CLUJ-NAPOCA ‘BABEŞ-BOLYAI’ UNIVERSITY
FACULTY OF ENVIRONMENTAL SCIENCES

PhD DEGREE THESIS

-Abstract-

RESEARCH ON INDOOR RADON AND RADON REDUCTION METHODS

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CLUJ-NAPOCA
2014

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Key words

device for measuring the radon concentration in the air, PSPICE simulation, SIMULINK simulation, electromagnetic disturbances, detection chamber, data transmission, radon concentration diminishment, remedy techniques, anti-radon membrane

Foreword

Thesis Goals

I started working on this thesis a long time ago, tackling with its topics from two standpoints. The former one was due to my training as a graduate of the Electronics & Telecommunications specialisation and the other one due to the collaboration with a prestigious group of physicists from the Cluj-Napoca BB University. The thesis may therefore be considered to be multidisciplinary, covering both fields specific to electronic conception and design and fields specific to applied physics.

Working on such a topic is mobilising, thanks to the main goal pursued, namely the elimination and the mitigation of a threat to human health. On reading for the first time about radon and its effects in Cosma and Jurcut's book from 1996, my interest in this field determined my future professional course. My first participation in a research project (CEEX no. 747, 2006) confirmed my interest in this field. On the occasion of this project and of the first researches made within the Electronics & Computers group from the Braşov 'Transilvania' University, I published my first column in 2007.

The thesis has two major goals :

1. conceiving, designing and practically executing the electronic radon detectors ;
2. the implementation of measures for reducing the radon concentration in the air in the Băiţa-Ştei area.

The thesis unity is provided by the fact that certain measurements of the radon concentration in the air performed within the application described in the latter part of the thesis were carried out by means of the devices whose design and execution were described in the former part of the thesis.

Within the former main goal I came across particular problems, other than the ones usually seen in designing. Please find below the goals set out for reaching the main goal 1 :

1. which one of the radiation measurement principles can be applied for measuring radon – the integrative one or by counting the impulses ;
2. what solutions for eliminating the electromagnetic disturbances can be appplied for providing measurement accuracy ;
3. in case of automatic measurements, how the remotely sent data can be ;
4. how a system by which the measuring device sends its coordinates for the measurement point to be identified can be integrated ;
5. how the good operation of such a device can be standardised and then determined.

Within the latter main goal, the worded aims were the following :

1. which one of the radon concentration diminishment methods can be applied ;
2. which one of the radon concentration diminishment methods is more efficient ;
3. the analysis of efficiency for various methods : depressurisation underneath the floor (radon collector), ventilation enhancement underneath the floor, positive pressurisation, inside ventilation increase, the isolation of the floor and walls cracks and clefts, the application of the membrane that hinders the radon penetration.

This thesis is oriented toward practical achievements, which is due to my engineering call. The practical achievements, two variants of radon measurement devices, with an original patented construction, and the active participation in the remedies from the Ştei Băiţa area, which led to a significant drop of the radon concentration, are the thesis strengths.

Thesis Structure

The thesis is structured in 4 chapters, which contain a presentation of my achievements in a logic succession both as a temporal development and as a technical order.

Chapter 1, **Radon**, begins by a brief introduction, which shows what radon is and what the risks of excessive exposure are. It reminds specific aspects of how the problem is dealt with in the European Community, in the US and in Romania and it specifies the exposure limits. It furthers sets out the problem of the high concentration of radon in the Ștei Băiţa area and of the need for the remedy measures that were tested in Chapter 3. The utilisation of the radioactive materials derived from the 'Băiţa' uranium mine for erecting houses and the foundations structure led to an enhancement of the radon concentration and caused an increase in the incidence of the cases of lung cancer. The latter part of the first chapter briefly describes a few electronic devices of the radon concentration in the air and presents certain main characteristics. It also describes in brief the method of measurement by means of track detectors and it finally lists a few patents related to radon measurement.

