



RTM 1688-2 RADON / THORON MONITOR



User Manual

RTM1688-2

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Important Hint

The determination of the activity concentration of Radon is always a radiometric measurement, meaning a counting experiment. This causes a number of specific circumstances which have to take in consideration by the one who carrying out this task. Only the knowledge of those particularities allows the correct set-up of a test and avoids misinterpretations of the achieved results.

Please read carefully the next chapters "Theory of Operation" and "Statistical Error" to become familiar with this kind of radiometric measurements.

Theory of Operation

The Radon (Rn-222) gas concentration will be measured by the short living daughter products, generated by the Radon decay inside a measurement chamber. Directly after the decay, the remaining Po-218 nuclei will be charged positively for a short period, because some shell electrons are scattered away by the emitted alpha particle. Those ions are collected by the electrical field forces on the surface of a semiconductor detector. The number of collected Po-218 ions is proportional to the Radon gas concentration inside the chamber.

Po-218 itself decays with a half life of only 3.05 Minutes and about 50% (particles emitted towards the detector surface) of all decays will be registered by the detector.

The equilibrium between the Radon decay rate and Po-218 detector activity is given after about 5 half life times, say 15 Minutes. This time span defines the minimum achievable response time to a Radon concentration step.

Now, the decay chain is continued by the both beta emitters Pb-214 and Bi-214 followed by another alpha emitter, the Po-214. That means, each Po-218 decay causes one more detectable decay by the Po-214 which is delayed about 3 hours because of the superposed half life times of those nuclides. The emission energies of Po-218 and Po-214 are different and therefore it is possible to separate both nuclides from each other by alpha spectroscopy. The RTM1688-2 offers two calculation modes for the Radon concentration, one (Slow) includes both, Po-218 and Po-214 decays and the other one includes Po-218 only (Fast). The advantage of the "Fast" mode is the quick response to concentration changes while the "Slow" mode gives a sensitivity twice as high compared with the fast mode. The higher sensitivity reduces the statistical error of a measurement which depends on the number of counted decay events only. The user should select the calculation mode carefully with respect to the application specific requirements (see next chapter).

In case of Thoron (Rn-220), the direct daughter product Po-216 (which also underlies the ionisation process) is used to calculate the Thoron activity concentration. The half life of Po-216 is less than 1s and therefore the equilibrium state between gas concentration and collected activity on the detector is present immediately.

The half life of the Po-216 decay products Pb-212 (beta) and Pb-212/Bi-212 (alpha) are too long to use them for Thoron measurement. The single nuclides of the Thoron decay chain will also be separated by alpha spectroscopy.

Statistical Error (for non mathematicians)

The radioactive decay is a statistical process. That means, even if the Radon concentration is constant over the time, the number of decays N counted within several intervals of the same period will be different. N will vary around the mean value of all considered intervals. Considering an infinite number of intervals would lead to an average which one indicates the “true” result of N . For a single interval, the value of N will be either below or above the “true” value. This observed deviation is covered by the term “Statistical Error”.

Therefore each serious measurement contains beside the calculated Radon value the error band for a stated confidence interval. The commonly used confidence intervals are 1, 2 or 3 Sigma (σ) which refer to a likelihood of 68.3%, 95.45% and 99.73%.

For example, the correct interpretation of a measured Radon concentration of 780 Bq/m³ with a statistical 1σ error of $\pm 15\%$ is:

The real “true” Radon concentration lies with a likelihood of 68.3% in the range from 663 Bq/m³ (780 Bq/m³ - 15%) to 897 Bq/m³ (780 Bq/m³ + 15%).

Error Prediction

The relative statistical error E for a chosen confidence interval of k -Sigma can predicted from the number of detected counts N by the equation:

$$E[\%] = 100\% \cdot k \cdot \sqrt{N} / N$$

The simple consequence is: The higher the number of counts the higher is the accuracy of the measurement. From the opposite point of view one can ask: How many counts I have to detect to achieve a predefined uncertainty?

Two items will affect the number of counted decays: The sensitivity of the instrument at the one hand side and the time period used for counting process (integration interval) on the other hand.

While the sensitivity is an instrument specific constant, the integration interval may be expanded to the maximum acceptable value for the desired time resolution of a measurement series.

The relationship between the measured Radon concentration C_{Rn} and the number of counts N within an integration interval T is:

$$C_{Rn} = N / (T \cdot S)$$

whereby S represents the Sensitivity of the instrument, given in the unit [cts/(min*kBq/m³)].

The sensitivity using the slow mode is double as high as in the fast mode (see chapter “Theory of Operation”) and whenever the required response time is more than 2 hours the slow mode should selected.

