closed throughout the test.

In summer it may be impossible to satisfy the requirement, without the residents moving out for the duration of the test. If doors and windows are left open, it can nullify the test, except that if there is a radon problem under these conditions, then there will be a greater problem under closed house conditions.

Air conditioning often includes some fresh air ventilation, which dilutes the radon. Even if there is no ventilation, the cold air in the house will want to sink, increasing pressure in the basement, and thus reducing any flow of soil gas into the house. So air conditioning in the summer will tend to lower the radon level in the house.

For further detailed information, see the EPA “Indoor Radon and Radon Decay Product Measurement Device Protocols” publication, EPA 402-R-92-004, or view it at <http://www.epa.gov/docs/iedweb00/radon/pubs/devprot1.html>.

4.2.2 Purging

For the *RAD7* to be all set to go, ready to start a test, it should be purged for at least five minutes beforehand. This may be done in the car, en route to the test site.

Locate an inlet filter, a piece of tubing with a sleeve at one end and small tube at the other, and the laboratory drying unit. Connect the filter to the tubing: It should be a tight fit into the small diameter section. Remove the plastic caps from the drying unit and push the sleeved end of the tubing onto the tube connector, on the drying unit, farthest from the metal screw cap. Now attach the filter to the inlet of the *RAD7*.

Switch on the *RAD7*, push [MENU], [ENTER], [→] four times, to see >Test Purge on the display, then push [ENTER]. The pump will start. The display will show Stop purge? No. Leave the unit purging for five minutes, or longer. When you are ready to start the test, the easiest way to stop purging is to push the Menu key, or switch off the instrument.

4.2.3 Test Location

In general, the test should be conducted in the “lowest area in the house that is used, or could be adapted for use, as a living area”. This would include a full-height basement, but not a crawl space.

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Place the RAD7 near the center of the room, about 3 - 4 feet above the floor. Avoid walls, vents, fireplaces, windows, draft, and direct sunlight.

Where possible, connect AC power to the RAD7, to conserve and recharge the batteries.

The air intake will be the connector of the drying unit without any tubing attached (nearest the end with the metal screw cap), or the far end of the tube if one is attached to this connector. Make sure the air intake is at least 30 inches (75 cm) above the floor, and away from the walls.

Once set up in location, let the RAD7 continue to purge until ready to start the test.

4.2.4 Test Protocol

In any location there is often a diurnal variation of radon level. It is preferable, therefore, that the test period be an exact number of whole days. The EPA protocols require an average taken over at least two days. The RAD7 gives time resolution as well. A choice must be made, therefore, of the cycle time and the number of cycles (recycle). For 24-hour and 48-hour tests, the RAD7 has preset protocols which will make the choice for you. You can always change the choices (even in the middle of a test!), and, if you wish, save your preferences as the user protocol. You may, for instance, prefer to conduct 3-day tests, and, perhaps, use 24 cycles, each 3 hours long. The longer the test, the greater the precision of the result.

For a 24-hour or 48-hour test, using the preset protocol, before starting the test, go to >Setup Protocol 1-day, or 2-day, and push [ENTER]. You need, also, to decide whether to leave the tone Off, Chime, or Geiger, and whether to have short, medium or long format of printouts at the end of each cycle, and set the parameters accordingly.

For very long term monitoring, use the weeks protocol. This sets the RAD7 to run indefinitely, with 2-hour cycles. The internal memory capacity, of 1,000 cycles, will last nearly 12 weeks. If data is periodically downloaded to a PC, and erased from the RAD7, there is no limit to the measurement duration. With the laboratory drying unit used to dry the sampled air, the desiccant will have to be replaced every 7 to 14

days, depending on the humidity. The RAD7 needs external power for indefinite operation, but can survive, without loss of data, an interruption of power lasting up to 50 hours, or more, depending on the condition of the batteries.

For any other measurement period, you will need to set the parameters yourself. The cycle time, times the number of recycles, gives the duration of the total measurement. In almost every case, for continuous monitoring, choose Mode Auto, Thoron Off, and Pump Auto.

Once the RAD7 switches (after three hours) to Normal mode, the counts are included from Window C, which come from Po-214 atoms. These were once radon atoms, that entered the measurement chamber as much as an hour or more beforehand. Therefore, in Normal mode, the RAD7 is averaging the radon concentration from less than 20 minutes ago (Po-218) with the radon concentration from less than three hours ago (Po-214). So, for a long test in Normal mode, the cycle time should be set to one hour, or more.

Where there is a requirement for a fast response and detailed time resolution, then the cycle time may be set as short as half an hour, or even 20 minutes, but the Mode should then be set to Sniff, not Auto. Note, however, that counting only Window A, and for such short periods, the number of counts per cycle will be less than for longer cycles in Normal mode, and so the individual readings will have more scatter. Note, also, that short cycle times will fill up the memory more quickly (the capacity is 1,000 cycles), use up the desiccant more quickly, and, if the printer is being used, produce more printout.

4.2.5 To Print Or Not To Print

It is not necessary to run the printer during a measurement as all data, except for the detailed spectra, are stored at the end of every cycle, and are available for printing or downloading to a PC at any time. Furthermore, with no printer and the key pad locked, it is impossible for any unauthorized snooper to read the radon concentration during the run. On the other hand, use of the printer gives a convenient and informative hard copy of the results.

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For routine continuous monitoring, it is usual to set the printer format to short (Setup, Format, Short, [ENTER]).

Place the printer on the face plate, apply external power and switch on. Note that the printer will sleep, after a time, if there is no external power. Switch the RAD7 off, then on again. Information about the RAD7, and the setup, will print out. Data will be printed at the end of every cycle, and a summary, bar chart and cumulative spectrum will print at the end of the run.

When everything is ready, start the test (Test, Start, [ENTER]). The pump will start running and the LCD display will go to the first status window.

The house should remain in closed condition for the duration of the run. At any time, the status windows can be viewed. The relative humidity, temperature and battery voltage are all parameters that are worth observing. Rising relative humidity may indicate that the desiccant is exhausted, or that there is a leak in the sample path. The temperature reading gives a base for future reference, see below. A dropping battery voltage may indicate that the AC power is not connected.

4.2.7 Security and Quality Control

For a good measurement, it is essential that the RAD7 (or any measurement device, for that matter) remain in its place, and the house remain closed, throughout the run.

Anti-tampering tapes are available for the windows and doors. A soft, plastic adhesive, such as Blue-Tack, HOLDIT or Tac'N Stik, under the RAD7, will stick better the first time than in subsequent placings. An experienced hand can tell if the RAD7 has been moved. But perhaps the best anti-tampering defense is the data itself. With the time resolution in the data provided by the RAD7, anomalies are clearly revealed. A sudden change in radon concentration and in air temperature, during the measurement, is a strong indication of tampering, either by moving the instrument, or by opening windows. The key-pad lock prevents tamperers from looking at the data, or interfering with the measurement.

A detailed and systematic quality control protocol must be established by any user seeking certification. This should include a description of the measurement process, and the steps taken to ensure that the readings are reproducible.

The RAD7 is too accurate for any procedure in the field to be able to verify that it is working within specifications. However, it is good practice, on a regular basis, to compare the RAD7 readings with some other device, such as a passive charcoal collector. The two devices should be placed close together, with the RAD7 sampling point near to, but not touching, the charcoal collector. The measurements should also cover the same time period. The charcoal reading may then be compared with the RAD7 mean for the period. Remember, however, that some charcoal devices, and labs, may give readings which are in error by as much as 25%. If the RAD7 and the charcoal device differ by more than 10%, repeat the comparison as soon as possible, preferably with a different charcoal device, from a different lab. Look at the RAD7 cumulative spectrum, printed out at the end of a run, to see if it appears normal. If the RAD7 mean is consistently, significantly different from the readings of other devices in side-by-side tests, or if the spectrum looks abnormal, please call, or email, DURRIDGE for advice. In any case, we recommend that the RAD7 be returned to DURRIDGE Co., for recalibration, annually.

An excellent quality test, for the RAD7, is simply an examination of the cumulative spectrum printed out at the end of every run. If the spectrum looks normal, and the humidity, temperature, and battery voltage, are within normal range, then that is very strong evidence that the RAD7 is working properly, and the readings are reliable.

4.2.8 Finishing the Run

Even if no printout has been made at the end of every cycle, it is still useful to have a printout at the end of the run. If the RAD7 can be accessed before the run is finished, simply place the printer in position on the face plate and switch it on. After the last cycle is completed, the RAD7 will print the run summary, including the mean value, the bar chart of all the readings, and the cumulative spectrum. If the instrument cannot be accessed before the end of the run, the summary

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can be printed out later, but without the cumulative spectrum.

Switch off the printer and the RAD7. Disconnect the tubing from the desiccant and replace the plastic caps over the hose connectors. If the caps have been lost, a single piece of tubing may be attached between the two connectors, thus providing a seal to keep the desiccant dry.

Remove the inlet filter from the RAD7. It is good practice to leave the inlet filter attached to the plastic tubing. Replace the short piece of tubing connecting the inlet to the outlet. Putting the jumper between the inlet and outlet keeps the internal space of the instrument sealed, and thus dry, while still allowing air flow should the pump start running.

When moving the RAD7, please treat it with respect. It is rugged, but it is still an electronic instrument. Please avoid hard knocks and very harsh environments.

4.2.9 Examining the Data

In addition to the printout, data may be examined on the LCD, during or after a run. The records may also be downloaded to a PC, where they are then available for creating graphs and tables for printed reports.

On reviewing a set of data, first check that the relative humidity in the instrument stayed below 10% throughout the measurement. If it rose above 10%, it suggests that the desiccant was either removed, or became depleted. The RAD7 reads low if the internal RH rises above 10%.

The temperature during the measurement should remain fairly steady. Sudden changes of temperature in the record suggest that either the windows were opened, or the RAD7 was moved from its location.

If the house was not properly closed up until the measurement was started, you may expect to see a rising radon concentration during the first few hours of the run. If that is the case, any very low, early readings should be discarded in the calculation of the mean value for the house. That would mean manual calculation of the average, from the good readings. EPA protocols require at least 48 hours of continuous good data. If the

house was not closed up beforehand, a 3-day test could satisfy the EPA requirement.

If the air sampling point was changed for a while, or some windows opened, during the run, you may expect to see a change in air temperature, and change in radon concentration, during that period. Simultaneous changes of these two parameters is an indicator of tampering.

4.2.10 Very Short Term Monitoring

Some Home Inspectors choose to use the RAD7 for a short-term test, just during the home inspection. This means that they have full control over the test, and they can take the RAD7 with them, when they leave, on completion of the home inspection.

They close up the house, set up the RAD7 in the basement, choose a half-hour cycle time and a total run length (recycles) of, typically, four or five cycles. At the end of the run, the RAD7 prints out a bar chart of the increasing radon concentration, at half-hour intervals. The data gives the Home Inspector, and his client, a good indication of the radon situation. Adding 50% to the final half-hour reading gives an estimate of what would be the average radon level, for closed house conditions. If, during those two hours of the test, the radon concentration climbs towards, or over, the 4 pCi/L mark, then they can be confident that, with a full, EPA protocol test, covering 2 days, or more, the result would surely exceed the 4 pCi/L action level.