Chapter 2, **System of measuring the radon concentration in the air and data transmission from multiple locations**, is an ample chapter, where a large part of the original achievements, is concentrated. The conception and the design of two variants of electronic radon detector are described in detail, in the order of their development. Simulations were carried out in PSPICE and SIMULINK, which were used to compare two methods of measurement – one by integration and another one by counting the impulses. The simulations showed that the impulse counting method is more adequate for measuring small concentrations of radon. As a transducer, the ionisation chamber and the detection chamber with a photoelectric element were taken into account and simulated. Special attention was paid to the two-way entrance storey, which provides good immunity against electromagnetic disturbances. The chapter further describes the central unit with a microcontroller and the digital display, which shows numerical and graphical information on the measured concentration. The necessity of sending data remotedly called for the integration in the device of several communication equipment, among which the user can choose the most adequate one for the location where radon is measured. The best used system of communication was deemed to be GPRS by the structure of the GSM mobile telephony, which makes the data accessible over the Internet. The transmission system was completed by a GPS system, by which the measurement device transmits its geographical position. Two variants of radon detector were made : one with a ionisation chamber and another one with a detection chamber, as well as a software programme that can manage the readings of several devices, plus the geographical position of each of them. The programme generates alerts if the level of the radon concentration exceeds a certain allowed value.

Chapter 3, **Methods applied for mitigating the radon concentration in the air**, is the latter broad chapter that describes the remedy methods tested in the Băiţa Ştei area, at a pilot house, in order to reduce the radon concentration under the allowed limit values. One of the methods for mitigating the radon concentration, recommended by EPA (US Environmental Protection Agency) consists in extracting the air underneath the building and eliminating it in the atmosphere, from where the air currents will disperse the radon (EPA, 1992).

The most efficient methods for reducing the radon concentration are considered to be : depressurisation underneath the floor (radon collector), ventilation enhancement underneath the floor, positive pressurisation, inside ventilation increase, the isolation of the floor and walls cracks and clefts, the application of the membrane that hinders the radon penetration. On the other hand, in case of the new constructions the most efficient method proved to be the application of the anti-radon membrane on the internal surfaces, at the level of which the radon exhalation depends on the architectural characteristics of each selected house. The dwellings where the remedy measures were applied were selected as a result of the complete characterisation of the investigated houses and those where the radon concentrations exceeded 600 Bq/m^3. After the full characterisation of the investigated houses from the viewpoint of the radon profile, reports on the efficiency of the measures taken were drawn up. Part of the measurements were carried out by using the devices suggested by the author. The measurements took place in parallel, by means of calibrated instruments, according to standards and reference materials with the highest degree of reliability, in pursuance of the international orientations. The measurements correctness was performed by measurements with integrated detectors on long periods of time, in two seasons, in order to enhance the degree of trust for the exposure assessment. Chapter 3 contains the way in which a set of initial measurements can be made, the remedies performance in case of a pilot house and the check of the efficiency of each remedy method applied. It then sets out an automated system for monitoring and controlling the radon concentration, which is supplied by solar panels, as well as the experimental results of its application. The latter part of the chapter tackles with the errors in measuring a kind of radon detector because of the electromagnetic field. As measures of protection, materials and conductive membranes may be used, which have a twofold role : to mitigate the radon concentration and the intensity of the electromagnetic field. The researches are still at the beginning and the author thinks that the future researches can be oriented in this direction.

Chapter 4, **Conclusions and main personal contributions,** encompasses a few conclusions and an enumeration of his personal contributions, supported by the papers published.

Appendix 1, **Radon concentration decrease by soil pressurisation and depressurisation,** includes relevant graphs for the remedy experiments made by the author, but they would have uselessly burdened the thesis text in Chapter 3, therefore they were transferred to the appendix.

Appendix 2, **Selection of representative papers, listed in the database of ISI Web of Knowledge & IEEE Xplore**, comprises excerpts from the website of ISI Web of Knowledge & IEEE Xplore, which present the author's papers.

Chapter 1
Radon

1.1. Radonul – harmful effects

The exposure of important groups of population to the radon inside dwellings, the associated health risks, the prevention and remedy actions continue to be a dramatic problem in the European countries and in the areas from Romania with high concentrations of radon. Radon is a chemically inert gas, it is radioactive, odour-free, colourless and taste-free, its natural origin being in the ground by the disintegration of uranium and radium. The radon gas can be easily spread from the ground into the air and it disintegrates itself into the products with a short lifetime called radon successors (214Po, 218Po, 214Pb and 214Bi) (Cosma et al, 2009). The short lifetime successors get further disintegrated in strongly ionised radiation emissions, termed alpha particles, which can be electrically charged and attached to the aerosols, the dust and other particles from the air that we breathe. Consequently, the radon successors can be found at the level of the respiratory tract cells, where the alpha particles resulted from disintegration can induce lesions to the genetic material (DNA) and can thus cause lung cancer (Cosma et al, 2009). The inhalation of the short lifetime successors of radon contribute by approximately 50 % to the actual total dose received by humans from the natural ionised radiation in the world, according to UNSCEAR.

