User Manual

Thoron-Scout

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CONTENT

Important Hint

The determination of the activity concentration of Radon and Thoron is always a radiometric measurement, meaning a counting experiment. This causes a number of specific circumstances which have to be taken 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 becomes 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 Thoron-Scout 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 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

General

The new Thoron-Scout is a versatile, easy to use and state-of-the-art instrument focussed on the detection of Thoron (Rn-220) and Radon (Rn-222) in the ambient air. The required fast exchange rate of sampled air is realized by a highly permeable chamber placed outside the instruments enclosure. The relative Thoron sensitivity is comparable with the one of pump based instruments.

Beside the activity concentration of Thoron and Radon, air temperature, relative humidity and barometric pressure will be determined and saved to a non-volatile circular memory (first in – first out). Up to 2000 chronological data sets will be available for data transfer to PC including alpha spectrums. An internal real time clock ensures a correct time regime, a tamper lock indicates dislocation during the measurement. A display with backlight informs about the actual readings.

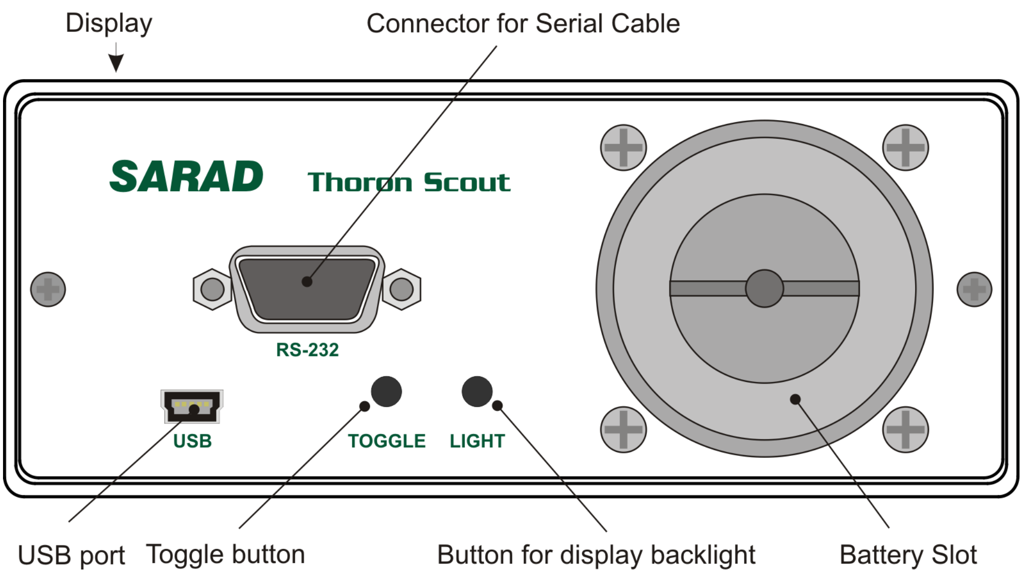
Neither mechanical parts like membrane pumps nor an external power supply are required. Therefore, use and exposition at home or at workplace is possible without any disturbance. A total duration of measurement of up to four weeks with continuous data recording is possible.

Due to its small dimensions and little weight, the Thoron-Scout can be shipped by mail to the place of interest/measurement without any additional man-power required for installation or start-up of an analysis – even untrained staff is able to start a measurement.

Entire part of delivery will be comfortable software for data read out and graph presentation, dose assessment and easy data backup.

- Read out of measurement data and adjustment of device parameter
- Interactive graphic display with zoom and pan
- Automatic backup of measurement data
- Selective export and conversion of customised time periods to text files for additional tasks (like import to EXCEL)

Front panel elements



Power supply

Power supply of Thoron-Scout is realised by two D size (Mono) batteries (also rechargeable). To open the battery slot, screw out the cover anticlockwise using a screw driver or a coin. Please pay special attention to the correct polarity of the batteries when inserted. The positive pole needs to be contacted to the front panel.
Change both batteries at the same time as differing charging levels may lead to failures. Use always batteries of the same type.
Close the battery slot by screwing clockwise for 45°. Ensure a tight sealing of the cover.

The Thoron-Scout offers an external DC input to supply the instrument by an AC/DC mains power adapter.
ATTENTION: Connect the AC/DC adapter only if batteries had been inserted before. Never use the instrument without batteries even if it is supplied by an external voltage, otherwise malfunction cannot be excluded.
If the AC/DC adapter is connected, the batteries will not be discharged. They will work as a buffer in case of mains power interruption. If rechargeable batteries are inserted, the batteries have to be recharged from time to time because of the self discharge process dependent on the used chemistry. They will **NOT** charged by the connected AC/DC adapter!
Using Alkaline batteries in combination with the external DC, the instrument can be operated over several years.
The connector for the AC/DC adapter (4.5V/500mA) is placed at the rear panel of the Thoron-Scout.

Changing the batteries will force you to adjust the re-set internal real-time clock. A concerning message appears on the display of the Thoron-Scout. Stored data remain in the memory and can be read out after changing of discharged batteries.
The selection of the right battery depends on the purpose and total duration of the measurement. For principals, NiCd- and NiMH-accumulators with a cell voltage of 1.2 V as well as alkaline-manganese or zinc-carbon batteries with 1.5 V can be used.
Important hint: Never use Lithium batteries - those cells provide a cell voltage of 3.0V or 3.6 V.