4.3 Sniffing

4.3.1 Why Sniff?

There are two main reasons for sniffing. One is to obtain a quick, spot reading of radon concentration, as a simpler substitute for grab sampling, and the other is to locate radon entry points. For each application, the method will be slightly different.

4.3.2 Locating Radon Entry Points

There is a very good chance that thoron (see page 33) will be present in the soil gas entering the building. It will, however, be detectable only

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close to the entry points. Thoron, therefore, if it is in the soil gas, can be considered as a tracer for fresh radon gas. Sniffing to locate radon entry points may, therefore, be focused on detecting thoron, if it is there, to speed, and simplify, the process. The same procedure will also give radon concentrations, provided that the sampling point is kept at one spot for at least 15 minutes.

4.3.3 Preparation

Detailed instructions are given in Chapter 1, section 5, on page 13. Choose Thoron in the Setup Protocol menu, and set the Tone to Geiger. Employ a small drying tube and, preferably, just a yard of tubing to the inlet filter.

4.3.4 Purging

While it is always good practice to purge the instrument before using it, there is less necessity before sniffing. In SNIFF protocol, the pump runs continuously, so the air sample will be flushed through every minute or two, and the measurement chamber will quickly dry out, even if the relative humidity starts above 10%.

To bring the humidity in the instrument down without wasting desiccant, the RAD7 outlet may be connected to the open end of the drying tube, making a closed loop, during the purge cycle.

After detecting high concentrations of radon and/or thoron, it is good practice to purge the instrument immediately after use.

4.3.5 Running the Test

With the RAD7 strap over one shoulder, holding the small drying tube as a wand, start the test. The first status window will be displayed in the LCD. Push the right arrow five times, to reach the B window status screen. This will show the CPM for thoron. You may also listen to the beeps, which have a different pitch for different windows. Thoron has a high-pitched beep.

Floor/wall, wall/wall and split-level seams are common locations for radon entry points. So are sumps, wells, beam pockets and utility conduits, entering the building from below ground level. It is useful, before starting the sweep, to have a sketch map of the area, with the likely culprits marked, on which to write down the readings.

While making this sketch map, the RAD7 can be taking a benchmark radon measurement in the center of the room. Take at least four 5-minute-cycle readings. Later radon readings, at likely entry points, can then be compared with this benchmark.

To start the sweep, hold the small drying tube as a wand, with the open end either in, or as close as possible to, the most likely radon entry point. Keep it there for at least five minutes. If the thoron count, in window B, during this time, exceeds 2 CPM, say, then you know a) that you were right in your suspicion, and that you are, indeed, close to a radon entry point, and b) that thoron is present in the soil gas, so you can concentrate on thoron for the rest of the survey. Move the wand a foot or so in any direction to see if the window B CPM changes appreciably, in the next cycle.

If there are few or no counts in window B, then either the location is not a radon entry point, or there is no appreciable thoron in the soil gas. You must, then, keep the wand in that position for another 10 minutes, or until the counts in window A start to rise rapidly. If, after fifteen minutes, there are still only a few counts in window A, and the radon concentration, displayed at the end of the third 5-minute cycle, is still very low, then you can be confident that the position is not a radon entry point. On the other hand, a high radon concentration, without thoron, does not necessarily indicate a radon entry point if the whole basement is high. In either case, you need to note the reading on your sketch map, and move to another likely point to repeat the process, first looking for thoron.

If no thoron is found at any time, then the map of radon concentrations, will help to identify entry points.

Once thoron has been detected, the whole search is made much easier. Reset the cycle time to two minutes. Spend one complete cycle at each suspected radon entry point, observing the counts in window B, or listening for the characteristic thoron beeps. You will quickly determine the location and relative strengths of the radon entry points, from the CPM in window B, for the different locations. Note that, in this procedure, you must ignore the counts in window A, because they refer to radon that entered the measurement

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chamber as much as 10 minutes previous to the observed counts.

Even if thoron is present at some points, there is still a possibility that there may be a radon entry point showing little or no thoron. This could occur if the path taken by the soil gas was very long, or the flow was slow. Conduit for a utility service, or a path up a hidden shaft in a wall, could delay the entry of the soil gas by several minutes. Each minute's delay halves the concentration of thoron.

4.3.6 Drilled Sampling Points

Some mitigators drill a number of test holes through the concrete slab, to sniff the soil gas beneath and to test the communication between different areas of the slab. They then install the suction points of the mitigation system where the sub-slab radon readings are highest. This approach is complementary to the search for actual radon entry points, as described above. Both methods are likely to result in a similar, final configuration of the mitigation system, though locating the entry points can also indicate where additional sealing is required..

4.3.7 Spot Readings

A spot reading may be accepted only as a rough indicator of the radon level at any location. This is not only because a short-term reading is less precise, but also because it does not average out the fluctuations in radon level through a typical day. The EPA protocol calls for a measurement to cover at least two days. Quite often, the indoor radon concentration tends to be higher in the early morning, after a cold night, and lower at the end of a warm day.

Furthermore, the radon concentration, typically, takes hours to recover from open doors and windows so, unless the house was closed up tight for many hours beforehand, the spot-reading radon level will be significantly lower than an average, taken over several days, in closed house conditions.

For this spot reading, the sampling point should be away from walls and floor. Thoron is not an issue in this measurement, so the larger, laboratory drying unit may be used, instead of a small drying tube. The cycle time may be left at

five minutes. At least four, better six, cycles should be taken, of which the first two should be ignored. Alternatively, increase the cycle time to 10 minutes, or more, and ignore the first reading.

To measure a radon level of 4 pCi/L, with a standard deviation of no more than 10%, needs a run of one hour (six cycles of ten minutes, say).

4.4 Grab Sampling

4.4.1 Applicability

When it is not possible to take the RAD7 to the location to be measured; when a grab sample is required while the RAD7 is pre-occupied with continuous monitoring; or when many grab samples are required, all within a short time, from different rooms of a building, then the grab sample capability of the RAD7 fills the need. However, if the RAD7 is available, and can be taken to the test location, then data quality is much improved by a) monitoring the radon level over an extended period of time, such as 1-day, or, if that is not a possibility, b) making a short-term measurement such as described in paragraph 4.2.10, on page 53, or else just sniffing for a spot reading, as described above.

Grab samples have the same shortcomings as spot readings, above. The radon concentration 'grabbed' is unlikely to be representative of the EPA average level at the location of the sample. The precision of the reading is also limited by the short time for counting.

4.4.2 Preparation

It is important that the RAD7 be well dried out prior to accepting the grab sample. First, purge the unit with fresh, dry air for five minutes. Then connect the laboratory drying unit in a closed loop with the RAD7 so that air from the outlet passes through the desiccant and back into the inlet. Note that air should always flow the same way through the desiccant. Purge for ten minutes then check the relative humidity (push [MENU] [ENTER] [ENTER], then the right arrow key two times). If the RH is not below 8%, repeat the process. Keep the pump running until ready to take the grab sample.

4.4.3 Protocol

Choose Grab from the Setup Protocol menu selection, and push [ENTER]. This will set up all the measurement parameters correctly. For the printout, choose Short from the Setup Format menu.

4.4.4 Taking the Sample

If the RAD7 is at the location, simply start the test ([MENU] [ENTER] [RIGHT ARROW] [ENTER]).

Alternatively, samples may be taken in tedlar air sampling bags. Samples of at least five liters are required. Any sampling pump may be used. Even the RAD7 could be used as a sampling pump, but remember to purge the instrument of old air first.

These bagged samples may be connected to the RAD7 and analyzed later. Make sure there is active desiccant and the inlet filter in place, between the sample bag and the RAD7.

4.4.5 Analysis

With the grab sample source connected to the RAD7, start the test ([MENU] [ENTER] [RIGHT ARROW] [ENTER]). The pump will run for five minutes, flushing the measurement chamber, and then stop. The RAD7 will wait for five more minutes, and then count for four 5-minute cycles. At the end of the run, the RAD7 will print out a summary, including the average radon concentration, a bar chart of the four cycles counted, and a cumulative spectrum. The measurement process takes 30 minutes.

If the analysis is made more than an hour after the sample was taken, a correction must be applied for the decay of radon in the sample.

4.5 Radon in Water

4.5.1 RAD H₂O

The RAD H₂O is an accessory to the RAD7 that enables you to measure radon in water with high accuracy, over a wide range of concentrations, obtaining your reading within an hour of taking

the sample. It is particularly suited for well testing, where immediate results are often required.

The RAD H₂O uses a standard, pre-calibrated degassing system and pre-set protocols, built into the RAD7, which give a direct reading of the radon concentration in the water sample, itself. The method is, in fact, a special case of the grab sampling method above.

The RAD H₂O comes with its own manual, to which you are referred for further details.

4.5.2 RAD AQUA

This is another RAD7 accessory, for continuous monitoring of radon in water. It has a high sensitivity, and rapid response.

Air, in a closed loop, is brought into equilibrium with water passing through the exchanger. The RAD7 operates in continuous mode, as in 4.2, on page 49.

The RAD AQUA also comes with its own manual, to which you are referred for further details.

4.6 Soil Gas Sampling

4.6.1 Application

The radon concentration in surrounding soil gas is one of many parameters that impact the radon health risk of a house. The construction of the house, the porosity of the soil, the height of the water table, and several other factors, are all important. Even if there is no radon in the surrounding soil, the house may still be at risk if it has a well in the basement, or is built on rock, over a fissure. Nevertheless, it is often of interest to determine the radon concentration in soil gas.

Thoron is usually associated with radon in the soil. When measuring soil gas, it is, therefore, particularly useful to determine the thoron content as well as the radon content. Should there be significant thoron, it may be used as a tracer, to find radon entry points, inside the house, see paragraph 4.3.2.

4.6.2 Soil Gas Probe

The cost, and complexity, of a soil gas probe increases with the depth to which it can be inserted. A variety of probes are available from DURRIDGE Company, the simplest of which will penetrate to a depth of 3 feet.

4.6.3 Preparation

Insert the probe. Make sure that there is a reasonable seal between the probe shaft and the surrounding soil, so that ambient air does not descend around the probe, to dilute the soil gas sample.

Between the probe and the RAD7 connect a water trap (which could be just a jar with two air-tight hose connectors in the lid), the laboratory drying unit, and the inlet filter. A water trap is included in the package when the DURRIDGE soil gas probe is purchased.

Set the protocol to Sniff. Soil gas is normally so high in radon that it is not necessary to use long cycle times to gain precision. Five minute cycle times are long enough.

4.6.4 Running the Test

Start the test. (Test Start [ENTER]). On the LCD you will see the first status window. Push the right arrow twice and the screen will display the temperature, relative humidity, battery voltage and pump current. Pay particular attention to the relative humidity and pump current. The relative humidity should gradually drop down to below 10%, and stay there.

If the pump current starts to rise much above 100 mA, it suggests that the soil is not porous, in which case it may be that a good soil gas sample cannot be drawn, no matter how powerful a pump is used. With the RAD7 pump current above 100 mA, the air flow rate will be significantly reduced from the nominal 1L/min. This will not affect the radon reading, but will reduce the effective sensitivity to thoron, as more of the thoron will decay en route to the RAD7. If desired, an additional pump may be used, but it should be placed upstream of the RAD7, so that the RAD7 is operating at normal pressure. In fact, with an external sampling pump in use, the RAD7 pump can even be switched off, altogether.