For the following examples a fast mode sensitivity of 4 cts/(min*kBq/m³) shall assumed while the slow mode sensitivity shall be 8 cts/(min*kBq/m³).

The first question could be: What an integration interval I have to set to get a statistical uncertainty less than 10% at a confidence level of 1σ if the expected Radon concentration is 200 Bq/m³?

A 1σ error of 10% needs 100 counts ($100\% \cdot 1 \cdot \sqrt{100} / 100 = 10\%$). Using fast mode the integration interval can calculated by

$$T(\text{fast}) = N / (C_{Rn} \cdot S) = 100 \text{ cts} / (0.2 \text{ kBq/m}^3 \cdot 4 \text{ cts}/(\text{min} \cdot \text{kBq/m}^3)) = 125 \text{ min.}$$

Because the required interval is longer than 2 hours, the slow mode is the better choice, leading to following result:

$$T(\text{slow}) = N / (C_{\text{Rn}} * S) = 100 \text{ cts} / (0.2 \text{ kBq/m}^3 * 8 \text{ cts}/(\text{min} * \text{kBq/m}^3)) = 62.5 \text{ min.}$$

That looks pretty but makes no sense because of the longer response time. So we will set the interval to 120 Minutes and ask for the statistical error in this case:

$$N(\text{slow}) = C_{\text{Rn}} * T * S = 0.2 \text{ kBq/m}^3 * 120 \text{ min} * 8 \text{ cts}/(\text{min} * \text{Bq/m}^3) = 192 \text{ cts}$$

$$E(1\sigma) = 100 \% * 1 * \sqrt{(N)} / N = 100 \% * 1 * \sqrt{(192)} / 192 = 7,22 \%$$

Now one could say 68.3% is not sure enough, I want to choose 2σ confidence interval to get a more trustable result:

$$E(2\sigma) = 100 \% * 2 * \sqrt{(N)} / N = 100 \% * 2 * \sqrt{(192)} / 192 = 14,44 \%$$

For interpretation look at the begin of this chapter.

Is an observed concentration change statistical significant or not?

If you have a look at the acquired time distribution you will see variations of the concentration from point to point. The question is now: Is it a real change in Radon concentration or only a statistical fluctuation?

The test is very simple: Define a confidence level with respect to your needs and look at the statistical error bands of the two points of interest. If the error bands do not overlap each other, the change in Radon concentration is significant otherwise it "can be or not can be".

Example 1:

Reading 1: $1500 \text{ Bq/m}^3 \pm 10\%$ → error band [1350 ... 1650 Bq/m^3]

Reading 2: $1300 \text{ Bq/m}^3 \pm 13\%$ → error band [1131 ... 1469 Bq/m^3]

The upper limit of the error band of the reading 2 is higher than the lower limit of the error band of reading 1. Because the "true" value could be placed within 1350 Bq/m^3 and 1469 Bq/m^3 , the variation of both readings is not statistically significant.

Example 2:

Reading 1: $1500 \text{ Bq/m}^3 \pm 10\%$ → error band [1350 ... 1650 Bq/m^3]

Reading 2: $1000 \text{ Bq/m}^3 \pm 15\%$ → error band [850 ... 1150 Bq/m^3]

The error bands of the readings do not overlap each other. Therefore, a statistically significant concentration change is given.

Two arbitrary points of a measurement series may be considered using this test. It is not necessary that the points are direct neighbours.

Detection Limit

The term Detection Limit defines the smallest value of the Radon concentration which delivers a non zero reading of the instrument within a given integration interval (at least 1 decay per interval). Because of the statistical behaviour a related confidence interval has to be stated.

Why is it necessary to know the Detection Limit? If the set integration interval is short and the Radon concentration low, the expected "true" value of the number of detected decays may be around or less than 1. Because of the statistical variations, intervals without any detected decay will appear frequently. The most extreme situation would be a measurement series with a lot of "zero" intervals and only one interval with one detected decay (because a decay can not be split).

When calculating the Radon concentration by the given formula, the concentration value for the interval with the one count is much too high while all other values show zero. Then, all intervals have to be averaged to get a usable result. This procedure is nothing else than to create an integration interval long enough to meet the Detection limit for the applied Radon

concentration. To avoid zero readings, set the integration interval with respect to the lowest expected concentration level during measurement.

The mean („true“) value of the number of decays during an integration interval in case of a Radon concentration in the surrounding of the detection limit is less than 16 and therefore the statistical fluctuations have to be derived by the Poisson distribution. The stated confidence interval gives the probability that the detected number of decays within the interval is not zero.

