NUKLEONIKA 2012;57(4):637–641

Wireless system for radiometric measurements

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Abstract. Wireless system for radiometric measurements contains probes, for gamma radiation measurements and other probes for radon concentration measurements in air and water. The probes have the form of droplet-tight cylinders powered from a local battery. Measuring data collecting unit, based on a portable computer, communicates directly with the probes in a wireless manner using the WiFi communication network, or through the internet using mobile phone GSM network. Serial port wire connection is also possible. The local battery ensures at least 14 days of continuous operation of the probes. For long term measurements, the probes can also be powered from solar panels. Construction and operation of the probes are described. Results of scintillation probes investigation are given. Detection efficiency of the developed probes is comparable with the laboratory probes offered in our country.

Key words: radiometric probes • radon concentration measurements • wireless communication

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Received: 10 September 2011
Accepted: 31 January 2012

Introduction

Fast progress in the field of data processing makes that in different branches of technology using the earlier developed devices becomes inconvenient or simply cannot be used. The same situation could be observed in radiometric gauges, where the information about a current result of measurements should be transmitted to some distance quickly (e.g. in a remote installation of measuring device from a control unit). This also applies to situations when we measure environment radiation and the signal informing about appearing threat must be sent to the appropriate emergency service at once. In order to meet those needs a set of measuring probes for industrial radiometry, with fast wireless transmission of their results, was designed and constructed (within a wider project). Simultaneously, the newest electronic components and solutions were applied to deliver a modern device into the market. As a result of our activities, three types of probes were developed: for industrial gamma radiation measurements, for measurements of radon concentration in air [1] and for measurements of radon concentration in water.

Simultaneously developing work on three types of probes resulted in a unified design of the main part of probes, so that by design they can be easy manufactured.

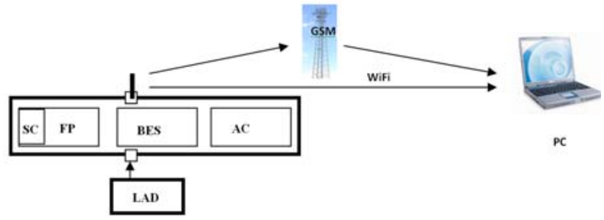

Fig. 1. Functional scheme of probes. SC – scintillator NaI(Tl) coupled with a photomultiplier FP forms a scintillation integrated detector (probes for radon measurements contain Lucas cells); BES – electronics block (microcontroller), high voltage power supply, wireless transmission network (WiFi, GSM), automatic gain control system; AC – local battery; LAD – external battery charger; GSM – GSM network; PC – central unit (industrial laptop).

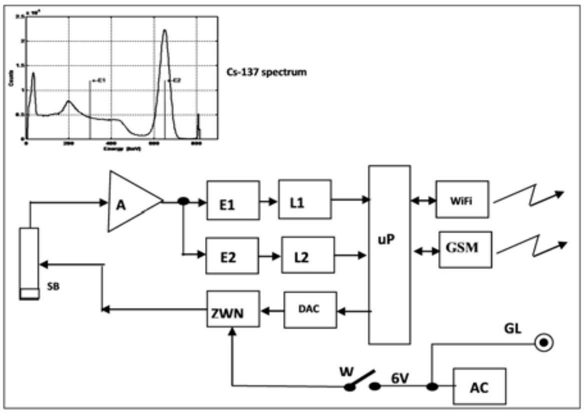

Fig. 2. Block diagram of electronic circuits probes and gamma radiation spectrum of ^{137}Cs. SB – scintillation integrated detector (scintillator NaI(Tl) with photomultiplier); A – pulse amplifier; E1 – discrimination threshold and L1 – measuring channel impulse counter; E2 – discrimination threshold and L2 – impulse counter used in automatic gain control; DAC – digital to analog converter used to photomultiplier voltage adjustment; ZWN – high voltage power supply for photomultiplier; AC – local battery; GL – battery charger socket; W – power cut off; μP – microcontroller; WiFi – wireless communication system; GSM – mobile communication system GSM with the internet.

Principle of operations and mechanical construction of the probes

Functional scheme of probes

Probes functional scheme and its communication with a central unit are shown in Fig. 1. Radiation registered by a detector (scintiblock or Lucas cell) is measured by programmable impulse counters in the electronics block (BES) under the control of microprocessor system. The counting results are saved in the probe memory and send either to a central unit (PC) using WiFi communication network or placed in the internet database (when using mobile communication GSM). Measurements transmitted from the probe can be presented in a real time as graphs on the computer screen PC or on a dedicated website. For backup purposes, measurements are saved in a computer memory or in a remote database.