4.6.5 Interpreting the Data

As with any Sniff test, the first two 5-minute cycles should be ignored. The next one or two cycles should be averaged, to arrive at the radon concentration of the soil gas.

For thoron, some estimate has to be made of the time taken for the sample, after it has left the soil, to reach the RAD7. This requires an estimate of the volume of the sample path, including the probe, water trap, tubing and drying unit, and an estimate, or measurement, of the flow rate. For example, if the total volume of the sample path is 2L, and the flow rate is 0.5 L/min, then the sample delay is about 4 minutes. If the thoron decays by half every minute, then after four minutes the concentration will be just 1/16th of the concentration in the ground. So, whatever thoron concentration the RAD7 measures should be multiplied by 16.

4.7 Emission Measurements

4.7.1 Application

With its internal pump, sealed sample path, and inlet and outlet connectors, the RAD7 is well suited to emission measurements. Furthermore, the ability to count only the polonium-218 decays means that dynamic measurements are clean, and not complicated by long-half-life events.

4.7.2 Open or Closed Loop Configurations

Emission will occur from bulk materials in an emission chamber, or from an enclosed surface. The RAD7 will draw air from the enclosure, through the desiccant and inlet filter, into the measurement chamber. The air may then be returned to the enclosure, from the RAD7 outlet, to form a closed loop. Alternatively, in an open loop configuration, the air drawn from the enclosure may be replaced with 'zero' air, from a cylinder, or with ambient air, which has a low and measured radon concentration.

With the closed-loop configuration, the system is first purged, and then, once closed, the radon concentration within the loop is monitored in Sniff mode, with short, e.g. 15 min., cycle times,

for a few hours. It is necessary to know the total volume of the closed-loop system. For this purpose, the volume inside the RAD7 may be taken as 1L. The initial rate of increase in radon concentration (neglecting the first 15-min cycle), multiplied by the volume, then gives the rate of emission of radon. A reduction in the slope, as the radon level builds up, may be due to leaks in the system, or to a reduction in the net emission.

With the open loop configuration, a steady, and known, flow rate must be established. If a cylinder of 'zero' air, or nitrogen, is used, then the RAD7 internal pump may be set to Off, and the pressure reduction valve used to control the flow rate. With ambient air, the internal pump may be set to On, for a continuous flow. In both cases, a flow meter is required.

A steady state should be achieved and a long-term measurement may be made. The rate of emission will equal the radon concentration times the flow rate. The precision will depend on the concentration and the duration of the measurement.

4.7.3 Bulk Emissions

An airtight box with two hose connectors, well separated, will usually work fine. The material is placed in the box. The box is connected, by tubing from one connector, to the laboratory drying unit, and thence to the inlet filter on the RAD7. The other box connector has tubing attached, which is either connected to the RAD7 outlet, for closed-loop operation, or, for open-

loop operation, connected to a cylinder of zero gas, or left open to ambient air.

Note that bulk emissions are affected by pressure fluctuations and by temperature and humidity. All these parameters can, and should, be controlled in both the closed-loop and open-loop configurations. Radon emission is also dependent on the grain size of loose materials, and porosity of any bulk material.

Thoron emission can also be measured in same apparatus. In the open loop mode, a correction will be required for the decay of the thoron during the time between emission and measurement in the RAD7. In the closed loop mode, another correction should be made for the proportion of

the thoron that gets fed back to the enclosure. Note that, for thoron, both the closed loop and open loop modes are steady-state measurements.

4.7.4 Surface Emission

For these measurements, an enclosure, with two hose connectors, has one side open, which is sealed against the surface under investigation.

The alternative procedures are similar to those for bulk emission measurement, as described above. Once the total emission rate, within the enclosure, has been calculated, it may be divided by the area of the surface within the sealed boundary, to determine the emission per unit area.

4.8 Thoron Measurement

4.8.1 Thoron and Radon

Thoron is an isotope of the element radon having an atomic mass of 220, so it is also known as radon-220. The word "radon" without a mass number almost always refers to radon-222. Thoron and radon have very similar properties. They are both chemically inert radioactive gases that occur naturally from the decay of radioactive elements in soils and minerals. Both thoron and radon are members of decay chains, or long sequences of radioactive decay.

While radon results from the decay of natural uranium, thoron results from the decay of natural thorium. Both uranium and thorium are commonly found in soils and minerals, sometimes separately, sometimes together. The radioactive gases radon and thoron that are produced in these soils and minerals can diffuse out of the material and travel long distances before they themselves decay. Both radon and thoron decay into radioactive decay products, or progeny, of polonium, lead, and bismuth before finally reaching stable forms as lead.

Thoron and radon and their respective progeny differ very significantly in their half-lives and in the energies of their radiations. While radon has a half-life of nearly 4 days, thoron has a half-life of only 55 seconds. Since thoron is so short lived, it cannot travel as far from its source as radon can before it decays. It is commonly observed that

compared to that of radon gas, a much smaller fraction of the thoron gas in soil ever reaches the interior of a building. Even so, thoron can still be a hazard since its progeny include lead-212 which has a half-life of 10.6 hours, more than long enough to accumulate to significant levels in breathable air.

4.8.2 Thoron Measurement Issues

Many difficulties impede the accurate measurement of thoron gas. The presence of radon gas (often found together with thoron) can interfere with a measurement. The short half-life of thoron gas makes some aspects of the measurement easier, but makes sampling method a critical issue. Thoron concentration can vary greatly through a space, depending on the speed and direction of air movement as well as turbulence. The position of the sample intake can strongly affect the results.

For many instruments, radon and thoron interfere with each other. Generally speaking, it is difficult to measure one isotope accurately in the presence of the other. But compared to other instruments, the RAD7 is much less susceptible to radon-thoron interference due to its ability to distinguish the isotopes by their unique alpha particle energies. The RAD7 separates radon and thoron signals and counts the two isotopes at the same time with little interference from one to the other.

Some issues of concern in measuring radon do not apply to thoron. The short half-lives of thoron (55 seconds) and its first decay product (Po-216 - 0.15 seconds) mean that thoron measurements can be made quickly and in rapid succession, since there is little concern with growth and decay delays. The RAD7 responds virtually instantly to the presence of thoron; its time constant for response to thoron is less than 1 minute. The chief limit on the thoron response speed is the pump's ability to fill the internal cell. And the RAD7 clears just as rapidly when you purge the instrument with thoron-free air. In fact, you need not purge the instrument at all as thoron's short half-life ensures that it will be gone in a few minutes.

In thoron measurement the sample pump must run in a continuous fashion, at a steady consistent flow rate. If the flow rate of the sampling pump changes, then the RAD7 thoron result will also change. Flow rate affects the amount of thoron in

the internal cell, since a significant fraction of the thoron decays in the sample intake system as well as within the instrument. For the most accurate thoron measurements we recommend that you use a consistent sample intake system (always use the same hose and filter arrangement) and pay special attention to air flow rate. Be sure the filters, hoses, and RAD7 inlet and outlet ports remain free from obstruction. Use a flow meter (rotameter or "floating ball" type) to check that the flow remains consistent. Note that the flow rate affects the thoron reading, but not radon due to its much longer half-life.

The RAD7 measures thoron concentration in the air at the point of sample intake. Since thoron varies from place to place depending on the motion of the air, the instrument operator may find it necessary to make measurements in several locations to properly assess a thoron situation. Fortunately, rapid-fire thoron measurements are very easy to do with the RAD7.

4.8.3 Calculation and Interference Correction

The RAD7 calculates thoron concentration on the basis of the count rate in spectrum window B which is centered on the 6.78 MeV alpha line of Po-216, the first decay product of thoron gas. To further avoid interference from radon, the RAD7 applies a correction to the thoron count rate to compensate for a small percentage of "spillover" from window C.

As of version 2.5, RAD7 calculates radon concentration from the count rate in window A (Sniff mode) or windows A plus C (Normal mode). The RAD7 compensates for interference from the long-lived progeny of thoron (10.6 hours) by applying a correction to the radon count rate in both Sniff and Normal modes. The correction is based on a fixed fraction of the count rate in the D window (around the 8.78 MeV peak of Po-212) which predicts the amount of thoron progeny activity in the A window (due to the 6.05 and 6.09 MeV peaks of Bi-212). Note that the uncertainty figures given with each reading include the effect of these corrections.

4.8.4 Avoiding Longer Lived Decay Products

Although the RAD7 now corrects for the buildup of the long-lived thoron progeny (10.6 hour), we

recommend that you avoid unnecessary exposure of the instrument to high levels of thoron for long periods of time. The presence of these long-lived progeny can make low level radon measurements somewhat less accurate than would otherwise be possible. But if you err, the 10.6 hour half-life of the thoron progeny makes for a temporary inconvenience of a few days at worst.

4.8.5 Decay Correction, Flow Rate, and Thoron Calibration

As discussed above, thoron's rapid decay causes the intake path and the air flow rate become important factors in calibration. The RAD7 factory calibration for thoron is based on a standard RAD7 inlet filter, a standard 3-foot long, 3/16 inch inner diameter vinyl hose, and a standard small (6 inch) drying tube. Deviation from this arrangement can change your thoron results. For example, if you were to use a very long hose for thoron sampling, then the sample might decay significantly before it ever reached the instrument inlet. The same thing might happen if you substituted the small drying tube with the large drying column. If you were to use a non-recommended inlet filter, the flow might be restricted enough to greatly lower the result.

4.8.6 Calculating Sample Decay

The thoron concentration at the inlet of the RAD7, C1, can be expressed mathematically as

$$C1 = C0 * \exp(-L * V1 / q)$$

where C0 is the original sample concentration, V1 is the volume of the sample tube + drying tube + filter (around 50 mL), q is the flow rate (around 650 mL/min), and L is the decay constant for thoron (.756 /min). A typical value for C1/C0 is then

$$C1/C0 = \exp(-.756 * 50 / 650) = .943 = 94.3\%$$

This is the number NITON assumes in the factory calibration. Adding a few extra feet of hose will not matter much (about 0.5% per foot), but if we were to use a 100 foot hose instead (V1 is around 580 mL) then the same calculation would give .509 or 50.9%, a significant reduction from 94.3%!

4.8.7 Calculating Internal Cell Concentration

The sample decays slightly in going from the RAD7 inlet to the internal cell, due to internal hose and filter volumes. This decay can be calculated in a similar fashion to the above, giving the internal cell inlet concentration, C2, about 95.5% of C1. Within the RAD7 internal cell, the equilibrium thoron concentration, C3, will be determined by the following formula:

$$C3 = C2 / (1 + L * V2 / q)$$

where L and q are as above, and V2 is the volume of the internal cell (around 750 mL). Typical values then give C3/C2 as

$$C3/C2 = 1/(1+.756 * 750/650) = .534 = 53.4\%$$

Multiplying this result by the sample decay factors calculated above, we obtain an overall concentration in the internal cell of 48.1% of the original sample. Recognising the uncertainty of several of the inputs to these formulas, particularly the flow rate, we will round the overall result to 50%.

4.8.8 Internal Cell Thoron Sensitivity Calibration

Preliminary investigations have shown that the RAD7's internal cell thoron sensitivity in cpm/(pCi/L) is identical to its radon Sniff mode sensitivity, to within 25%. We have no reason to expect any sizeable difference between the thoron and radon Sniff mode sensitivity values, so we are presently assuming that the two values are indeed nearly equal, and claim an uncalibrated thoron precision of +/- 30%.