The main epidemiological proof regarding the role of the exposure to occupational radon in the appearance of lung cancer comes from a multitude of studies performed on the uranium, tin and iron ore mines, especially in Europe and North America (Beir, 1999), (Lubin et al, 1994).

Joint analyses of several studies from China, Europe and North America confirmed that the radon from houses significantly contribute to the appearance of lung cancer (Pisa et al, 2001), (Tomasek et al, 2001) (Lubin and Boice, 1997) (Pershagen et al, 1994). Based on these studies, the International Agency for Research on Cancer (IARC) classified radon as human carcinogenic (IARC, 1988).

In order to determine the effect of the exposure to residential radon upon the risk of lung cancer, recent researches of European and North-American studies (Field, 2006), (Darby et al, 2006) clearly proved a high risk of lung cancer both to smokers and to non-smokers, even in case of the normal concentrations from the inside, from 40 to 300 Bq/m^3. The recent common analysis of some key European studies shows that 9 % of the deaths caused by lung cancer in Europe per year are due to the exposure to the radon from inside (Darby et al, 2006) for 29 European countries, to an average exposure of 59 Bq/m^3.

The exposure to radon and to its successors in one’s dwelling and workplace constitutes one of the highest, probably the very highest risk of ionised radiations. An estimate of the risk leads to thousands of cancer deaths per year due to the exposure to radon and especially to its disintegration products. Nevertheless, radon is a risk factor that can be controlled and reduced for reasonable prices, thus saving lots of life. In order to reach this goal, it is important for the national authorities to inform the public on the risks associated to radon, to adopt a legislation and to issue instructions that limit the exposure to radon and to resort to remedy measures for the dwellings with high concentrations of radon. Such information, that is legislation and radon concentration mitigation methods, will be issued according to the scientific results, after the researches carried out and the efficiency of the remedy methods is proven (Åkerblom, 1999).

It is essential for the European states to issue recommendations, rules, directives or laws on the limits of radon and practices in constructions for the fight against radon and for the future actions of reducing the radon concentration in houses and at one's workplace. In order to have a significant effect upon the radon problem, the answers to the questionnaire show that the reference levels and rules of radon must be adopted, otherwise the progresses linked to the implementation of the methods for diminishing the risk linked to the radon exposure will be very small. Research programmes for measuring and mitigating radon in the risk areas were carried out in many countries. Consequently, only those countries with adopted rules had successful programmes, the remedy actions being enforced in more than 10,000 buildings.

The International Commission on Radiological Protection (ICRP), the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA) repeatedly encouraged the countries to draw up research programmes in the field of radon. The countries were encouraged, among others, to issue reference levels for radon in houses and at workplaces, to come up with guidelines for localising the buildings with radon, to check whether there is the risk of high concentrations of radon prior to beginning a new construction and to implement limits for the concentrations of the natural radioactive elements in the construction materials. In 1990, the European Commission issued the Recommendation 90/143/Euratom for the population's protection against the exposure to inside radon. The recommendation identified 400 Bq/m³ as a level of considering the remedy action in the existing houses and 200 Bq/m³ as a level for the new houses (Commission of the European Communities, 2009).

For the existing houses, the 400 Bq/m³ reference level is applied by the member countries Austria, Denmark, Greece and Sweden, as well as by such non-EU European countries as Belarus, Estonia, Lithuania, Norway, Poland, Russia, The Slovak Republic and Yugoslavia. Ireland and the UK have 200 Bq/m³ consultation reference levels and Luxembourg has a 150 Bq/m³ consultation reference level.

In Romania only regional measurements for inside radon have been carried out and ranged between a few dozens of Bq/m³ and a few thousands of Bq/m³. Such radon concentrations measurement studies were carried out by the Hygiene & Public Health Institutes from several cities, such as Bucharest, Iaşi, Timişoara or Cluj (Cosma et al, 2009).