Block diagram of probes

In Fig. 2, a block diagram of probes electronic circuits is presented. Impulses coming from the output of a photomultiplier are amplified in the amplifier A, next they reach the impulse discriminators E1 and E2 and finally are counted by counters L1 and L2 under the control of a microcontroller. Discriminator E1 and counter L1 form the main measuring channel of the radiation registered by the photomultiplier. Discriminator E2 and counter L2 form an auxiliary circuit to control the gain of the photomultiplier.

High voltage power supply for a photomultiplier ZWN (with multiple duplication of voltage) is controlled by a digital to analog converter DAC implemented in the microcontroller. The probe is powered from a local battery AC (7.2V/10Ah). The battery is charged by an external battery charger connected to the socket GL. Switch W is used to connect the power supply to the electronics.

Automatic gain control – based on an example of scintillation probe

Photomultiplier automatic gain control [2] is carried out when the scintillation integrated detector SB is being radiated with an external gamma source ^{137}Cs. Figure 2 shows the gamma radiation spectrum of ^{137}Cs source and the location of E1 and E2 thresholds on the spectrum. Impulse count rates n_1 and n_2 above E1 and E2 thresholds are being measured at the nominal gain U_o of the photomultiplier and a $k_0 = n_1/n_2$ ratio is calculated. The values of U_o and k_0 are saved in the microcontroller memory. Whenever turning the device on, the voltage U_o is loaded from the memory. When the automatic gain control of the photomultiplier is used, a new impulse count rates n_1 and n_2 are measured, and a new $k_x = n_1/n_2$ ratio is calculated. Ratio $k_x/k_0 = 1$ for the nominal gain of the photomultiplier, $k_x/k_0 > 1$ for the gain lower than the nominal one, $k_x/k_0 < 1$ for the gain higher than the nominal one. Basing on the k_x/k_0 ratio, ΔU voltage is calculated, which tells us how much the voltage of the photomultiplier should be adjusted to obtain the nominal gain. This new voltage of the photomultiplier $U = U_o + \Delta U$ is saved in the microcontroller memory.

Mechanical construction of probes

Design solution of radiometric probes and probes for measuring radon in air and water are shown in Figs. 3, 4 and 5. The cover of the probes consists of two cylinders, both closed from one side and equipped with a thread on the other, used to twist the top and bottom part of the probe together, and a cylindrical ring with holes allowing access to the battery charger socket, to the power supply cut off, and to the wireless communication antenna socket. Batteries and electronics block are located inside the top cylinder.

Whenever charging of batteries is completed and when turning power supply on, the holes in the middle ring must be closed using screw nuts.

Depending on the type of the probes, either scintillation integrated detectors (Fig. 3 radiometric probes)

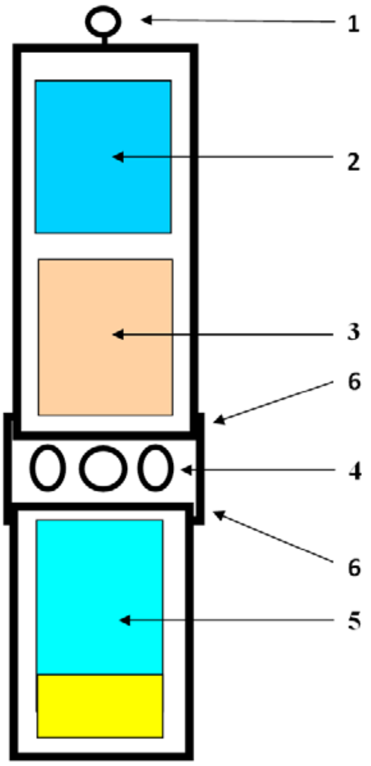

Fig. 3. Radiometric probe. 1 – grip of probe; 2 – battery; 3 – electronic block of probe; 4 – ring; 5 – scintiblock; 6 – thread.

or photomultipliers with Lucas cells (radon measuring probes) are located inside the bottom cylinder.