With calibration against a thoron standard assessed by gamma spectrometry we are able to state the thoron sensitivity with much higher certainty. This thoron calibration is offered as an option and for this we claim an overall accuracy of +/- 20%. Otherwise we estimate the overall thoron sensitivity to be 50% of the radon Sniff sensitivity to account for sample decay in the intake and internal cell. The RAD7 has a typical radon Sniff sensitivity of .25 cpm/(pCi/L), so we estimate the typical thoron sensitivity to be around .125 cpm/(pCi/L).

4.8.9 Setting up a Thoron Measurement

Sniffing for thoron is much the same as sniffing for radon, except it tends to be a little faster. If you are just "prospecting", you probably will not be very interested in getting the most accurate results possible, so technique is not critical. But if you are trying to make an accurate measurement, technique is of great importance.

For accurate thoron measurement, always use the same sample taking arrangement. Keep the sample tubing short: no more than 6 feet (2 meters) total length. Use one of the small drying tubes supplied with the instrument, filled with fresh (blue) desiccant. Always use an inlet filter, free from flow restrictions or clogs. Avoid obstructing the intake of the sample tube. For the most accurate results, check the flow rate with a flow gauge to be sure it is consistent from measurement to measurement. Use the RAD7's Setup Protocol command to choose Thoron protocol for a 5 minute repeating cycle. Be sure the instrument has been "dried out" before making a measurement. Position the sample tube intake and start the test.

4.8.10 Thoron Mode

Thoron mode causes the RAD7 to print both thoron and radon concentrations (in pCi/L or Bq/m³) in continuous data logging or in subsequent printing of data. Thoron mode also directs the automatic pump setting to continuous pump operation to assure a fresh sample.

The setup parameter "Setup Thoron" allows you to select Thoron mode On/Off, for configuring a particular test to perform thoron readings.

The protocol "Protocol: Thoron" provides a standard test for sniffing both radon and thoron in 5 minute cycles.

4.9 Managing Background

A major concern in radon testing is background. The RAD7 has a number of features that help to keep short and long-term background under control. These are discussed in chapter 3.11. Following a few simple rules will help to keep background to a minimum.

Short term background is activity left in the detector after the air sample has been flushed from the measurement chamber. The higher the radon concentration and the longer the sample is held in the cell, the more daughter activity it leaves behind. So, to avoid background, when you see high radon readings, finish your measurement, and purge the sample cell promptly. Take the instrument somewhere with little radon, such as outdoors. Make sure the drying tube is connected, and select >Test Purge. Let the RAD7 purge for 5 to 10 minutes, or longer if the sample was exceptionally "hot".

The two alpha peaks decay at different rates. The polonium-218 peak, in window A, decays with a 3.05 minute half-life. So in 10 minutes it will be down to about one-tenth of its original count rate. The peak in window C, however, will take over two hours to get down to one-tenth its count rate.

Rather than wait around for hours, you can start the next test in Sniff mode, which ignores window C. In fact, the preset, one and two-day, monitoring protocols, in the RAD7, use Auto mode, which starts a measurement in Sniff mode and automatically changes to Normal mode after three hours. This takes care of all but extreme exposure to very high radon.

You can always measure the short-term background, with 5-minute Sniff mode tests. Run a few to see that the background is low.

5. PC Connection

5.1 RS-232 Serial Port

5.1.1 Capabilities

The RAD7's built-in serial port allows you to transfer data to your personal computer. Once the data has been transferred, you may use CAPTURE or the software of your choice to manage the data and create tables, graphs and reports.

The standard RAD7 firmware, with RADLINK remote control software installed, enables two-way communication between the RAD7 and another device.

The RAD7 serial port follows RS-232 convention for compatibility with nearly all personal computers. A USB/RS232 adaptor is provided standard with every new RAD7.

In order to take advantage of the RAD7 data transfer capability, you will need appropriate hardware (PC with USB or RS232 serial port and null-modem serial cable), as well as appropriate software (CAPTURE for Windows, Mac or Linux), which will be explained below.

5.1.2 Hardware Bridge

Most PC's come with one or more USB or RS232 serial port connectors, which can connect the computer to a modem, mouse, printer, or another device.

If there is no RS232 serial port a USB/RS232 adaptor is required. The latest driver for the particular device and for the PC operating system should be downloaded and installed in the PC.

You will need the proper cable to link the RAD7 serial port to your computer. The cable should be a "null-modem" type, as the RAD7 serial port emulates a computer rather than a modem. If you prefer, you can use a normal "modem" cable along with a "null-modem" adapter on one end or the other.

5.1.3 Software Bridge

In order to receive data on your computer, you will need software that can "capture" the data and

store it to memory or disk file. CAPTURE for Windows, Mac or Linux is designed to make this task easy. It also offers sophisticated graphing and analysis capabilities.

The latest version of CAPTURE may be downloaded from the DURRIDGE web site (<www.durridge.com>, by clicking on the beta site link on the downloads page.

5.1.4 Applications

CAPTURE is intended to provide all the analytical and visual capabilities likely to be required. It also stores copies of the data in various formats for exporting into spreadsheet and database programs.

5.1.5 Technical Specifications for the RAD7

The RAD7 serial port follows RS-232C convention for signal levels. Positive voltage (+3V to +15V) indicates logic state 0 (SPACE), while negative voltage (-3V to -15V) indicates logic state 1 (MARK).

The connector pin-out follows the IBM PC convention for the 9 pin serial port. The handshaking lines (DTR, DSR, RTS, and CTS) are not fully implemented, and should be considered non-functional (NF), but X-on/X-off flow control can be used.

RAD7 Serial Port Pin Assignments

Pin	Name	Comment
1	Carrier Detect (CD)	NF
2	Receive Data (RD)	
3	Transmit Data (TD)	
4	Data Terminal Ready (DTR)	NF
5	Signal Ground (SG)	
6	Data Set Ready (DSR)	NF
7	Request To Send (RTS)	NF
8	Clear To Send (CTS)	NF
9	Ring Indicator (RI)	NF

The RAD7 serial port has complete hardware implementation for two-way communication at 300, 600, 1200, 2400, 4800, 9600, and 19,200 bits per second (baud); these speeds are available through the 'Special' commands of the

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RADLINK remote control package. The default speed is 1200 bps.

RAD7 Communication Parameters

Default rate	1200 bps
Data bits	8 bits
Parity bit	None
Stop bits	1 bit

5.1.6 Serial Port Output

All stored test data are available for serial port output through the "> Data Com ###" command. Specify the run number in the command line. Output from the RAD7 serial port is entirely ASCII numeric. Each cycle produces a record containing 23 fields. Carriage-return line-feeds separate the records. Within each record, commas separate the fields. Fields may have leading zeros, extra space characters, trailing decimals, etc., but these will not bother CAPTURE or most data-base or spread-sheet programs.

RAD7 Data Record - 23 data fields per record:

1. Test number - ranges from 001 to 999
2. Year
3. Month
4. Day of month
5. Hour
6. Minute
7. Total counts
8. Live time (minutes, resolution 0.1 min.)
9. Percent of total counts in window A
10. Percent of total counts in window B
11. Percent of total counts in window C
12. Percent of total counts in window D

(Note: These 4 windows will not add up to 100% since counts can come into channels below or above these windows.)

13. High voltage level - 2200 V to 2300 V
14. High voltage duty cycle - Ranges 0 to 100%, with typical values of 10-20%
15. Temperature - may be in degrees Celsius or Fahrenheit, depending on *RAD7* setup
16. Relative humidity of sampled air - should be kept below 10% for most accurate test
17. Leakage current - range 0-255. Above 20 is cause for concern

18. Battery voltage - below 6.00V is a discharged battery. Does not affect accuracy of test, but indicates need for recharge.

19. Pump current - Ranges 0-250 mA. Typically 40-80mA, above 100mA indicates possible clogged filter or obstruction.

20. Flags byte. individual bits show settings;
Bit0 set to indicate pump is in TIMED mode
Bit1 set to indicate pump ON continuously
Bit2 not defined

Bit3 set to indicate tone is in GEIGER mode

Bit4 set to indicate beeper is activated

Bit5 set to indicate that spectrum will print after each test

Bit6 set for multiple (recycle) test mode, else stops after test is complete

Bit7 set for SNIFFER test mode. Clear is N

21. Radon concentration result in pCi/l, Bq/m³, cpm, or # counts, depending on the units the RAD7 has been setup to use.

22. Uncertainty - 2 sigma error - of concentration in the SAME units as the concentration (not %).

23. Units byte - Individual bits must be extracted to get settings;

Bits 0 and 1 indicate concentration unit, 00 = cpm, 01 = # of counts, 10 = Bq/m³, and 11 = pCi/L.

Bit2 through Bit6 are not defined.

Bit7 indicates temperature unit

(0 = Fahrenheit, 1 = Celsius)

A run can contain many cycles of data, with one record per cycle. Here is an example of a single record:

```
009,99,10,29,04,18,4823.,337.8,45.4,  
2.9,46.6,0.3, 2201,14, 23.7, 5, 7,7.09,  
00,125,28.32743,8500846,255<CRLF>
```

5.2 RADLINK

5.2.1 Capabilities

The remote control package, now installed standard with every RAD7 sold, enables the RAD7 to be controlled from a distance by sending commands through the built-in serial port. This package makes all the ordinary RAD7 keypad commands available through a remote device connected to the serial port. Using a remote terminal or computer you may, for example, change the RAD7's operating parameters, start a

test, stop a test, or receive data from the RAD7. The package permits users to implement automated communication between the RAD7 and computing equipment for the purpose of remote centralized data collection or control.

Radlink also provides several additional functions, not otherwise available. For instance, with RADLINK you can change the baud rate, download the entire data stored in the RAD7 with a single command, and control relays directly from the RAD7.

5.2.2 Requirements

Remote control software resides in non-volatile memory (NVRAM), but does not decrease the amount of memory available for storing radon data.

The most simple implementation of remote control is through a direct wire link from the RAD7 to a personal computer or terminal. This requires a serial null-modem cable from the RAD7 to the serial port connector on the computer or terminal or USB adaptor.

The simple, direct serial port to serial port connection has a range limited to around 50 feet (15 meters) by the RS-232-C standard. Options for extending this range include RS-232 line boosters, current-loop and other types of interface converters, short-haul modems, and leased-line modems.

You may use standard data modems to communicate over the telephone system to one or more remote RAD7 monitors, so that when you want to get some data or start a new run, just "dial up" the instrument of your choice. The modem should be Hayes compatible and should be set to auto-answer.

If you intend to use a personal computer to communicate with and control an instrument, you will probably need some kind of terminal emulation software for your computer. Several low-cost commercial software products are available for data communication that allow you to send commands, receive replies, and transfer data in and out of your computer using its serial port or USB port with an adaptor. Microsoft Windows has hyperterminal, a built-in

communication package, that can perform these functions without additional software.

5.2.3 RAD7 Remote Command Format

The format of commands to the RAD7 serial port match, as closely as possible, the format of the commands available to the user at the RAD7 keypad. For example, the command to change the cycle time to 1 hour is "SETUP CYCLE 01:00". The command to turn off the audio beeper is "SETUP TONE OFF". The command to send over the data from run number 3 in comma-delimited form is "DATA COM 3". The upper/lower case of the command does not matter, nor does the numeric format of numbers. In the last example, "data com 03", "Data Com 3", and "dAtA coM 03.00" all work equally well.

