Radon Monitor

Radim 5

Instruction Manual

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1.0 Description of the Monitor

The monitor was designed on the basis of the requirement for an apparatus that would determine the average radon concentration in residential areas with acceptable sensitivity. Estimation of the radon risk in residential areas is usually based on year-round measurements using tracker detectors. In justified cases, it is also possible to estimate the risk on the basis of the average radon concentration, which is measured simultaneously in several rooms of the residence of interest for at least one week. These measurements are usually carried out using electret detectors, which are sometimes subject to random self discharging. The Radim 5 monitor is intended to replace electret detectors and extends their capabilities using a computer that stores the results of the measurements and thus permits the determination of variations in time. The **Radim5WP version** of Radim5 is intended for **extreme condition, when 100% relative humidity or dust environment is expected**.

Concept of the instrument:
The instrument is based on experience gained with the Radim3 and Centra monitors and the need to design an instrument

- that would determine the average value of the radon concentration (RC) and also changes in this concentration in time,
- in which the processed data would be completely transferred to a PC,
- that would be small (Hand-held Radon Monitor Radim5),
- that would be simple and inexpensive,
- that would be powered by alkaline batteries and have a sufficient operating time,
- water- proof, robust box with windows, covered by radon- permeable foil.

Concept of the detector:

The concentration of radon is determined by measuring the α-activity of the decay products of the conversion of radon, ^{218}Po (RaA) and ^{214}Po (RaC'), collected from the detection chamber on the surface of a semiconductor detector by an electric field. Half of the hemispherical chamber consists of a grid, covered with two layers of material. The material captures the radon products formed in the external space and protects the detector against light and dust. As a majority of the radon decay products formed are positively charged, the chamber is connected to the positive pole of a high-voltage source (hereinafter HV) and the surface of the detector is connected with the negative field - ground of the HV source. Positively charged radon decay products (hereinafter dpRn) are neutralised by negative ions. This effect is dependent on the air humidity - the effectiveness of the detection system is thus humidity-dependent. To decrease the effect of humidity, it is useful to increase the HV and design the chamber so that most of the electrical lines of force are directed towards the surface of the semiconductor detector. The shape of the chambers and especially the surroundings of the detector were computer-modelled in the radon detectors of the Radim2 and Radim3 types. The detection efficiency of the system in the Radim2 and Radim3 monitors attains enormous values and the dependence on the humidity was decreased to a minimum (it has been estimated that 80% of the positively charged dpRn are collected on the detector surface). The dimensions of the Radim5 detection chamber were decreased compared to Radim 3 to a volume of 140 ml, so that the entire instrument fitted into a small casing. As the chamber dimensions are smaller, a source of only 400 V is used in Radim5, in place of the 2 kV source used in Radim3. A further difference between Radim3 and Radim5 lies in the fact that Radim3 counts impulses formed in the decay of RaA, and the equilibrium between the concentration of radon (RC) and the number of impulses is established after 15 minutes - the time response of Radim3 is very short. In order to increase the overall sensitivity of