The area with the highest radon concentrations in Transylvania is represented by Ştei-Băiţa (Bihor), where values of up to 4000 Bq/m³ were detected. For 15 years, the research studies in the Băiţa area have been carried out by the Environment Radioactivity Laboratory (Prof. PhD Constantin Cosma and the Radon Group) within the 'Babeş-Bolyai' University. The Ştei-Băiţa (Bihor) area includes the Ştei town and a few villages (Băiţa Plai, Băiţa Sat, Nucet, Fânaţe, Câmpani), with a total number of 16,300 inhabitants, localised in the Bihor Mountains, in the North-West of Romania, in the vicinity of the 'Avram Iancu' and 'Băiţa' uranium mines. The utilisation of the uranium scraps from the uranium mines (functional in 1950-1990) as a construction material, the erections on soils with a high permeability and the structure of the foundations that enables the radon infiltration from the level of the ground inside dwellings are the main causes for the high concentrations of radon recorded in this area. The majority of these residential buildings were built by radioactive waste materials. Similar problems can be found in the apartments where the ground-floor plates touch the ground and are 1 km away from the uranium mine (Băiţa Plai). On the other hand, the weather conditions caused the partial withdrawal of the uranium ore from the stock and the scraps in the Crişul Băiţei water, which then got infiltrated in the basements of the apartment buildings near the mine. What is more, the transportation of the uranium ore without the observance of the radioprotection standards and the perspective of closing down the mine call for several investigations, in order to provide the protection of the local population.

The preliminary results on the radon concentration in the Ştei-Băiţa area show a 234 Bq/m³ yearly average, 5.2 times higher than the national reported value, and the percentage of the houses with concentrations higher than 500 Bq/m³ is approx. 30 % (Cosma et al, 2009). An incidence of lung cancer in the Ştei-Băiţa (Bihor) area was noticed, as mentioned in our recent publications about the lung cancer caused by radon (Cosma et al, 2009). At the same time, a large number of houses were identified with a high risk of radon. According to the results obtained and to the data supplied by the Population's Statistics, the estimate for this area was that 25 % of the lung cancer deaths are assigned to the exposure to the radon from inside. The current evaluations are higher, still they remain comparable to the ones of 16 % (5 % to 31 %) estimated by the European studies (Darby et al, 2006) and also to the 11 % ones (0 to 28 %), as reported in the combined analysis of the North-American studies (Field et al, 2006).

Health is considerably affected by environmental pollution, so that the mortality rate is higher than in other areas, the rate of lung cancer appearance is also higher and the life expectancy is reduced by a couple of years. The critical situation calls for the remedy measures to be taken into consideration. The aim for applying these measures is not only to diminish the level of radon from inside, thus increasing life expectancy for the inhabitants of the area under study, but to do this with a minimal impact on the buildings structure and on those who live there. In order to have certain records for the dwellings that need remedying, a campaign for measuring and monitoring the radon in all the houses from the Băiţa-Nucet-Cîmpani area is necessary.

The utilisation of the radioactive materials coming from the 'Băiţa' uranium mine for building houses and the foundations structure, along with the soils with high levels of radon, represent the main sources of the high concentrations of radon measured inside the typical dwellings in the area under investigation. The utilisation of the radioactive materials from the uranium mines for building houses and consolidating foundations represent a phenomenon never seen in other similar areas from Europe.

1.2. Measurement of the radon concentration in the air

In the air outside, the concentration depends on the soil, the air currents etc. and on other factors. The risk of getting sick is very low. High concentrations can be found around the uranium mines. In the water, the radon concentration is higher deep inside, higher concentrations having been measured in the residential waters. For buildings, the concentration is higher at the basement and at the ground-floor and depends the most on the soil, on the construction materials and on the soil insulation. The type of the building, the materials used and the ventilation system affect the radon concentration.

The measuring methods differ according to the type of samples and the measurement goal (Papp, 2011) :

1. canisters with carbon content liquid, which absorbs the particles resulted by the radon disintegration. The liquid is analysed by counting the particles withe the help of a scintillation counter. The method needs laboratory analysis.

2. alpha particle detectors, which are small-sized plastic films that get exposed for a longer time : 1 to 12 months (integrating methods). The films are sensitive and record the trajectories of the particles that are analysed in the laboratory.

3. the electret ion detector, which contains an electrostatically charged disc of raylon : the ions generated by the radon disintegration modify the load and are thus detected.

4. the measurement by means of special devices, which record the alpha particles by various methods – ionisation chamber or uncapsulated semiconductive transducers – and continuously display the measured value.

The measuring periods can be :

1. short – between 2 days and 3 months – and are carried out in the lowest living premises, at least 50 cm away from the ground, far from sources of heat, humidity or fans

2. long – longer than 3 months.