You can use any of the ordinary RAD7 commands, but a few extra commands have been added that you may also use, or in some cases substitute for other commands. These commands all start with the word "SPECIAL". One such extra command is the command "SPECIAL STATUS" which gives information about the current status of the instrument, just like "TEST STATUS", but does not continue to update the information every second; instead, it returns control to the user.

The Control-C character functions as a remote "menu" key that can be used to interrupt certain activities and get ready for a new command. The RAD7 replies with a prompt, the greater-than character ">", that tells you it is ready for a new command. When using a terminal emulator program, you will always type commands at the prompt.

All commands must be followed by a carriage return character, denoted here as <CR>. No command will be activated until the <CR> goes through. Once you have typed a command, always end with a carriage return keystroke. This key may be marked "Enter" or "Return" on your keyboard.

If the RAD7 cannot understand your command, such as if you typed words in the wrong order or misspelled something, it will respond with "? ERROR", followed by a list of acceptable command words.

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5.2.4 Special Keys

If you are using a terminal emulator package, you can gain a few special keys by making sure your terminal has been setup to give ANSI standard escape codes for the function keys and cursor control keys. Set your terminal for either ANSI, VT-52, or VT-100 mode to get these functions. The function keys F1, F2, F3, and F4 act as a remote RAD7 keypad, corresponding to the RAD7 keys <menu>, <enter>, <backward arrow>, and <forward arrow>. As mentioned previously, the Control-C character also acts as a

remote <menu> key. The backspace/delete key on your keyboard allows you to correct misspelled commands before the carriage return. If this key does not work, then Control-H may do the same function.

5.2.5 Special Commands

A series of special commands have been added to the ordinary RAD7 commands to provide functions of special interest to remote control users. See paragraph 2.5 Special.

6. CAPTURE

6.1 Introduction

CAPTURE is intended to simplify the transfer of data from the RAD7 to a computer, and its subsequent analysis. Versions are available for Windows, for Mac (universal binary) and for Linux. The latest versions of the Windows and Mac programs are available for download from the DURRIDGE web site (www.durridge.com). Go to the downloads page and click on the beta site link.

CAPTURE, after downloading data from a RAD7, saves a raw data file (.raw) with the name and destination chosen by the user, parses the data in the file, highlights any bad records and displays a graph of the entire data set. Sophisticated tools are then provided for a detailed analysis of the data. A cleaned-up data file (.cdt) and tab-delimited file (.txt) can also be saved to disk along with the raw data file.

CAPTURE can also read a data file from PC memory and process it just the same as one downloaded directly from the RAD7.

The MAC version of CAPTURE has the look and feel of a MAC application whereas the Windows and Linux versions have their own look and feel. The example screen shots below are from the MAC version but the text applies to all.

6.2 Installation

Download the appropriate version of CAPTURE from the DURRIDGE web site. In Windows the installer program is run. For a Mac click on the .dmg file. The resulting folder should then be copied into the applications directory. In both cases the user should be logged on as administrator.

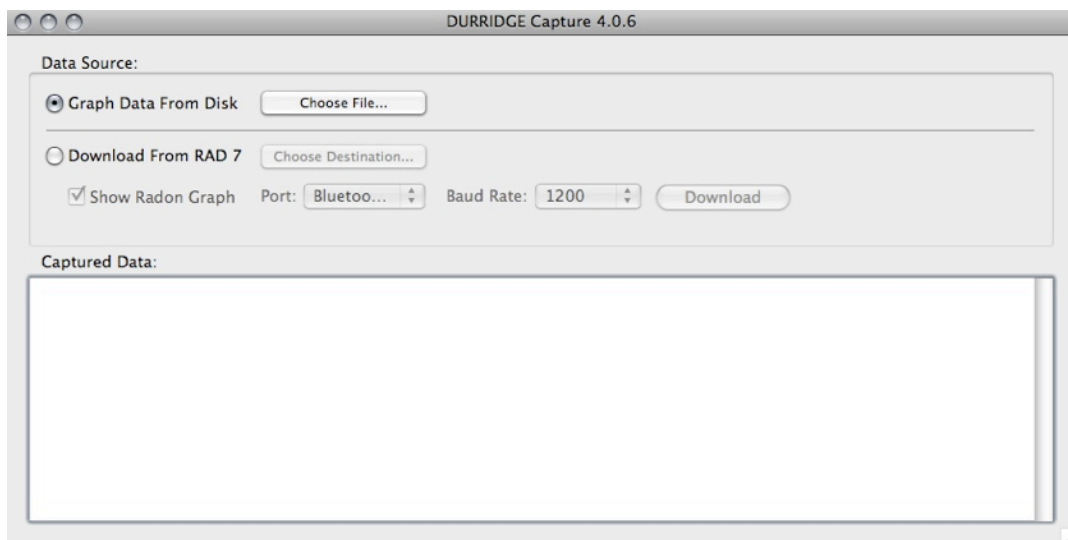
6.3 File from disk

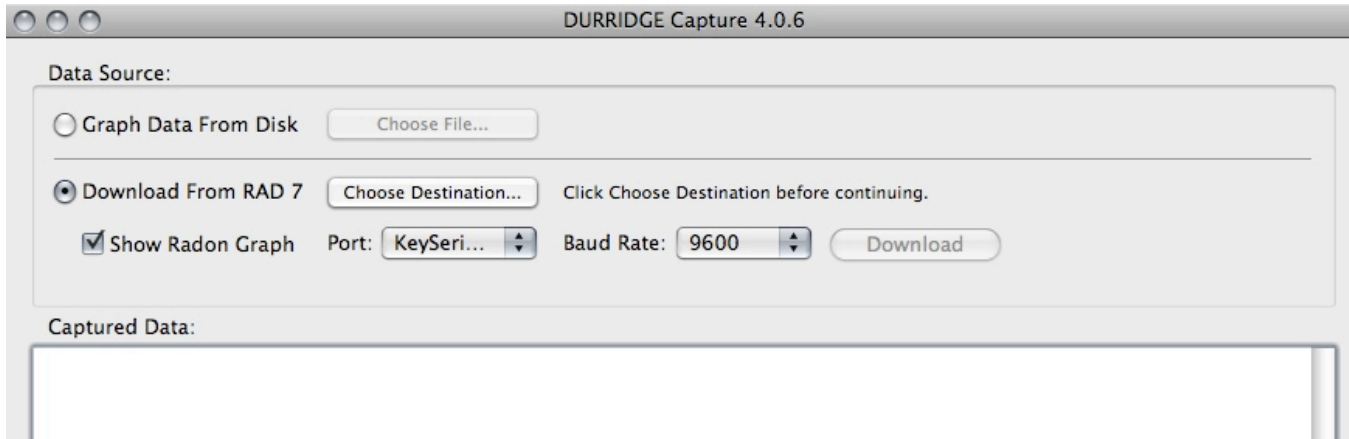
Click on the “Graph data from disk” button then click on the “choose file” control. This will produce a browse window with which you can select the file to be graphed.

CAPTURE can read comma-delimited ASCII text files with the following extensions: .RAW, .CDT, .DAT, .CAP and .TXT.

A file in the correct format but with the wrong name extension can have the name changed to conform with the naming protocol and thus become readable by CAPTURE.

CAPTURE will immediately examine the file, parsing it, looking for and identifying bad data, see paragraph 6.5 below.





6.4 Downloading from RAD7

6.4.1 Connection to RAD7

Connect a null-modem cable between the RAD7 RS232 connector and the RS232 connector on the PC or on a USB/RS232 adaptor plugged into a USB connection on the PC. (Make sure the PC has a working driver for the USB/RS232 adaptor. If not sure, go to the adaptor manufacturer’s web site and download the latest driver for that adaptor and for the PC operating system.)

6.4.2 RAD7 Setup

Set the RAD7 baud rate to 9600 baud (Special, SetBaud, 9600 [ENTER]). Please note that some older RAD7s do not have RADLINK installed, in which case they are limited to the default baud rate of 1200 baud.

6.4.3 CAPTURE Setup

Click on the “Download from RAD7” button.

a) Choose Destination

Click on “Choose Destination”. Browse to the data directory, creating one if necessary. Choose a suitable file name for your data file, such as the serial number of the RAD7 plus the date.

b) Show Radon Graph

To see the data graphed on the screen leave this button checked.

c) Port

Choose the correct port from the drop-down list.

If you are using a USB/RS232 adaptor and are uncertain which is the right port do the following: Without the adaptor attached to the PC, run CAPTURE and note the serial ports available. Close CAPTURE, attach the adaptor to the PC, run CAPTURE again and see the new serial port. That is the one associated with the adaptor.

d) Baud Rate

From the drop-down list choose the same baud rate as was set on the RAD7 (see 6.4.2 above). If the RAD7 does not have RADLINK installed choose 1200.

6.4.4 Initiating download

On the RAD7 with RADLINK go to Special ComAll but DO NOT PRESS ENTER.

On the PC click “Download”.

On the RAD7 push ENTER, whereupon you will see the data entering the window on the PC screen. When complete, the entire contents of the RAD7 memory will be transferred to the PC.

If the RAD7 is without RADLINK go to Data Com NN. Use the arrow keys to pick the run number to be downloaded. DO NOT PRESS ENTER.

On the PC click “Download”.

On the RAD7 push ENTER, whereupon you will see the data entering the window on the PC screen. When complete, all the records of the chosen measurement run will be transferred to the PC.

If, in either case, the data was not transferred, or only junk characters appeared on the screen, re-check the set-up of both RAD7 and CAPTURE, correct the error and try again.

6.5 Parsing

On completion of data acquisition CAPTURE parses the data, collecting information from the various data fields in each record. If any of the data is outside the acceptable range of operation there will be a warning message pop up on the screen. If the problem is such that the data is useless or is not accessible, the offending record will be tagged.

If the data set has tagged records, the user will be invited to save a cleaned-up (.cdt) data file, in addition to the raw data file already saved, and to display a graph of the cleaned up data.

6.6 Thoron Parameters

After parsing and before graphing, CAPTURE looks for thoron calibration parameters. If these have not been entered (in the Preferences window) a screen will be displayed asking for either confirmation of the default values or for the required values to be entered.

6.6.1 Spill factor

While over 98% of the 214-Po decay alphas will give a count in window C of the spectrum, a very small percentage of the alpha particles will be emitted nearly parallel to the surface of the detector. These lose significant energy before finally entering the charge depletion region of the detector, thus producing a count in a lower-energy window, such as window B.