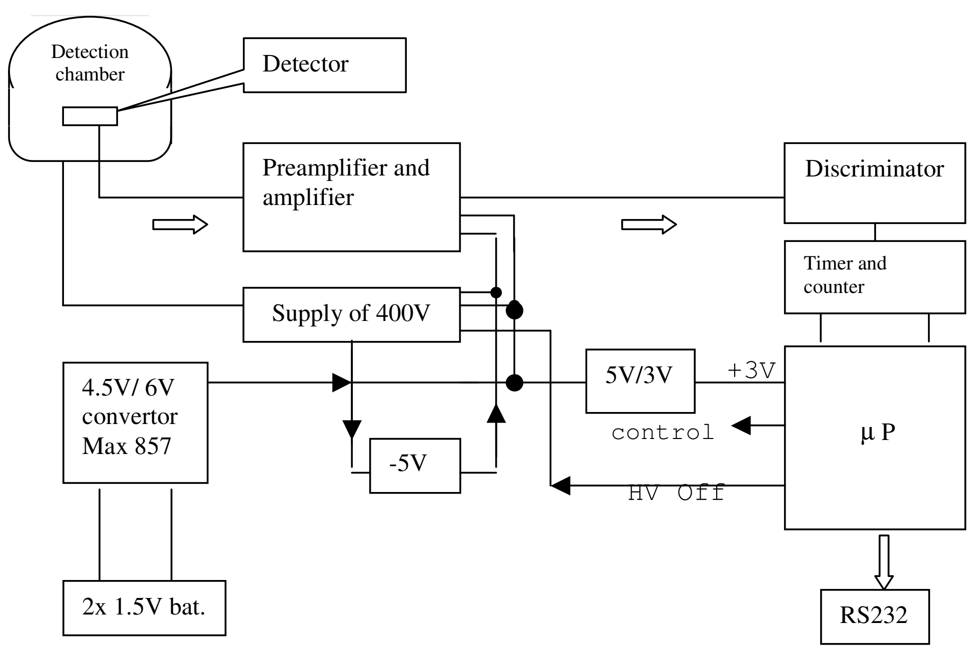
Radim5 to an acceptable level, the Radim5 monitor records the impulses formed by decay of RaA and also RaC' - equilibrium between RC and the total number of impulses is established after 3 hours.

Concept of the electronics:
This was based on the requirements of:
- decreasing the power input to a minimum,
- storing the results of 0.5 hour measurement in a memory with the measuring time,
- starting the measurement by turning the measurement on, stopping the measurement by turning the instrument off,
- the start of the measurement being dependent on no error being present - the "Err" light does not come on. This light comes on if

1. the test that starts up automatically at the beginning of each measuring interval is unsuccessful,
2. the battery voltage is too low.

A decrease in the power input is achieved:
- by using a MAX 857 DC-DC converter, with low standby consumption, high efficiency at low current and ability to convert the voltage in the range 2.4 to 6 V - thus the entire voltage range of batteries can be utilised,
- by the use of low-power operational amplifiers,
- by the design of the HV source,
- by the fact that only the amplifier, HV source and CMOS - impulse counter and timer are active.

A block scheme of the monitor is depicted in the following diagram.



2.0 Physical Tests of the instrument

2.1 - Determination of the dependence of the instrument response on the high voltage

High voltage applied to the chamber affects the sensitivity of the instrument and the humidity dependence. The voltage must be such that the sensitivity basically does not depend on its value. In order to decrease the overall consumption of the instrument, it is useful to employ as low a voltage as possible. It is thus necessary to find a compromise. Thus, the following experiment was carried out:

In place of the large detection chamber, the Radim5 detection chamber was placed in the Radim3 instrument and the Radim3 electronics were connected in the usual manner, i.e. a window was adjusted around the RaA peak and measurement of the spectrum using an external multi-channel analyzer was employed to determine that the ratio of the number of impulses in the window around the RaA peak to the overall area of the spectrum equals 0.528 when RaA is in equilibrium with RaC' (the Radim3 electronics were employed because the Radim3 instrument is especially useful for automatic data storage, Radim3 measures the temperature, humidity and pressure and the instrument has a feature for remote control and reading of the results). The detection chamber was not connected to the internal high-voltage (HV) source, but to an external source that was adjustable from 0 to 2000 V.

The Radim3 instrument with the Radim5 chamber was immersed in a barrel with a volume of 100 l together with a reference Radim3 instrument. Uranium ore was used as a radon source with a concentration of about 8000 Bq/m^3; the relative humidity was 68% and the temperature was 22 ^oC. The air in the barrel was homogenized using a small ventilator placed in the barrel. The number of impulses in the window around the RaA peak was measured at voltages of 600V, 500V, 400V and 300V. As the barrel is not perfectly sealed, RC changes in time (the decrease in RC is substantially compensated by the continuous production of radon by the radon source); the measured number of impulses was related to RC measured by the reference Radim3 instrument. The results of measuring the N_{RaA}/RC ratio and the responses are given in Table 1. The instrument response, defined as (number of impulses/hour)/(Bq/m^3) was calculated by multiplying the ratio N_{RaA}/RC by a coefficient of 2/0.528 (the number of impulses N_{RaA} was measured at half-hourly intervals and Radim5 registers impulses in the whole spectrum).