Confidence Interval	Required Mean Value for N at the Detection Limit
63,2 %	1
95 %	3
99,75 %	6

Example:

Determination of the detection limit of the Monitor using the „Fast-Mode“ and an integration interval of 60 Minutes. The confidence interval shall be 95% (that means in about 95 from 100 intervals a no zero reading should appear):

Required mean value (number of counts from table): $N = 3$.

Calculating the detection limit by formula:

$$C = N / (T * S) = 3 \text{ cts} / (60 \text{ min} * 8 \text{ cts}/(\text{min} * \text{kBq}/\text{m}^3)) = 0,00625 \text{ kBq}/\text{m}^3 = 6,25 \text{ Bq}/\text{m}^3$$

The detection limit in this case is 6,25 Bq/m³.

Operating the Instrument

Power supply

Please insert the fuse at the backside of the instrument before using the instrument. The instrument has no power switch because the power consumption of the electronic circuits is less than the self discharge of the battery. After inserting the fuse the instrument enters the stand by status, the display will show "RTM 1688 SN:XXXXX". It is necessary to set the real time clock of the instrument in that case (see manual "Radon Vision")

To maximise the capacitance and battery life time, the battery should be charged from time to time (each 3 months) even if the instrument is not in use. Otherwise the battery may become discharged deeply which can cause malfunction of the internal microprocessor. Remove the fuse if battery maintenance is not guaranteed over long periods.

The instrument is powered either by the internal 12V/3.2Ah lead gel battery or by the AC/DC wall adapter included in delivery. The battery allows an autonomous operation for more than 24 hours. The battery will be recharged as long as the AC/DC adapter is connected, the red LED on the "TOGGLE" button turns on. It takes about 8 hours for full charging in case of a totally discharged battery. The end of the charging process will be indicated by a lighting LED on the "LIGHT" button.

If the battery voltage drops below 11.8V, the display will show the phrase "LOW BATTERY!" after finishing each integration interval. The measurement is still continued for several hours. Pressing the "TOGGLE" button leads to the standard display output. If the battery voltage decreases down to 11.2V the running sample will be stopped and the instrument enters the stand by status.

Carrying out a measurement

Press the push button to start a new measurement series. The pump starts and the display will show the remaining time to complete the first integration interval.

```
RTM1688 SN:00001
Wait 120 Minutes
for first data !
```

The actual status and set-up information (see below) may be displayed by pressing the button again.

If the first interval has been completed, five different display pages are available. The several pages can be toggled by repeatedly pressing the push button. Depending on the selected system of units, the concentration values are given either in 'Bq/m³' or 'pCi/L' (mbar/inHg, °C/°F)

The first page shows the actual Radon concentration (calculated for the last sampling interval) with the statistical error for a 1 Sigma confidence interval. If "Fast" mode was selected, a starlet is appended to the word "Radon" in the first row. Right beside, the time stamp is given when the integration interval of the calculated concentration was finished

The bottom row contains at the left hand side the total number of integration intervals since the last start of a measurement series. At the right hand side the pre-set integration interval and the remaining time period of the actual sample is displayed.

```
Radon*      12:20
            85Bq/m3±10%
#34      117/120Min
```

Page two gives the same information for Thoron (Rn-220)

```
Thoron      12:20
            124Bq/m3±16%
```

#34 117/120Min

The readings of the additional sensors are shown at the third page. Those values represent the average derived from all “one Minute shots” of the whole integration interval.

Ambient 12:20
21.5°C 987mbar
46%rH 12.3V

The next page shows the average values of the Radon and Thoron concentration from the begin of the actual measurement series. The total sampling time is given in the first row.

Average 68.0Hrs
Rn: 314Bq/m³
Tn: 141Bq/m³

The last page contains the status information, beginning with the date and time of the start of the measurement series followed by the actual alert settings in the second line. The lower line shows the selected pump and sniffing mode.

>>17.04.06 16:32
ALM: 250Bq/m³
CONT. SNIFF216

To finish a measurement series keep the push button down and wait for at least four beeps from the buzzer. Then, if the button is released, the sample will be stopped. If the button has been locked by software, the button has to be unlocked before.

Operation Modes

Pump

There are two different pump modes available, either continuous or interval pumping, selectable by software. In continuous mode the pump is running during the whole measurement period while the pump will switch off after the first five Minutes of each new integration interval in case of interval mode. If the selected integration interval is less than five Minutes the pump will run continuously too.

Alarm

If the measured Radon concentration exceeds the programmable alarm limit, the buzzer will sound shortly each second. The alert has to be acknowledged by pressing the push button. The alert check is performed after completion of each integration interval. If the alert is enabled, "ALARM ON" will appear in the lower line of the status page.