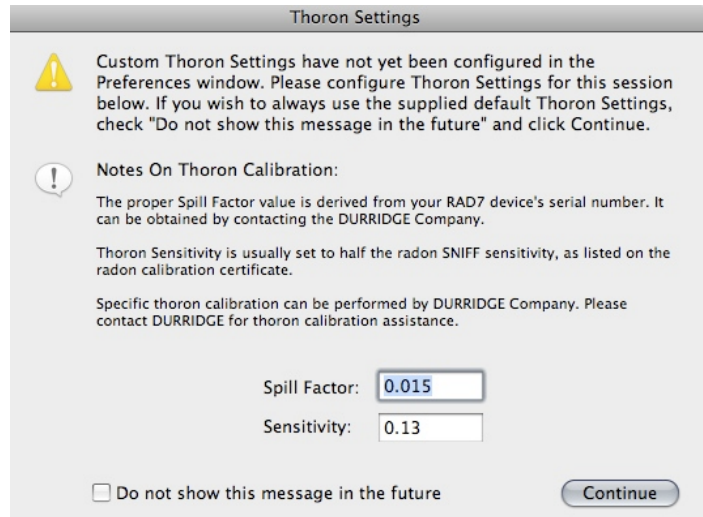
During calibration, the spill factor from window C to window B is measured and recorded in the RAD7 memory. This factor is used by the RAD7

to correct the count rate in window B for thoron readings when in thoron mode.

As a default value, CAPTURE uses a typical spill factor of 0.015 or about 1.5%. This is normally adequate but if the user wants to plot thoron values made after several hours of measurement of high radon levels, so that the count rate in window C is high, then it would be desirable to obtain the spill factor as measured at the last calibration. This is available from DURRIDGE Company (781) 687-9556.

6.6.2 Thoron sensitivity

When thoron is used as a tracer for new soil gas the absolute value of the thoron sensitivity is irrelevant. For such applications, the thoron sensitivity in the RAD7 is arbitrarily set at half the radon ‘sniff’ sensitivity. This is a good guess as typically about half the thoron will have decayed away during sample acquisition (with correct thoron protocol including the small drying tube and thoron mode set in the RAD7).



CAPTURE does not know the RAD7 sensitivity and therefore chooses a default value for thoron sensitivity of 0.13 cpm/pCi/L (0.0035 cpm/(Bq/m3)). This will be good enough for normal use.

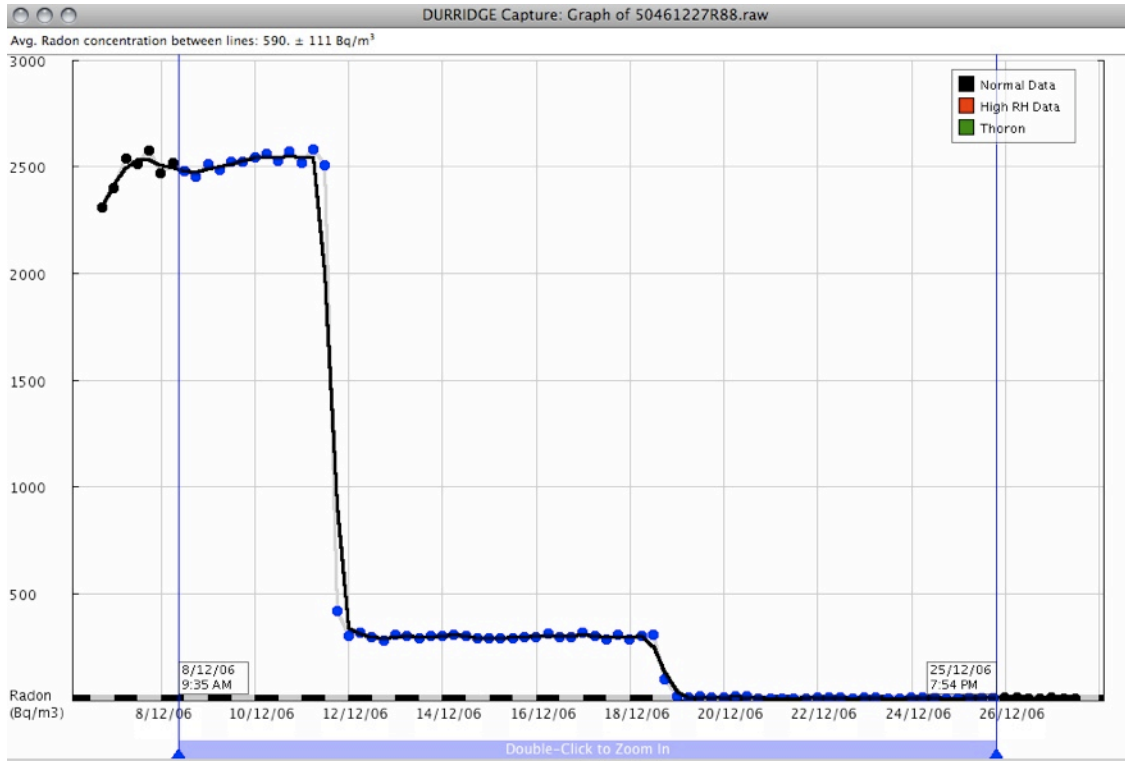
The user may improve the estimate by looking up the radon ‘sniff’ sensitivity on the RAD7 calibration certificate and dividing that number by two.

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For those who have a need for more accurate thoron measurement, the RAD7 can be calibrated by DURRIDGE Company for thoron sensitivity in whatever setup configuration the user desires. To be able to use that calibrated sensitivity it is essential that the same setup be used for the measurement as was used for the calibration. Specifically, a flow meter should be used to verify that the air flow rate during the measurement is the same as it was during the calibration.

If you click “Do not show this message in the future” CAPTURE will put the displayed values in the preferences file and use them for future thoron graphs without asking the user again. The values may be changed at any time by going to the preferences window.

Click ‘Continue’ and a graph will be displayed.



6.7 Main Graph

Initially, all the data points in the file will be displayed. This may consist of short measurement runs separated by long intervals.

6.7.1 Time axis

Along the X or time axis is a black and white line. It is black during morning hours, from midnight to noon and white during afternoon hours from noon to midnight.

Time markings and vertical grid lines are adjusted according to the time range and the dimensions of the graph.

6.7.2 Vertical axis

The vertical axis scales automatically to accommodate the range in values of the data being displayed.

Units may be selected from: Automatic, Bq/L, Bq/m³, dpm/L and pCi/L. Automatic means choosing the same units as those chosen for the original readings on the RAD7 itself. The rest are calculated from the original readings.

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If thoron is displayed, the thoron scale may be different from the radon scale and be placed on the righthand side of the graph, in green.

6.7.3 Graph lines

Graph lines join points judged to belong to the same run. The line weight may be adjusted and it may also be smoothed to reduce statistical variation.

Good radon data gives a black line and good thoron data a green line. If the relative humidity in the measurement chamber rises above 14% the line color for radon data changes to red.

6.7.4 Data points

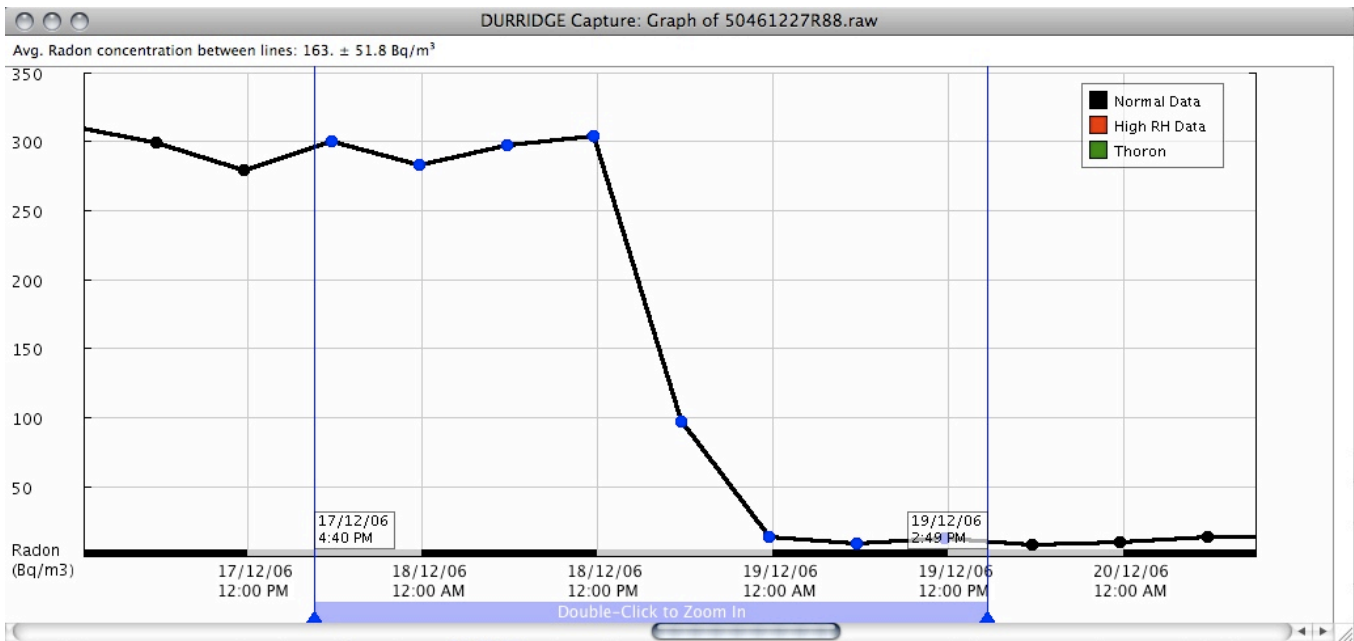
Data points may be displayed or hidden. Those within the selection (see below) are blue and those outside are black.

6.7.5 Cursor lines

The two vertical cursor lines define a selection of the data between the two lines. Each line may be dragged separately to bracket an area of interest on the graph. The time and date of each cursor line is indicated in a box at the bottom of the line.

Double clicking between the two cursor lines will zoom the graph in to display the selection, with a small border on each side.

If the lines are not moved, double clicking between them will toggle the zoom in and out. If the lines are moved, double clicking between them will always zoom in.



The selection may be scrolled along the time axis by holding down the shift key and clicking and dragging the mouse. On releasing the mouse click the vertical axis will adjust its range to accommodate the new data range. Also the scroll bar beneath the graph may be used to scroll along the time axis.

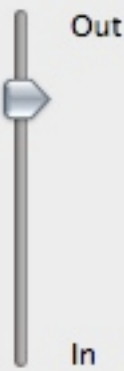
The average radon concentration in the selection is displayed at the top of the graph and also in the Graph Statistics box. The uncertainty given is that of the average and is determined by an analysis of the scatter in the data points.

Graph Controls

Smoothing:

Line Weight:

Units:

Graph Zoom:


Show Radon
 Show Thoron

Lock Y Scale To:
 Radon
 Thoron
 Both
 Neither

Manual Y Scale:
 Hi: Bq/m³
 Lo: Bq/m³

Show Legend
 Show Points

Show Log
 Show Spectrum
 Show Stats

6.7.6 Mouse

The mouse may be used to drag cursor lines and to drag the selection, see above. Bringing it close to a data point will show the radon concentration, date and time for that point. In addition the graph statistics box will show more information for that data point.

The mouse is also used for other typical control and selection functions, see below.

6.8 Graph Control Panel

The control panel, on the left of the screen, provides direct access to those functions controlling the graphical display. None of these functions make any change to the data itself, only to the graphical display.

6.8.1 Smoothing

The number to be chosen is the number of data points involved in calculating the smoothed radon value. For example, 3-point smoothing means that the point plotted is the weighted average of the data point and one point on either side.

Please note that smoothing not only reduces statistical scatter but also smooths out the response to sudden, real

changes in radon concentration.