Tab. 1 Dependence of the response on HV

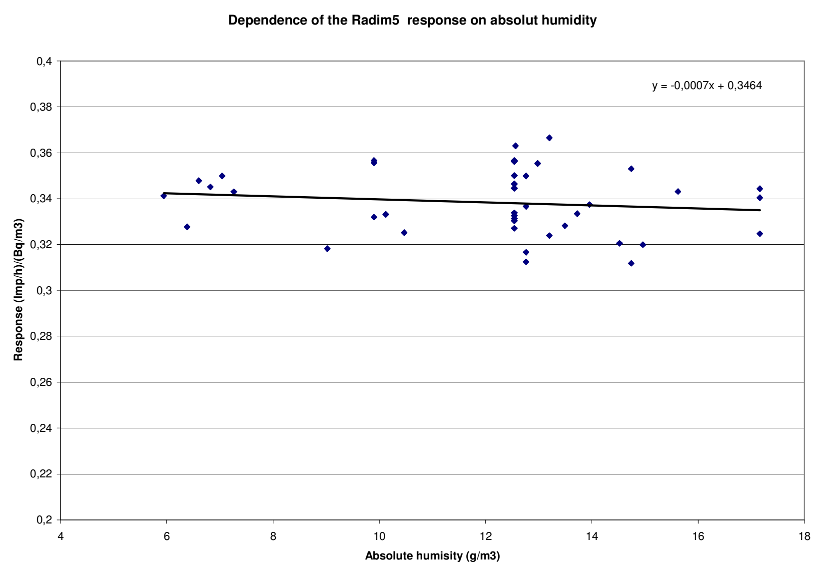
High voltage	N_{RaA}/ OAR	Standard deviation	Response (impulse/h/Bq/m3)	Standard deviation
600 V	0.0884	± 0.002	0.334	± 0.008
500 V	0.0909	± 0.002	0.343	± 0.009
400 V	0.0861	± 0.004	0.325	± 0.014
300 V	0.0837	± 0.005	0.315	± 0.016

The change of the response with the voltage lies within the range of the statistical error; nonetheless, a regression straight line was fitted through the results by using the least squares method (R = 0.81): Response = 0.296 + 0.00007 HV

And thus, at 400V, a response of 0.324 is obtained and, at 500V, 0.331. A change in HV by 100V causes a change in the response by 2.3%. It is apparent that the working **voltage can be decreased to 400V.**

2.2 - Determination of the humidity dependence of the response

Experimental method:
The Radim3 instrument with the Radim5 chamber and a reference Radim3 instrument were left in the barrel. The relative humidity in the barrel was decreased to about 20% using an external vessel containing silica gel, through which the air from the barrel was forced. The external vessel with the desiccant were disconnected and radon from an external source was injected into the barrel. The humidity was gradually increased automatically to about 35% and then about 0.5 ml of water was injected into the barrel - the humidity increased to 45%. Through gradual injection of water, the humidity was then increased up to 85% over about 18 hours. Similarly to above, the number of impulses N_{RaA} was related to RC determined using the reference Radim3 instrument (the Radim3 monitor automatically introduces a correction for humidity and the correctness of this adjustment has been verified in a great many experiments). The response was then calculated from this ratio. Fig. 1 depicts the dependence