Measuring probes for radon in air concentration measurement (Fig. 4), using natural diffusion of radon into

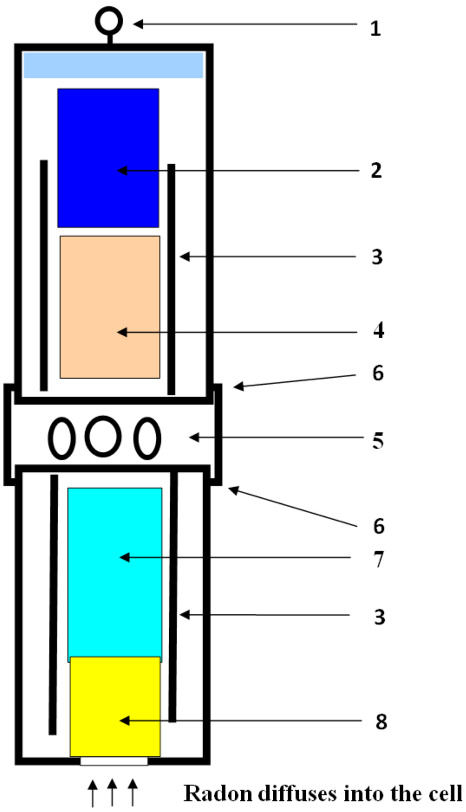

Fig. 4. Radon concentration in air measuring probe. 1 – grip of probe; 2 – battery; 3 – support; 4 – block of electronics; 5 – ring; 6 – thread; 7 – photomultiplier; 8 – Lucas cell (flow cell).

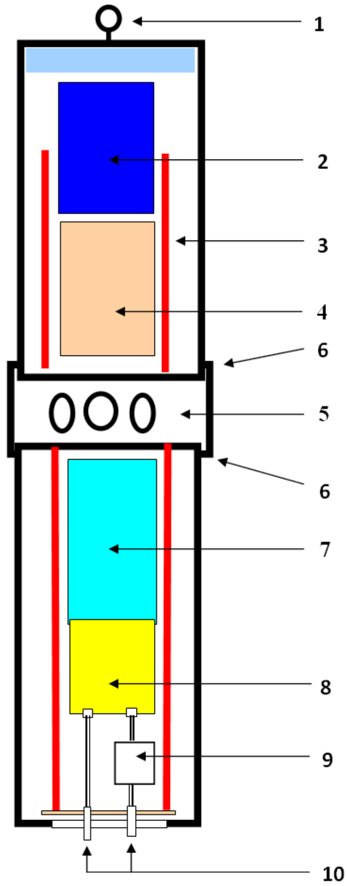

Fig. 5. Radon concentration in water measuring probe. 1 – grip of probe; 2 – battery; 3 – support; 4 – block of electronics; 5 – ring; 6 – thread; 7 – photomultiplier; 8 – Lucas flow cell; 9 – air pump; 10 – stubs to connect spiral membrane.

the Lucas cell through a light tight membrane placed at the perforated top of the cell opposite the cell window.

The probes for radon in water concentration measurement (Fig. 5) using the standard Lucas cell with two stubs connected with elastic pipes to a membrane in the form of a pipe up to 4 m long and an external diameter of 5 mm, wound around perforated cylinder, Φ 11 cm, making a spiral form of the membrane. The membrane is immersed in water. Radon from water diffuses into the membrane. A small air pump of the probe forces radon in the membrane radon to flow through the Lucas cell in a closed loop. Water temperature sensor is also immersed in water.

Chamber, in which the photomultiplier or scintillation integrated detector can be found, is lightproof and even the top cylinder (batteries and electronics) is removed.

Parameters and data processing for measuring radon concentration in air and water

- Programmable measuring time: 5, 10, 15, 30 min, 1, 2, 3, 6, 12, 24 h.
- Pulses from the Lucas cell are counted during the whole measurement cycle and are normalized to (counts/min), and at the end are converted into:
  - Bq/m^3 for the radon in air concentration measurement, according to the formula:

(1) $$C = n \cdot \frac{1000}{60 \cdot v \cdot 3 \cdot \varepsilon} = n \cdot k \quad (\mathrm{Bq/m^3})$$

where: $n = m / (1 - m \cdot \tau)$ – the true counting rate, (counts/min); $m = m - n_b$ – counting rate m after cutting off background n_b, (counts/min); τ – dead time of measuring circuit, (min); τ = ca. 10^{-6} s = 1.7×10^{-8} min; v – Lucas cell volume (0.17 dm^3); ε – alpha radiation detection efficiency (for Lucas cells it equals to about 0.7 – calibration determined); k – proportionality (calibration) coefficient ($k = 32.68/\varepsilon$).