6.8.2 Line weight

Adjusts thickness of graph line.

6.8.3 Units

Choose from selection. Automatic takes the original choice when the readings were made.

6.8.4 Graph Zoom

The vertical slider may be used to zoom in and out.

6.8.5 Show radon, thoron

Check these buttons to display the radon and/or thoron data.

If thoron is checked, CAPTURE will look to see if it thinks the thoron data is valid. If it is then the thoron data is graphed.

If not valid, a message will appear across the top of the graph "Invalid thoron readings are hidden. Check the thoron info button for details." On checking the thoron info button, after explaining why the thoron data is invalid, the user is given an override option to display the thoron data anyway, regardless.

6.8.6 Lock Y scale

The vertical scale may be locked to the radon data, the thoron data, both (with the radon scale on the left and thoron on the right of the graph) or neither. With 'neither' you enter your own upper and lower limits to the range.

6.8.7 Show Legend

This toggles on and off the display of the legend showing the colors of good radon, high-humidity radon and thoron lines.

6.8.9 Show Points

Toggles on and off the display of the individual data points. It is particularly useful to show the points when zoomed in to short time periods with a smoothed graph display. On the other hand, for

long time periods with closely spaced points, it is better not to show the individual points.

6.8.10 Show log

The log is a record of the tasks performed by CAPTURE. Displaying the log may be useful for trouble shooting and diagnostic purposes.

6.8.11 Show Spectrum

Toggles the spectrum display on and off.

6.8.12 Show Stats

Toggles the graph statistics box on and off.

6.9 Spectrum

CAPTURE can synthesize a spectrum that appears similar to that which may be printed out by the RAD7 at the end of each cycle and at the end of the run. In this case, however, the spectrum is based on the total counts in each of the windows, A,B,C,D of the selected points in the display. It is useful as an illustration and to visualize the growth of counts in window C as time progresses in a measurement run. However, this is not identical to the spectrum generated by, and printed by, the RAD7. Its use as a diagnostic tool is strictly limited.

6.9.1 Spectrum synthesis

The CAPTURE spectrum puts the peaks in Windows A through D in their correct place in the windows and it takes all counts that occur outside the A,B,C and D windows and puts them together as a peak at 5.3 MeV, caused by the presence of ²¹⁰Po on the detector surface. All the peaks are shaped to look something like a real RAD7 spectrum.

6.9.2 Pathological spectra and CAPTURE

The CAPTURE spectrum would all be correct for a RAD7 in good health. However, there are various pathological spectra that may be generated by a sick RAD7 where the peaks are not in their correct position and/or there are spurious points in and outside the A,B,C,D windows that are distributed randomly across the

entire spectrum (see chapter 3.13.4). These symptoms would be manifest in a real spectrum printed by the RAD7 but not in the synthetic CAPTURE spectrum.

6.9.3 Bar chart spectrum

To better indicate the relative counts in the windows, the CAPTURE spectrum may be displayed as a bar chart instead of the synthetic spectrum shape. In either case, the count rate is displayed under each peak or bar and the polonium isotope whose decays contribute to the peak is indicated at the top.

6.10 Graph Statistics box

This box is divided into three sections, the upper section, referring to the entire data set, the middle section, referring to the selected data set and the lower section, referring to an individual data point.

6.10.1 Entire data range

The data is self explanatory. The box shows the average radon level and thoron if appropriate. It gives the average relative humidity and temperature, the number of data points and the time range from the first to last data point.

The uncertainty displayed is that for the average value and is based on the actual scatter of the data points. However, if the statistical uncertainty is less than +/-5%, the uncertainty displayed will be +/-5% as this is the limiting accuracy claimed for the instrument.

6.10.2 Selected data

The data for the selected data points is identical in nature to that in the box above, except that it now is based on only the data points in the selection on the graph.

6.10.3 Point nearest to cursor

In addition to the data given in the pop-up box by the point, this section of the statistics box gives the uncertainty, the relative humidity, temperature, the cycle live time and the number of counts on which this measurement is based.

6.11 Drop Down Menus

Some of the options under this heading are generated by the operating system. Others are duplicated in the controls window on the screen.

6.11.1 Preferences

In the preferences screen choose whether to overwrite or append data when downloading data if the destination filename already exists.

Choose your preference of date format; dd/mm/yyyy or mm/dd/yyyy.

You can enter a thoron sensitivity and spill factor for each RAD7 you own. These will only apply if you are measuring thoron according to strict thoron protocol. Deviation from thoron protocol in any way will invalidate the sensitivity set in the RAD7.

6.11.2 Export Data

Clicking this gives the options of exporting:

- a) a cleaned up data file that will not generate error messages in ASCII text format,
- b) a file with tabs instead of commas to delineate fields or
- c) copying the file to the clip board for pasting into a spreadsheet program.

For options b) and c), clicking 'next' brings up a list of fields that may be included in the exported file.

Clicking 'next', asks for a filename and destination.

6.11.3 Export Selected Data

Does the same as Export Data, above, except that the file will contain only the selected data on the screen between the cursor lines.

6.11.4 Save Graph Picture

This saves an image of the graph as displayed on the screen but without the legend and without the cursor lines.

6.11.5 Join Data

With this command you are able to join two RAD7 data files together. Any duplication of records in the files is eliminated. This can be particularly useful if there are two or more files of data from the same RAD7 covering different time periods of a single radon study.

6.11.6 Copy Graph Picture

Provides a means to copy the graph to the clip board for pasting into some other application. The legend is included if displayed.

6.11.7 View menu

The View menu provides alternative access to the controls in the control panel.

7. Maintenance

Provided the RAD7 is treated with respect, the only maintenance required by the instrument is its regular recalibration. For this, it should be returned to DURRIDGE Company, who will check the health of the instrument, and who will incorporate the new calibration factors in the instrument firmware.

If the instrument is to be used in a harsh environment, where water and/or mud may be splashed on the face plate, the RAD7 should be put in a box or large plastic bag. The air input may be brought into the container by a plastic tube from the sampling point. The air outlet should be left in the container, so that the RAD7 becomes surrounded by clean and dry air.

7.1 Accessories - Usage and Care

7.1.1 Desiccant

Two sizes of desiccant tubes are supplied. In the Normal Mode, use the large 2" diameter tube (laboratory drying unit). This unit will last for days under continuous operation at high humidity before it needs regeneration.

When used as a Sniffer, the small desiccant tube is recommended. It will last for several hours before replacement or refilling of the tube is necessary. To regenerate the desiccant, the granules should be removed from the tube and spread evenly in a thin layer on a metal or glass tray. Heat at about 200°C (400°F) for two hours or until granules turn uniformly blue. Allow the desiccant to cool in an airtight container before refilling the plastic tube.

How long will the desiccant last? This is a common question, and the following information should be helpful.

7.1.2 Laboratory drying unit

The column holds approximately 500 grams of Drierite desiccant. This desiccant can adsorb at least 10% of its weight in water, so the water capacity of the column is at least 50 grams. The RAD7 pump develops a flow rate of about 1 liter

per minute. With the RAD7 set for continuous monitoring with timed pump operation, the pump operates 20 to 30% of the time. We will assume an average flow rate of 0.3 liters per minute.

The following table shows the moisture content of air at various conditions of temperature and humidity, and the expected lifetime of a charge of desiccant in the Laboratory Drying Unit.

RH	Deg. C	Deg. F	Column Life Days
30%	20	68	23.1
30%	35	95	9.8
50%	20	68	13.3
50%	25	77	10
90%	10	50	13.7
90%	15	59	10
90%	20	68	7.4
90%	25	77	5.5
90%	30	86	4.2

7.1.3 Small drying tube (small tube)

The small drying tubes each contain 30 grams of Drierite desiccant. The water capacity of each tube is 3 grams. We will assume that the Rad7 pump operates continuously, for an average flow rate of 1.0 liter per minute. The table shows the expected lifetime of a small drying tube under various humidity conditions.

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RH	Deg. C	Deg. F	Tube Life Hours
30%	20	68	10
30%	35	95	4.2
50%	20	68	5.7
50%	25	77	4.3
90%	10	50	5.9
90%	15	59	4.3
90%	20	68	3.2
90%	25	77	2.4
90%	30	86	1.8

7.1.4 Cascading drying tubes

To extend the time before desiccant depletion, you may cascade several drying tubes in series. Two factors limit the number of drying tubes you can use. First, each additional drying tube or column adds a small amount of resistance to the air flow, so the pump will have to work a little harder. But the resistance added by a drying tube is much less than the resistance of the inlet filter, so you should be able to cascade several without severely restricting the air flow. Second, each additional tube adds a time lag between sample intake and instrument response.

For continuous monitoring, a 10- to 20-minute lag may be perfectly acceptable, but for sniffing it may not be. You can conservatively estimate the time lag by taking four times the volume of the drying system and dividing by the average flow rate. Consider a continuous monitor application using a laboratory drying column of volume 0.8 liter with the pump in timed operation, giving average flow rate of 0.2 liters per minute. Four times the volume divided by the flow rate gives 16 minutes for the estimated lag time. This would be perfectly acceptable for continuous monitoring. For radon sniffing, you will usually use the small drying tubes (volume .032 liter), which create negligible delays of less than a minute, even at low flow rates. You can cascade several small drying tubes without trouble.

Do not cascade drying tubes when sniffing for thoron, since thoron's 56-second half-life necessitates that you keep delays to an absolute minimum. For thoron sniffing, use a single small

drying tube, and set the pump for continuous (on) operation. Keep hose length to 6 feet (1.8 meter) or less.

7.1.5 Filters

Inlet Filters are supplied that fit the metal inlet fitting (male Luer type). These filters block ultra fine dust particles and all radon daughters from entering the RAD7 test chamber.

The filters are manufactured in various pore sizes by several companies, including Millipore and SRI. We favor pore sizes of 1.0 microns or less; pore sizes as small as 0.4 microns can be used with the RAD7 pump.

The filter should be replaced when it has become noticeably discolored or has clogged enough to impede the flow of air. If you cannot suck air easily through the filter yourself, it's time to change the filter.

When you operate the RAD7 in construction areas or basements, dust can quickly build up in sampling hoses, drying tubes, and inlet filters. This dust will slowly clog the filter, restrict air flow, and create strain on the pump. You will have to replace the inlet filter. To greatly slow the buildup of dust, we recommend that you attach a "prefilter" to the intake of the sampling hose, to prevent coarse dust particles from entering. Then, the inlet filter will remove the ultra-fine dust particles that pass through the prefilter and drying system.

We find that automotive gasoline filters can serve as convenient and inexpensive prefilters. A particular filter, intended for Volkswagens, is a small, disposable, clear-plastic capsule containing a pleated paper filter. This filter effectively removes most dust from the air stream, greatly extending the life of the inlet filter. You can buy this type of filter in almost any auto parts store for around \$3.

7.1.6 Batteries

Your RAD7 has enough battery capacity to go for two to three days without any external power source. Electronic circuits control the charging and discharging of the battery, avoiding overcharge or destructive discharge. If you maintain the batteries according to the following

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directions, you can expect to get two to five years of heavy service from them.

Keep the batteries fully charged as much as possible. Try to recharge promptly after use.

The RAD7 batteries charge whenever the power cord is connected to AC wall power and the RAD7 switch is on. Batteries will not charge with the switch off. Plug the power cord in first, then throw switch to on to put the RAD7 into fast charge mode.