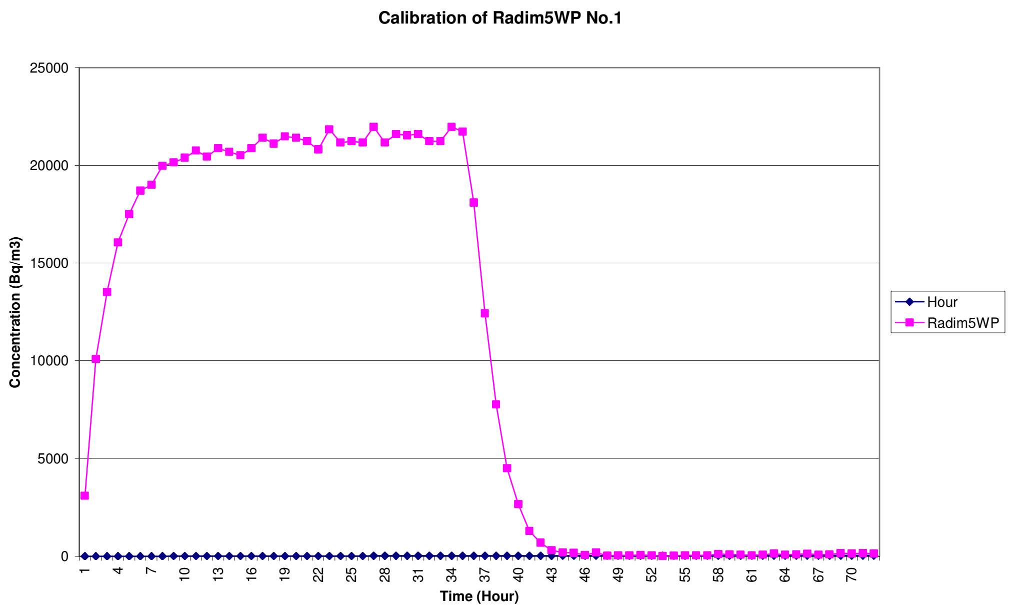


of the response on the absolute humidity.
It is apparent that the humidity dependence of the response is negligible - a straight line was fitted to the measured values:
Dependence on the relative humidity (RH) : response = (0.346 ± 0.009) - (0.00015 ± 0.00017) x RH
Dependence on the absolute humidity (RH) : response = 0.346 - 0.007 x AH
A change in the humidity from 50% to 90% causes a change in the response of -4.1%.

2.3 - Determination of the time – response of the Radim5WP monitor.

Experimental method:
The Radim5WP monitor and a reference Radim2P monitor were inserted into the closed barrel. Radon was injected from external source into the barrel. Radon concentration of about 22 000 Bq/m^3 was reached. The air in the barrel was homogenised using a small ventilator placed in the barrel. The Fig.2 depicts the results of Radim5WP measurement after the filling of barrel by radon and after removal of monitor from barrel into laboratory condition with radon concentration of about 50 Bq/m^3.

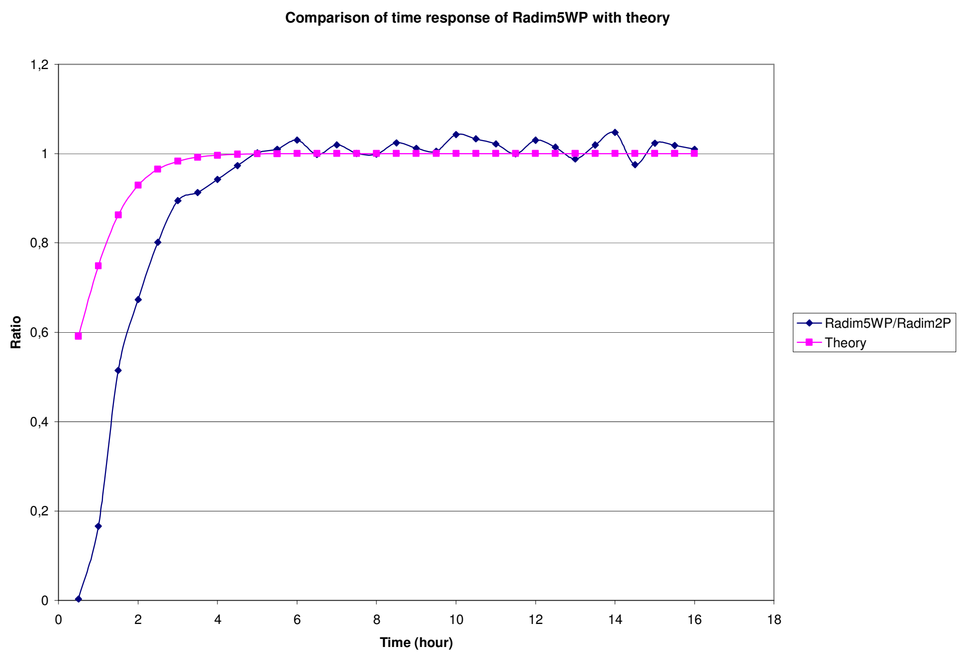
Fig.2: Results of Radim5WP measurement after steep increase and decrease of radon concentration.