For long term measurements or frequent measurements with small periods of usage, the use of alkaline-manganese cells is recommended as those batteries provide a high energy density (up to 17000mAh) and a low self-discharging.
Time-to-time measurements for short term are best supplied by rechargeable batteries, as they may be charged prior to usage. NiMH cells provide an energy density of up to 8000mAh compared to NiCd-cells with a maximum of 5000mAh. In addition, maintenance to avoid memory effects is not required for NiMH type but self-discharging is higher.
Because the capacity of any cell type is dependent on temperature, storage condition and age (especially rechargeable batteries), the following data is only an approximation:

Alkaline-manganese 17000mAh:	up to 4 weeks
NiMH 8000mAh:	up to 2 weeks
NiCd 5000mAh:	up to 1 week

If the battery cell voltage drops below 1.1 Volts, a warning “LOW BATTERY!!” appears in the display each minute. Nevertheless the measurement can last for many more hours.

```
LOW BATTERY!!
```

The remaining capacity is 15 ... 25% depending on the chemistry of the used cells. After pressing the Toggle button display presents measurement results as usually. If longer measurements are planned, the batteries should be replaced before to avoid unexpected measurement break. If the cell voltage drops further, below 0.9 Volts, the running sample is stopped automatically and the device enters the stand-by mode with “CHANGE BATTERIES” indication.

```
CHANGE BATTERIES
    Thoron-Scout
      SN:00256
    CHANGE BATTERIES
```

After plugging the power supply and waiting one minute the measurement can be started anew.

The uptake of power during stand-by is about 15 – 20 % of a measurement. Anyway: In case of storage of the instrument without usage, batteries should be removed.

Carrying out a measurement

Press short the Toggle button to start a new measurement series. The display will show the remaining time to complete the first integration interval.

```
    Thoron-Scout
      SN:00256
  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 of the Toggle 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 the “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 third 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
      TSC-00256
```

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

```
  Thoron      12:20
      124Bq/m³±16%
  #34   117/120Min
      TSC-00256
```

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
    TSC-00256
```

The next page shows the average values of the Radon and Thoron concentration from the very 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
    TSC-00256
```

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 mode for the acoustic signal (buzzer).

```
>>15/06/19   12:34
ALM:    10000Bq/m³
INTVL.    BUZZ.OFF
    TSC-00256
```

To finish a measurement series keep the Toggle button down and wait for at least four beeps from the buzzer. If the button is released, the sample will be stopped, and the device will be brought into the stand-by mode.

```
  Thoron-Scout
    SN:00256
```

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

All the settings for the operation mode of the device can be performed with usage of the software application delivered with the unit. Please refer to the software manual for further instructions.

Pump

There is no pump in the Thoron-Scout. The air exchange depends on diffusion process only.

Alarm

If the measured Thoron or 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 indicate Radon by an audible signal. That means that 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 so called ring-buffer architecture. That means, the last 2047 data records (data of last 2047 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.

Data transfer (RS232 and USB interface)

The serial interface according RS232 standard is required to read out measurement data and to adjust the measurement parameter of the Thoron-Scout. Please note that the power consumption of the instrument is about five times higher if connected to the PC by the data transfer cable. In case that the device is permanently connected to a PC, the battery life-time is reduced due to that. The RS232 port is also used for connecting a modem or ZigBee wireless adapter.
Alternatively, the USB port can be used for communication. In that case, a software driver (available on SARAD website) must be loaded and installed before. The communication path appears as an additional COM port in RadonVision.
Both interfaces cannot be used simultaneously because the RS232 port will be disconnected automatically after plugging the USB cable into the port.

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% 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: What an integration interval T 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% rquires 100 counts (100%* 1 * $\sqrt{(100)}$ / 100 = 10%). Using the fast mode, the integration interval can calculated by

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

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 * √(N) / N = 100 % * 1 * √(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(2σ) = 100 % * 2 * √(N) / N = 100 % * 2 * √(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 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 to 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:

$C = N / (T * S) = 3 \text{ cts} / (60 \text{ min} * 8 \text{ cts/(min*kBq/m}^3)) = 0.00625 \text{ kBq/m}^3 = 6.25 \text{ Bq/m}^3$

The detection limit in this case is 6.25 Bq/m³.

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)	12 / 120 Minutes
Sensitivity Thoron	0,42 cts/(min*kBq/m^3)
Sensitivity Radon (fast/slow)	0,85 / 1,5 cts/(min*kBq/m^3)
Sample Interval	1 … 255 Minutes (adjustable)
Memory	2047 data records
Internal volume (chamber)	approx. 60 ml
Power supply	
Battery operation	> 30 days
AC/DC adapter	4,5V/0,5A
PC -Interface (Serial)	USB or RS232, 9600 Baud, 8N1
Dimensions	175 mm x 135 mm x 90 mm
Weight	1,1 kg (with Batteries)
Tamper detection	if instrument is moved > 8 Seconds
User interface	Display 4 x 20, 2 push buttons, buzzer

Caution

Please, do not carry the Thoron-Scout by holding the black cover!

Please do not carry out the measurements when Thoron-Scout is exposed to strong, direct light source.