With the power cord plugged in and the RAD7 measuring radon, the batteries will charge slowly. Full recharge takes about 48 hours.

With the power cord plugged in and the RAD7 in fast charge mode (not measuring radon), the batteries will charge more quickly. Full recharge takes about 24 hours. The battery voltage indicator on the display (go to the third status window) will reach 7.10 to 7.20 volts when the batteries are fully charged and the power cord is still plugged in.

If the batteries are deeply discharged, to the threshold of battery damage, an electronic circuit will completely disconnect them to avoid further discharge. The circuit will then not allow battery operation until they are completely recharged. If this occurs, you may still be able to operate the **RAD7** from AC power until the batteries recharge. Expect the recharge to take 48 hours.

Never store the **RAD7** without first recharging the batteries. If you intend to store the **RAD7** for a long period of time, you must recharge the batteries at least every four months, as they can be damaged by self-discharge on the shelf. Otherwise, you may have to replace the batteries before you can use your instrument again.

Battery voltage can be read from the Status display, and appears on printed output. A fully charged battery will rest at 6.40 to 6.50 volts. As the battery discharges, its voltage drops steadily to 6V. If the battery voltage ever goes below 6.00 volts, it is fully dis-charged and should be recharged as soon as possible. As the battery charges, its voltage rises steadily until it goes above 7V. Consider the battery fully charged if it charges at above 7V.

7.1.7 Real-time Clock and Non-volatile Memory

The RAD7's Real-Time-Clock (RTC) and Non-Volatile Memory unit (NVRAM) allows the RAD7 operator to switch power off without losing data or disrupting the clock time and date. These functions are powered by a lithium cell with an expected lifetime of ten years.

7.1.8 Printer and Adapter

The printer is manufactured by Hewlett Packard for one of their lines of programmable calculators. It comes with its own manual, and you should familiarize yourself with its operation. Specifically, you should be aware that it operates through an infra-red optical link and should be positioned on the top of the RAD7 to match the data link on the detector. It runs on its own batteries, or by an adapter plugged into AC current

The printer features an automatic power-down mode to conserve battery power. This means that it will switch itself off about 10 minutes after it stops receiving data from the RAD7 computer. This power-down mode can be avoided by using the AC adapter, to keep the printer supplied with external power. To reactivate the printer, should it go to sleep, press the paper advance button.

7.2 Operating ranges

Parameter	Minimum and Maximum
Temperature	0EC - 40EC 32EF - 104EF
Relative Humidity, external	0% - 95%
	Note: Must be non-condensing
Relative Humidity, internal	0% - 10%
Battery Voltage	6.00V - 7.20V
Pump Current (pump off)	00 - 10
Pump Current (pump on)	30 - 90
High Voltage	2100V - 2400V
HV Duty Cycle	8% - 20%
Leakage Current (room temperature)	00 - 20
Leakage Current (maximum temp.)	5 - 80
Signal voltage level	0.15 - 0.30

7.3 *Service and Repair*

7.3.1 Calibration

DURRIDGE maintains a radon calibration facility that includes a controlled, standard source of radon gas, and a controlled-temperature environmental chamber. All RAD7 alignment and calibration is done here, as well as basic testing and quality assurance. We determine calibration factors by direct comparison to "master" RAD7's, which were themselves compared with EPA and DOE instruments, and which have participated in international inter-comparisons of radon instrumentation. The calibration accuracy is independently verified by direct determination of the radon chamber level from the calibrated activity and emission of the standard radon source. In addition, we periodically intercompare with other radon chambers. We generally achieve a reproducibility of better than 2% with our standard RAD7 calibration. Overall calibration accuracy is in the range of "5%.

The EPA recommends (and we agree) that all continuous radon monitors be calibrated at least every six months in a radon calibration chamber, although most RAD7 users are satisfied with annual recalibration. DURRIDGE's standard RAD7 calibration requires four to five working days from the receipt of the instrument. And we usually return it to you via the same shipping method you used to get it to us - from "slow boat" to "next day air." As a preliminary to recalibration, we give every RAD7 a brief inspection, and test one or two critical parts. If additional service is required, this may delay the return of the instrument.

We recommend that you arrange for your calibration ahead of time, to avoid possible delays. When sending your RAD7 for calibration, please send the instrument only, without the accessories, and please pack it well, with at least an inch of packing all round.

At present, only DURRIDGE can make adjustments to your instrument's alignment and calibration factors. If you determine, on the basis of an independent intercomparison (e.g., another calibration chamber) that you would like to adjust your RAD7's calibration by a known amount, we can generally perform this service and send back

your instrument within one day. Requested calibration adjustments of more than 10% are considered highly unusual and require the written permission of the instrument's owner.

7.3.2 Repair

If you discover that your RAD7 is malfunctioning, we recommend that you first call DURRIDGE and talk to a technician. A surprising number of minor "disasters" can be avoided by long-distance consultation. The next step, if consultation fails, usually is to send your instrument in for evaluation and repair. Please send any documentation of the problem that you might have (notes, printouts, etc.) and a short note describing the problem. Be sure that you put your name and telephone number on the note. Within 48 hours of our receipt of the instrument, we will call you to give a prognosis.

Bear in mind that a repaired instrument often requires complete re-calibration, so a one-week turn-around may be the best we can do. If you absolutely need an instrument during the repair time we can sometimes arrange to send you a "loaner" instrument.

7.3.3 Shipping

The RAD7 is shipped to you in a plastic bag, packed in a box with "popcorn, and finally packed inside another box that also holds all the accessories. The inner box, by itself, is too small for the return trip, when you need a calibration or repair job. You need to find a bigger box, with space for one inch packing all round the RAD7. A 14" cube box is fine. Pack and seal the box carefully.

Please do not ship any accessories, unless they are relevant to the problem.

All return shipments to DURRIDGE must be prepaid, and unless you instruct us otherwise, we'll return it to you via the same shipping method you used to get it to us - from "slow boat" to "next day air", freight collect.

7.3.4 Upgrades

Whenever you send your RAD7 in for repair or calibration, you have the option of having the latest available software installed. Most RAD7's

can be upgraded to the latest hardware configuration as well. You will be informed periodically of whatever new features are available for your RAD7. Please advise if you want to have an upgrade made. We intend to keep our RAD7 customers happy by keeping their instruments up-to-date, state-of-the-art.

7.4 *RAD7 Quality Assurance*

While the annual inspection and calibration, carried out by DURRIDGE Company, is the most effective quality assurance, and the prime requirement of EPA, there are other tests and observations that may be made that will give assurance of good performance throughout the year.

7.4.1 **Spectrum**

At least once a month, the spectrum printed by the HP printer should be observed. The cumulative spectrum, printed at the end of a run, has the most data points and is, therefore, the most useful for this purpose. All that is required is that the printer be placed on the face plate and switched on, with external power, at the end of a 1-day or 2-day run. It doesn't matter what format is chosen, the summary printed at the end of the run will conclude with a cumulative spectrum, after the bar chart. Alternatively, the RAD7 will print a spectrum at the end of every cycle if the format is set to LONG. However, this will include only the counts during that cycle. For the spectrum to be useful it should have at least 100 counts. There should be clearly defined peaks and little or no

noise across the spectrum. The peaks should be located in the middle of the windows. A clean spectrum is indicative of an instrument in perfect working order, and hence of reliable and accurate readings.

7.4.2 **Spill Factor**

Due to the occasional alpha particle emitted, from a polonium atom on the detector surface, at grazing incidence to the surface, there is always a small, low-energy tail to the peaks. This may be observed in the printed spectra. There is thus a spill of 214-Po counts from window C into window B. It is normally around 1% to 1.5% in a current production RAD7. The actual value is measured during the calibration process and the spill factor used to compensate for this phenomenon when measuring thoron in the presence of radon.

If the detector becomes contaminated in use, or either electronic or detector failure causes noise in the system, thus making the low-energy tail thicker, or the peaks broader, then this spill factor will increase. The value can be calculated from any reading, provided that it is known for sure that there was no thoron in the chamber. The percentage of counts in windows B and C is given in fields 10 and 11 of each record in memory (see ¶ 5.1.6). The spill factor is simply the ratio of the values in those two fields.

It is recommended that the spill factor be noted every month. Any sudden change is cause for further study of the instrument, and an examination of the spectrum.

7.5 *RAD7 Specifications*

Specifications for the RAD7 exceed those of all radon gas monitors made in North America, as well as those in its price range world-wide. This is a partial list of specifications that make the RAD7 so highly regarded in the field.

Target Gases: Radon 220 (Thoron) in addition to Radon 222.

Spectrum: Only instrument under \$10,000 world-wide that prints out the alpha energy spectrum, showing radon and thoron signature peaks. Prints out radon concentration as a function of time.

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RAD H ₂ O:	An attachment for fast and accurate analysis of radon in water on site.
Recovery:	Most rapid in the industry. Leave a hot spot and in 20 minutes the reading of the RAD7 is down to less than 5% of its high value.
Remote:	Remote and modem control capability available.
Detector:	Passivated, Implanted, Planar Silicon detector, insensitive to vibrations and noise that plague many other detectors. Extremely low background. If there is no radon, there are no counts in the radon window of the RAD 7.
Calibration:	Highly stable. Typical drift is less than 2% per year.
Dynamic Range:	0.1-10,000 pCi/L (4 - 400,000 Bq/m ³). As there is no background, it easily measures down to 0.1 pCi/L. Extremely useful since most readings are (happily) below 1.0 pCi/L.
Sensitivity:	In sniffer mode: 0.2 CPM/pCi/L. In normal mode, 0.4 CPM/pCi/L.
Operating Modes:	48-hour and 24-hour pre-set protocols. Radon and Thoron SNIFF MODE, for continuous diagnostics. High and low-sensitivity water protocols. Grab-sample testing. User-defined, and saved, custom protocol.
Pump:	Microprocessor controlled, timed or continuous: 1 liter/min.
Data Storage:	1,000 radon concentration measurements, including time, date, temperature, humidity, battery voltage, thoron and statistical uncertainties.
Data Display:	Two line x 16 character LCD display. Multiple windows and extensive menus.
Cycle Time:	Cycle intervals set to your requirements, 2 minute to 24 hours.
Controls:	Keyboard: 4 keys. Very easy to operate. Standard procedures are pre-programmed, so an unskilled operator can use them. Individual setups can easily be pre-programmed and saved.
Output:	RS-232 port, to download to computer. Can also be used for remote control of RAD7 and/or control of external relay box, with optional RADLINK Software.
Power:	110V (or 220V) AC. Overvoltage category II Sealed Lead-Acid, Gates Monobloc type 0819-0012, 6V 2.5Ah, rechargeable batteries for 72-hour operating time per charge. Built-in charger and power management system. Optional low voltage AC/DC input allows operation, and internal battery charge, from car accessory socket.
Size:	9.5" x 7.5" x 10.5", 9.2 pounds. With shoulder strap. Case: High-impact, high-density case. The RAD7 has passed many drop tests.
Printer:	Hewlett Packard 8224OB Alpha-numeric. Infrared link, no cord needed. Data, bar charts and spectra may all be printed during or at the end of a run.
Environment:	0°C—50°C; 0%—99% RH non-condensing. Storage temp: -40°C - 60°C.