As the concentration inside of the barrel was not strictly stable (the barrel is not totally tided) the results of the Radim5WP measurement was related to the reference Radim2P monitor. The time response of Radim2P is very fast: counting rate is in equilibrium with radon concentration after 10 minutes and radon diffusion into the detection chamber is very fast. As the Radim5 detects also RaC´ the equilibrium between counting rate and radon is obtained after equilibrium of RaA (Po^{218}) and RaC´ (Po^{214}) with radon, i.e. after about 3 hours. The detection chamber of Radim5WP is inside of tight box. There are 3 windows in the box, covered by thin foil. An open question is a delay, caused by diffusion of radon through the windows. The delay can be determined when the theoretical increase of RaA and RaC´ with the ratio Radim5WP/ Radim2P is compared (time response of the Radim2P is very short with respect to response of Radim5WP).

The comparison of the Radim5WP response with theory is given in Fig.3. From the given curve we can conclude that diffusion through the windows caused **additional delay about 1.5 hour.** This additional delay is acceptable for usual monitoring as typical day- variations lasts about 7 hours.

Fig.3: Comparison of time response of Radim5WP with theory.



2.4 – Reduction of the relative humidity inside the instrument.

The response of the instrument is nearly independent of relative humidity- see above. But when the monitor is placed into a cave with practically 100% humidity there is the **high risk of water condensation** when temperature is changing. Water condensation on insulator surface causes spurious impulses. It is very useful to reduce humidity inside the box in order to protect monitor against this effect. There is a special tube- "desiccant compartment" on the left side of the box where the bag with the desiccant – $CaCl_2$ can be inserted ($CaCl_2$ was selected from usual desiccants as it does not absorb radon- see later). Open question was the capacity of the "desiccant- bag" and how long it can reduce humidity inside the instrument box.

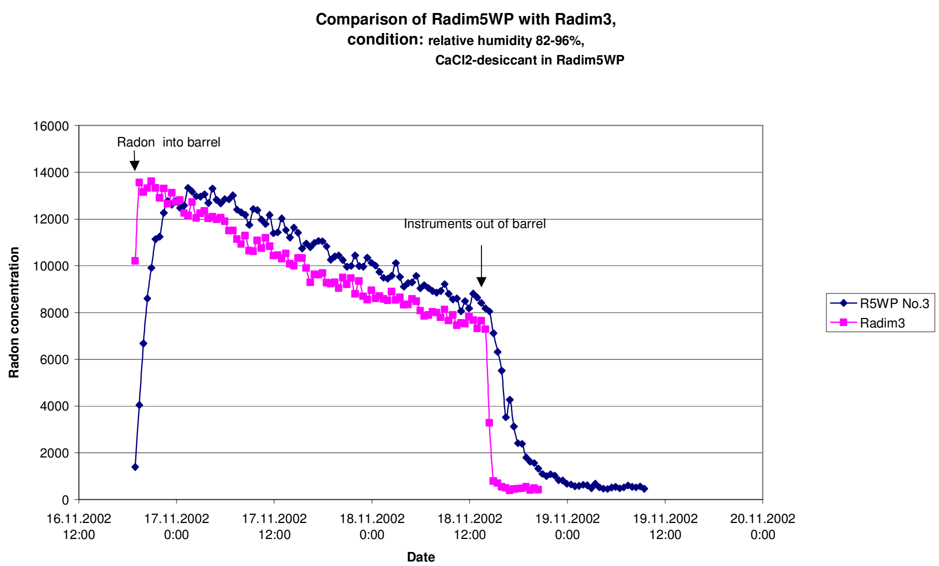
Experiment:

The ready box with precise electronic hygrometer/thermometer inside of the box was used for the experiment. Starting experiment the relative humidity was 67,4%, temperature 25.4^{o}C (absolute humidity was 16.1 g/m^3) . Then " the fresh desiccant bag" was inserted into the compartment and the box was placed into closed aquarium where the relative humidity was 98%, temperature 26%. After 6 hours of drying, relative humidity inside the box was 27.4% (absolute humidity was 6.8 g/m^3) and after 18 hours was 26.6 %. The desiccant reduces absolute humidity for 9.3 g/m^3. **In a cave where relative humidity is 100%, but temperature is about 7^{0}C the absolute humidity is 7.5 g/m^3 only. It is clear that the desiccant bag is able completely absorb air- water inside the box.** As water- vapours diffusion can be expected trough the windows and through box leakage, an open question was, how long the desiccant bag can keep reduced humidity when the instrument is used in 100% relative humidity environment. Therefore the Radim5WP box was kept in the aquarium where humidity was above 96% and relative humidity inside the box was traced for longer time. The lowest value of relative humidity was 26.4% and then the humidity was increasing about 0.6% per day. From this measurement we can conclude that the **desiccant bag should be replaced after 60 days**.

2.5- Absorption of radon by desiccant.

It is known that some desiccants, as silica-gel absorbs radon. The molecular sieve was tested in the first experiments. But when the Radim5WP was calibrated and the desiccant bag was inserted into the monitor we found that time- response was deteriorated: when the monitor was placed into the barrel and barrel was filled from external source of radon the counting rate was not in equilibrium with radon concentration after 20 hours. Removing monitor from the barrel the counting rate returns to the normal condition after 30 hours. This delay is caused by sorption and de-sorption of radon in the desiccant. Using desiccant bag with $CaCl_2$ no additional delay was observed- see Fig.4 and compare with Fig.3

Fig.4- Comparison of Radim5WP No.3 with Radim3. The desiccant bag with $CaCl_2$ was inserted into Radim5WP.



4.0 Operation of the Instrument

4.1 - Inserting the battery

A. Unscrew the lid of the battery compartment placed on the right side.

B. Insert the batteries. MAKE SURE THE BATTERIES ARE INSERTED IN THE RIGHT DIRECTION! (the negative pole of the battery is directed down the instrument).

D. Screw the lid of the battery compartment As the contacts on the battery are quite thick, it is necessary to press hard on the lid and screw.

After connecting the lid with the batteries, the green LED may flash weakly; however, then **the red LED "Error" must flash brightly**. If this does not happen, the batteries must be disconnected by unscrewing the lid, wait 30 seconds and then screw the lid again. The correct functioning can be checked by starting the measurement. After inserting the batteries, the instrument is brought into the regime STOP, all records remain preserved and information on connection to the power source is stored.
Note: It is possible to take out and insert the batteries during the measurement; however, when the measurement is restarted, information on the time without power is lost. Thus, it is useful to write down the date and time of starting the new measurement.

4.2. Start and stop measurement

RADIM5 is controlled by a single button on the front panel, which can be used to start and stop the measurement. In order to prevent pressing this button accidentally, the following procedure should be followed when starting or stopping the measurement:

- Press and release the button; the time of pressing is not important; when the button is pressed, the red LED – "Error" comes on.
- After about 1 second, the red LED again comes on and the button must be pressed again during LED lighting, hold it down and when the LED goes off, to **immediately release it**.