› Bq/L for the radon in water concentration measurement, according to the formula:

(2) $$C = n \cdot \frac{1}{60 \cdot v \cdot 3 \cdot \varepsilon} \cdot k_w = n \cdot k \quad (\mathrm{Bq/dm^3})$$

where: $n = m/(1 - m{\cdot}\tau)$ – the true counting rate, (counts/min); k_w – coefficient of the solubility of radon in water,
$k_w = 0.105 + 0.405{*}\exp(-0.0502{*}T)$; T – water temperature (°C); k – coefficient ($k = 0.03268 \times k_w/\varepsilon$).

- Measurement results are collected in the probe memory. They can be transferred to a computer or to an internet database after the measurement or any time later. Then, a package containing a few measurement results is sent. This time is programmable. This kind of transmission of measurement results is used in long-term measurements, in which constant preview of data is not required. In the case of lack of communication no data is lost, moreover they are re-send after recovering communication.
- Low battery signal. When the probe battery is low, the administrator of the system receives a message informing him about that. When the GSM communication is used, an alarm message SMS is sent, however when a WiFi network or serial port wire connection are used, a proper communique is displayed in the program recording measurement.
- Automatic gain control of photomultiplier voltage is active when the count rate is sufficiently high.

Efficiency of scintillation probes

Measurements were made for a group of isotopes used in research laboratories and industry. The probe in horizontal position was irradiated by a set of isotopes put at a distance d from the centre of the probe face. In this geometry, radiation from the source of activity A that reaches the surface of the probe is $\beta \times A$. The size of β is the ratio of the active scintillator surface to the surface of a sphere of radius d.

(3) $$\beta = \frac{\pi \cdot r^2}{4 \cdot \pi \cdot d^2}$$

where: r – radius of the scintillator face.

By measuring probe count rate I (minus background) we can calculate efficiency of the probe as:

(4) $$w = \frac{I}{\beta \cdot A}$$

The results of efficiency w determinations for a ^{137}Cs source of activity 37×10^4 Bq and ^{60}Co activity 37×10^3 Bq are shown in Table 1 [3, 4]. Due to the low activity of ^{60}Co, measurements of w for that source were performed only at a small distance d from the probe surface, to avoid mistakes related to statistics.

Table 1. Efficiency of the scintillation probes.

Source	Activity (kBq)	Distance (cm)	Probe number	High voltage (V)	Efficiency (%)	Background (counts/s)
^{137}Cs	370	10	2	604.8	21	30
^{137}Cs	370	45	2	606.0	41	31
^{137}Cs	370	10	4	623.6	22	29
^{137}Cs	370	50	4	623.6	36	29
^{60}Co	37	10	4	580.0	40	15
^{60}Co	37	20	4	580.0	51	15

Approximate efficiency for ^{241}Am source radiation was about 10%.

Conclusions

Within the project UDA-POIG.01.03.01-14-065/08 dated 20.02.2009 an attempt to implement the latest technologies, associated with wireless communication, in construction of gauges designed for radiation measurement was made. This work concerns three types of probes for measuring radon concentration in air, in water and for measuring gamma radiation. Applied design solutions allow using probes in laboratory conditions and in industry.

Technical and radiometric parameters which were obtained do not differ from those derived in similar gauges accessible in Poland. Efficiency of scintillation probes: 50% for ^{60}Co with 15 cps background, 36% for ^{137}Cs with 30 cps background and 10% for ^{241}Am was achieved.

The applied automatic gain control ensures stable, continuous operation in different environmental conditions (like temperature fluctuation) and eliminates the aging effect of photomultiplier in a wide range. Battery power supply, and WiFi as well as GSM modules installed in the probes enable operation in the field environment, wireless communication of the probes with a central unit and fast data transmission. A few probes (e.g. for radon measurement in water, in open air, in cave air) can be connected to network with a collective short range communication module.

Acknowledgment. This work was carried out in the frame of Innovative Economy Operational Program project number UDA-POIG.01.03.01-14-065/08-00 "The new generation of intelligent devices with a wireless tele-transmission of radiometric information" (task no. 1 and 3).

References

1. Bartak J, Machaj B, Pieńkos J (2002) Apparatus for measuring radon concentration in air. In: Nuclear technology in industry, medicine, agriculture and environment. Institute of Nuclear Chemistry and Technology, Warsaw, 2:303–312
2. Machaj B, Bartak J, Jakowiuk A (2008) Method of automatic gain control for photomultiplier when ionizing radiation is measured periodically. Patent Application no. P 386616
3. Parameters of scintillation probes. http://www.polon-alfa.pl
4. Van de Graaf E, Limburg J, Koomans R, Tijs M (2011) Monte Carlo based calibration of scintillation detectors for laboratory and *in situ* gamma-ray measurements. J Environ Radioactiv 102:270–282