Fast/Slow Mode

"Fast" and "Slow" mode will determine the kind of calculation of the Radon concentration. Please refer to the chapters "Theory of Operation" and "Statistical Error".

Sniffing

The sniffing function allows to detect Radon by an audible signal. That means each decay of the daughter products (either Po-216 only or Po-216 and Po-218, dependent on the user settings) will cause a short beep. Especially the Po-216 (if present) with its short half life will give a rapid information about local concentration changes.

Data Handling

Data Storage

All data are stored in a non volatile memory using a circle architecture. That means, the last 511 data records (data of last 512 integration intervals) remains in the memory. Older data will be overwritten if the memory exceeds the limit. Because the complete measurement data

are transferred during download to the PC, the memory should be cleared after successful data transmission and storage on hard disk. This will save time during the next transmission and avoids redundant data storage.

Each data record is stored after completion of the integration interval and contains the full information of this single integration interval:

- time stamp
- integration time
- alpha spectrum
- readings of additional sensors

All sequential records with a time distance to the last record equal to the integration interval are interpreted later as one measurement series. The measurement may be interrupted as often as desired to finish the old and start a new measurement series. There is no limit for the number of series. Single point measurements are also possible.

Printing a protocol

The RTM1688-2 enables the direct printout of acquired data on the portable protocol printer GEBE GPT4333. Only the last acquired measurement series can be printed. Connect the printer to the RTM by the adapter cable (9-pin SUB-D male to 3-pin round connector) included in delivery.

To switch on the printer press the right button at the panel (arrow). The green LED starts blinking. Note: after about one minute, the printer switches off automatically if no print job has been carried out.

To force a protocol print, the instrument has to be set in stand-by mode - stop measurement in case of a running sample.

Start the print out by pressing the "TOGGLE" button for at least 5 seconds (wait for four beeps). During print out the display will show the phrase "...print protocol".

If a new series was started unintendedly, the measurement may be stopped again before completing the first interval. The print data remain valid as long.

The protocol header contains the serial number of the instrument, the beginning and the end of a measurement series, the Radon and Thoron average concentrations and the time period used for averaging (between start and end of the test). The header is followed by the records of the measurement series containing time stamp, Radon and Thoron concentration and environmental sensor readings.

RTM1688 SN:00040

Begin	06/12/23	12:34
End	06/12/24	17:34
Average	12.2Hrs	
Radon	1234567Bq/m ³	
Thoron	1234567Bq/m ³	

04/27/06	15:32
Radon	1234567Bq/m ³ +12%
Thoron	1234567Bq/m ³ +12%
25.5°C	56%rH 1002mbar

... more records

GEBE GPT4333 printer information: The printer is supplied by an internal rechargeable NiMH battery which can be recharged using the 6V/800 mA AC/DC mains power adapter. It takes about 5 hours to complete the charging process. During charging the green LED blinks green and if the battery reaches the final voltage, the LED lights permanently green. A discharged battery is indicated by a red blinking LED. The LED blinks also red in case of paper end detection.

To insert a new paper spool, the paper compartment can be opened by pulling slightly the lever at the top of the cover. Unroll approximately 10 cm from the new paper spool and insert the spool in the way that the unrolled end comes from the bottom up at the keypad (front) side. Pull the paper end over the keypad and close the cover again.

For more detailed information please look at the printer's operation manual.

Data transfer

The acquired measurement data can be downloaded to a PC using the serial interface. Connect the PC interface cable (9-pin SUB-D female to 3-pin round male) to both, instrument and PC COM port. If the PC is not equipped with a standard COM port a USB to Serial converter can be used. For further information read the software manual.

Technical Data

Measurement Ranges

Radon, Thoron	1 Bq/m ³ ... 10 MBq/m ³
Temperature	-20 °C ... 40 °C
Humidity	0 ... 100 %
Bar. Pressure	800 mbar ... 1200 mbar
Response time (95%) Radon (fast/slow)	15 / 150 Minutes
Sensitivity (fast/slow)	2.5 / 5.5 cts/(min*kBq/m ³)
Sample Interval	1 ... 255 Minutes (adjustable)
Memory	511 data records
Pump rate	0.25 l/min
Internal volume (chamber + air loop)	approx. 250 ml
Power supply	
Battery operation	> 7 days (continuous pumping) > 14 days (pump in interval mode)
Recharge Time	8 Hours
AC/DC adapter	18V/1A
PC/Printer-Interface (Serial)	RS232, 9600 Baud, 8N1
Dimensions	232 mm x 182 mm x 135 mm
Weight	3.5 kg
Tamper detection	if instrument is moved > 8 Seconds
User interface	Display 3 x 16, 2 push buttons, buzzer