If an incorrect procedure is followed, the red LED – "Error" flashes for long interval; otherwise the following states are indicated:

- 3x long flashes of red LED –" Error"	STOP measurement
- 3x short flashes of green LED - RS232	START measurement in the BCKG regime
- 3x long flashes of the green LED - RS232	START measurement in the MEAS or TEST regime

4.3 Choice of operating regimes

Choice of the operating regime, adjustment of parameters and other functions are carried out **using a PC**. The data records of the individual regimes are, understandably, different. RADIM5 can be operated in one of three measuring regimes:

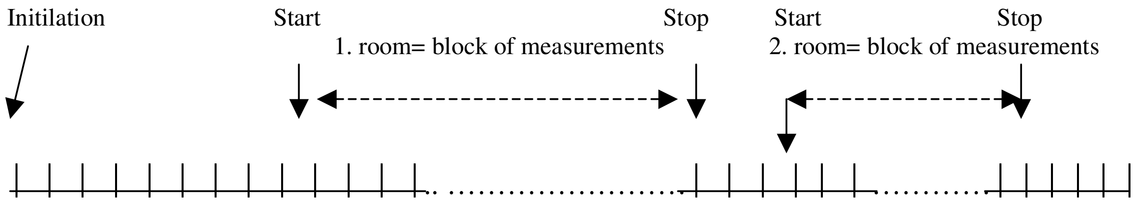
A. Regime MEAS - basic measurement of the radon concentration

This is the basic measurement regime with HV source turned on. After this is started, LED RS232 flashes three times. At half-hour intervals, the number of impulses is stored in the memory for later processing by the PC. Prior to commencing each measuring interval, it controls the state of the batteries, the remaining memory capacity and the detection part (self-testing). LED-Count and LED RS232 flash briefly. If an error is found in any parameter, an entry is made in the memory and this state is notified by flashing of the red LED-Error at intervals of about 10 seconds. If only a low power voltage is found, further measurements are possible; otherwise, the measurement is stopped. Detection of each impulse is signalled by flashing of LED-Count. After the measurement is stopped, it can be started again at any time by starting up the instrument measurement regime again.

B. TEST regime
In this regime, the instrument generates impulses that it send to the input to the amplifier and counts the resulting impulses. The counted number is compared with the number of impulses measured. This regime is intended only for testing the instrument. It can be adjusted or cancelled only using the PC.

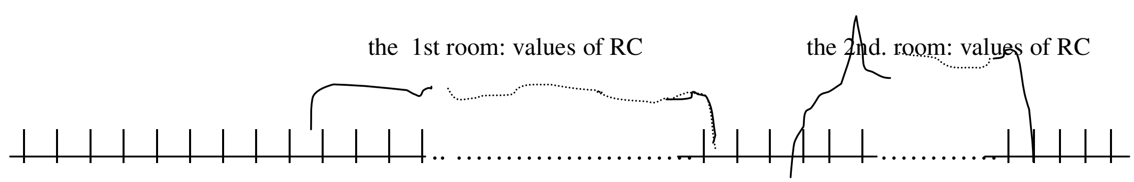
C. BCKG regime - measuring the background
Using the PC, the BCKG regime is selected, which differs from the Meas regime only in that the HV source is turned off. For measuring the background, **the instrument must be placed in an environment with low RC level** - preferably out in the open.
After starting the background measurement, LED-RS232 flashes briefly 3x, the number of impulses is counted and the record is stored in the memory as in the other regimes. After stopping the measurement, this regime is automatically turned off and, after starting up again, the standard measurement is started in the MEAS regime.

4.4 Manner of storing data and timing
Information on the measuring results must be accompanied in the monitor by information on the time when the individual measurements were started up. This requirement is usually met using a special memory, equipped with a constantly running clock. The Radim5 instrument is not equipped with this memory because it has quite high current consumption. The aspect of "timing" is resolved in Radim5 by using a precise oscillator and counter of "half-hour" impulses, which is read off together with the counter of the impulses produced by the radon detector. The "time" is then derived from the instant of zeroing the time counter. This zeroing is carried out using the "Initiation" function in the PC program. Time runs from this instant to the instant of the next initiation. As the start and end of the measurement are set manually and need not be fully synchronized with the initiation, **the first and last measurement in the half-hour interval may be affected if start and stop of the measurement are not carried out at a time that is a multiple of the half-hour interval from initiation**. The situation can be depicted as follows:



Time axis (marks indicate half-hour intervals)

The results of all the measurements, stored in the Radim5 memory and depicted by the PC program, will then have the following appearance:



and the results of measurement of a great many rooms - blocks - can be stored in the Radim5 instrument.