User Manual RTM1688-2

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Content

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 is 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 become 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 time 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 the 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 be also separated by alpha spectroscopy.

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 month) 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 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. The pressing of the “TOGGLE” button leads back 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.

Input Filter

The instrument is equipped with a high efficient multi-stage filter to prevent penetration of daughter products into the measurement chamber. This filter will be protected against contamination by an additional syringe filter fitted to the air inlet. Do not use the instrument without that filter and replace it if required (becomes dark if loaded with dust). Take care for the correct flow direction. Some filters can block the air flow completely when used in wrong flow direction.

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 repeated 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. These values represent averages which are derived from all "one Minute shots" of the entire 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 start 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. 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.

Adjustment of the sampling interval

The adjustment can be carried out as long the sampling is stopped. The “TOGGLE” button must be hold down for at least 6 seconds (beeper). On the display appears:

INTERVAL: 1min

Now, the interval can be toggled by the button between 1, 5, 10, 15, 30, 60 and 120 minutes. To accept the new setting, the button must be pressed again for at least 6 seconds.

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 the user to detect Radon by an audible signal. That means that any disintegration 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 circular architecture. That means, the last 2047 data records (data of last 2047 integration intervals) remain 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 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 AP 1300. 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 the delivery. To switch on the printer press the right button at the panel. The LED is constant, green. Note: after about 30 seconds, the printer switches in the sleep mode if no print job is carried out. To start a protocol print, the instrument has to set in stand-by mode - stop the measurement in case of a running sample. Start the printing out by pressing the “TOGGLE” button for at least 5 Seconds (wait for four beeps). During printing out the display will show the phrase “...print protocol”. If a new series was started unintended, the measurement may 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 start 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:XXXXX

Begin        06/12/23 12:34
End          06/12/24 17:34
Average             12.2Hrs
Radon          1234567Bq/m³
Thoron         1234567Bq/m³
-----------------------------
04/27/06              15:32
Radon     1234567Bq/m³±12%
Thoron    1234567Bq/m³±12%
```

```
25.5°C   56%rH   1002mbar

... more records
```

AP 1300 printer information: The printer is supplied by an internal rechargeable NiMH battery which can re-charged using the 9V/270 mA AC/DC mains power adapter. It takes about 15 hours to complete the charging process (full charged). During charging the LED lights orange and blinks short green. A discharged battery is indicated by a short red blinking LED. The LED blinks also red in case other problems.

To insert a new paper spool, the paper compartment can be opened by sliding the Lid Release Button forward until the lid springs open. Unwind a small amount of paper from the roll and insert the paper roll into the printer. Close the lid down, and the paper is loaded. 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.

Version RTM1688-2 MODBUS

General information

A modified firmware is implemented in this version of the instrument which allows the integration of the unit into MODBUS RTU (industrial standard) based networks. Because the RTM1688-2 offers no native RS485 hardware interface, the instrument must be connected to the bus lines through a commercial available RS232/RS485 converter. The converter must support the automatic switch-over between the transfer directions. We recommend a converter with optical-isolated RS485 data lines such as EXPERT EX9520R. The MODBUS interface supports only the transmission of the recent readings. For all other functions the SARAD standard protocol has to be used. The protocol frames are explained in detail by the document "SARAD_MODBUS_Protocol". The complete MODBUS Documentation can be found in the internet under "modbus.org".

In comparison with the standard instrument, for the MODBUS version the following functions are skipped:

- Protocol printing
- Toggling of physical unis (US/SI) – only SI units are supported
- Display of setup parameter on the instrument display

Selection of the transfer protocol, Addressing

To identify a instrument within a network, a unique address in the range of 1…250 must be assigned. This address can be programmed into the instrument using the initialization software "RadonScoutInit". The edit field "RD:SWV WR:ADR" contains after loading the configuration parameters (GET) the recently programmed firmware version. Now, the desired address can be entered and transferred to the instrument (SET). Please note that the parameters have to be read at first before uploading the new setting.

The requested transfer protocol can be chosen by the Toggle button of the RTM1688-2. Keep the button down for four beeps and release it. After that, the actually used protocol is shown at the display. a short keystroke toggles the available protocols. For configuration purposes (e.g. setting the address), data download etc. the item "SARAD protocol" must be selected. The items "MODBUS 9600bps" and "MODBUS 19200bps" select the MODBUS protocol running a different bus speeds.

After selection of the protocol, the button must be pressed again for four beeps to come back to the main menu.

Implemented MODBUS functions

Function code 0x03 (read holding register)

Valid register addresses are:

Register Address	Register content	Number of registers	Format

0x0000	Radon concentration [Bq/m³]	2	Float
0x0002	Statistical error of Radon concentration [%]	2	float
0x0004	Average Radon concentration since last start [Bq/m³]	2	Float
0x0006	Battery voltage [V]	2	Float
0x0008	Temperature [°C]	2	Float
0x000A	Relative humidity [%]	2	Float
0x000C	barometric pressure [mbar]	2	float
0x000E	Thoron concentration [Bq/m³]	2	Float
0x0010	Statistical error of Thoron concentration [%]	2	Float
0x0012	Average Thoron concentration since last start [Bq/m³]	2	Float

IEEE 745 float values (4 Byte) are transmitted as two sequential 16 bit registers. The number of registers to be read must be two. That means, only one value can be transmitted per frame. Other values and not stated register addresses will cause an exception response.

RTM1688-2 GEO Version

The RTM188-2 GEO is a special version of the RTM1688-2. The control panel of the unit, the battery and an optional modem have been integrated into a sealed enclosure (IP68 protected). The Radon measurement chamber, sensors for temperature and humidity as well as the tilt detector are placed into a separate soil gas probe. The probe is connected to the main unit by a single cable with a maximum length of 10 Meters.

The operation of the instrument is equal to the standard version.

Power Supply

The 12 V / 12 Ah Lead-Gel battery is placed below the control panel. The battery life time is approximately 2000 hours under normal environmental conditions. Low temperatures or ageing will reduce considerably the battery capacity. Only a few handles are necessary to replace a discharged battery by a new one on site. For that, open the enclosure and remove the cable sockets from the battery. Loosen the nuts of the mounting rail and remove the rail. Pull out the battery onwards. To insert a new battery follow those instructions in reversed order. ATTENTION: Take care for the right polarity of the battery terminals! A wrong polarity will definitely damage the instrument!

If the capacity of the original battery is too less, a larger 12 V lead acid battery can be connected to the external power socket. In this case it is strictly required to remove the internal battery firstly. Please check the right pin assignments of the connectors

The battery can be charged using the charge circuit of the control panel. Thus, the “CHARGE” socket of the control panel and the external power socket are connected by a cable with a plug on the panel side. It is recommended to use a separate powerful charger if using a battery with a high capacity because the charge current of the internal charge circuit is limited to approximately 500 mA. The external voltage of 15 to 18 VDC may be applied permanently. Then, the internal battery works as a buffer in case of a power interruption.

Optional GSM Modem

The GSM modem is attached to the chassis below the battery. A special data cable enables the communication between the instrument and the modem. The cable have to be connected to the “SERIAL” socked of the control panel and to the 9-pin SUB-D socked of the modem.

The antenna is connected to the coaxial (SMA) terminal at the opposite panel of the modem. A short adapter cable is used to match the SMA standard to the standard antenna connector. The screwed cable gland beside the power connector allows the user to draw the antenna cable into the enclosure. It is not possible to operate the antenna inside the enclosure. The metal walls will attenuate the GSM signal dramatically.

The modem is supplied by the external power socket and will work only if an external voltage is present. The power cable has to be connected to the power socked of the modem beside the antenna connector.

Please note that the modem consumes a multiple of power compared with the instrument even if it sleeps. The direct connection of the modem to the battery should be realised only if the continuous recharging is provided. Discharging the battery below 11 V may damage the battery and should be prevented by an additional voltage level switch.

Connection of the Soil Gas Probe

Connect the soil gas probe only if the measurement has been stopped before or if the power supply has been interrupted (both, battery and external DC). Check the correct fit of the plug. The cable must be no longer than 10 Meter. Keep it as short as possible depending on the installation conditions.

Please read also the hints for installation and operation of the soil gas probe given in the application note AN-007.

Specifications differing from the Standard Version

Sampling	large area diffusion membrane
Response time (fast/slow)	dependent on the used membrane
	60 / 180 Minutes (125µm Silicon rubber)
Sensitivity (fast/slow)	0.8 / 1.8 cts/(min*kBq/m³)
Battery life time	approximately 2000 hours (without modem)
Dimensions / Weight	Electronics enclosure 230mm x 280mm x 111mm / 4kg
Soil gas probe	76.1mm dia. x 125mm (without socket); 650g

For further specification read the separate data sheet.

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 1σerror of ±15% is:

The real "true" Radon concentration lies with a likelihood of 68.3% within 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 be predicted from the number of detected counts N by the equation:

$E[\%] = 100\% * k * \sqrt{(N)} / N$

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 could 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:

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

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 be 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: Which integration interval T has to set to get a statistical uncertainty less than 10% at a confidence level of 1σif the expected Radon concentration is 200 Bq/m³?

A 1σerror of 10% requires 100 counts (100%* 1 * $\sqrt{(100)}$ / 100 = 10%). Using the fast mode, the integration interval can be calculated by

$T(fast) = N / (C_{Rn} * S)$ = 100 cts / (0.2 kBq/m³ * 4 cts/(min*kBq/m³) = 125 min.

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

T(slow) = N / (C_{Rn} * S) = 100 cts / (0.2 kBq/m³ * 8 cts/(min*kBq/m³) = 62.5 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(slow) = C_{Rn} * T * S = 0.2 kBq/m³ * 120 min * 8 cts/(min*Bq/m³) = 192 cts E(1σ) = 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 2 □□ confidenc
a more trustable result:

E(2σ) = 100 % * 2 * $\sqrt{}$(N) / N = 100 % * 2 * $\sqrt{}$(192) / 192 = 14.44 %

For interpretation look at 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 the 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 the Radon concentration is significant otherwise it “can be or not can be”.

Example 1:

Reading 1: 1500 Bq/m³ ±10% → error band [1350 ... 1650 Bq/m³]

Reading 2: 1300 Bq/m³ ±13% → error band [1131 ... 1469 Bq/m³]

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/m³ and 1469 Bq/m³, the variation of both readings is not statistical significant.

Example 2:

Reading 1: 1500 Bq/m³ →10% →error band [1350 ... 1650 Bq/m³]

Reading 2: 1000 Bq/m³ →15% →error band [850 ... 1150 Bq/m³]

The error bands of the readings do not overlap each other. Therefore, a statistical 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 cannot 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 the table): N = 3. Calculating the detection limit by the formula:

C = N / (T * S) = 3 cts / (60 min * 8 cts/(min*kBq/m^3)) = 0.00625 kBq/m^3 = 6.25 Bq/m^3 The detection limit in this case is 6.25 Bq/m^3.

Disposal instructions

Batteries and accumulators must not be disposed of in the garbage, but you are legally obligated to return them to the appropriate waste collection centres. The measuring instruments must be disposed of in the electronic waste or handed to the manufacturer at the end of their service life for proper disposal. If necessary, they have to be decontaminated before.

Technical Data

Measurement Range	
Radon/Thoron	1 Bq/m³ … 10 MBq/m³
Temperature	-20 °C … 40 °C
Humidity	0 … 100 %
Bar. Pressure	800 mbar … 1200 mbar
Response time (95%)	
Radon fast	15 Minutes
Radon slow	120 Minutes
Thoron	1 Minute
Sensitivity (fast/slow)	3 / 6.5 cts/(min*kBq/m³)
Sample Interval	1 … 255 Minutes (adjustable)
Memory	2047 data records (circular structure)
Pump rate	0.25 l/min
Internal volume (chamber/air loop)	approx. 250 ml Power supply
Power supply	
Battery operation	> 7 days (continuous pumping)
	> 10 days (pump in interval mode)
Recharge Time	8 Hours
AC/DC adapter	18V/1A
Interface	USB, RS232
Protocols	SARAD proprietary
	MODBUS RTU (9600/19200bps)
	ASCII Protocol print
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