The devices record a medium concentration of radon by integrating the measurements. Please find below the description of a few such devices :

1. the device manufactured by the National Safety Products (USA) : the model from 2006 measures concentrations between 0.1 and 999.9 pCi/l. This device is used by environment inspectors, consultants and private persons. The sensor used is a ionisation chamber supplied by 250 V DC, where the alpha particles produce an impulse counted by the digital processing system of the device. The software part transforms the transducer’s indication into a particle concentration. The measurements can be on short term (7 days) and on long term (maximum 5 years, after which a reset takes place). The concentration average is displayed every hour. If a certain threshold of the radon concentration is exceeded, an alarm gets started. The device is constructively endorsed by UL and CSA.

2. the device made by GT Analytic, called Ramon 2.2 : as a transducer, this device uses a semiconductive element. The air that contains radon is diffused in the detection chamber and the issued alpha particles are detected by the semiconductive element. The measuring accuracy is

below 10 %, which falls both into EPA's requirements and into the EC's. The display is in Bq/m^3, the maximum measured value is 9999 Bq/m^3 and the lowest value is 1 Bq/m^3. The device is TÜV certified. Devices from the same supplier, meant to professional applications and at higher prices are Radim 3A – for measuring the radon from the air – and Radim 3W – for water measurements. The sensor is a semiconductor, the device can work supplied from the network and from accumulators and it is equipped with an RS232 interface for the connection to the computer.

3. a portable measuring device, Radim 5, can operate up to 150 days, being supplied by batteries. A more complex device, which also contains a computer interface, is Alpha II, from the Diversified Research company – figure 1.7.

4. the system with elecrets from RAD ELEC Inc. The elecrets are raylon discs that get charged electrically. The electrets are put in a ionisation chamber that provides an electric field inside. The ionised particles are deviated in the electric field by the electrets and upon the impact the electric load of the electret gets modified. A measuring device counts these modifications and displays the results.

The ionisation chamber may be used as a transducer for electronic measuring devices. This chamber is a closed enclosure of various shapes (close to the cylindrical one), where there are two parallel flat electrodes and air under normal conditions or with forced circulation. The electrodes form a flat condenser. Upon decomposing, the radon atoms will cause air ionisation and the ionised particles will give birth to a measurement current in the exterior circuit. When continuous voltage is applied to the chamber electrodes, inside the chamber there appears an electric field, which directs the ions toward the electrodes. In the absence of the electric field, the ions have a random movement. The ionisation caused by the decomposition of a radioactive particle causes outside the appearance of a small current, which brings forth voltage on a resistance. There appears a voltage impulse, which can be seen or taken and recorded by means of an electronic measuring system. The measurement of the number of radon particles in the air needs a source of polarising the ionisation chamber by variable voltage, in order to set up the best detection voltage.

Chapter 2

System of measuring the radon concentration in the air and data transmission from multiple locations

2.1. System of measurement by means of a detection chamber

A device for measuring the radon in the air, with a modular structure, so that it can be adapted to a wide range of applications, was designed and also a system of data transmission on several ways, which can be selected subject to the place where the measurement is made. The block diagram of the device is provided in figure 2.1.

The main constructive characteristics of the device are :

1. One chose to use an ATMEL Atmega 16 microcontroller, with sufficient performances for this application and at a low price. Another important aspect had in mind was that the microcontrollers from the ATMEL AVR family are more widely used in Romania and purchasing is easier in the hypothesis of a series production. The device includes a local graphic display, which can show the radon concentration in the air and a brief graph can be made.

2. The device structure is modular, for a greater flexibility. This means that the variant made comprises a GSM-GPRS modem, but the microcontroller enables the connection to a telephony line outside (it has a hardware and software interface). In addition, the analogical circuit enables working with the detection chamber from the inside and also the connection of a ionisation chamber outside.

3. The transmission system was designed in such a way as to allow several measuring devices to be connected to a data server that collects data and centralises them. The software programme alerts whether the radon concentration exceeds a certain limit. Similar performances are described in Yamamoto et al, 1998 and Roca et al, 2004.

4. The device portability is provided by the fact that supply is made by a 12 V accumulator, which can be charged from the network.

5. For the data to be sent in specific time moments, a GPS reception module was added, which interprets the temporal data from the GPS signal.

6. Two measuring methods were implemented :

- by integration
- by counting the impulses

The two methods will be analysed further on in this chapter.

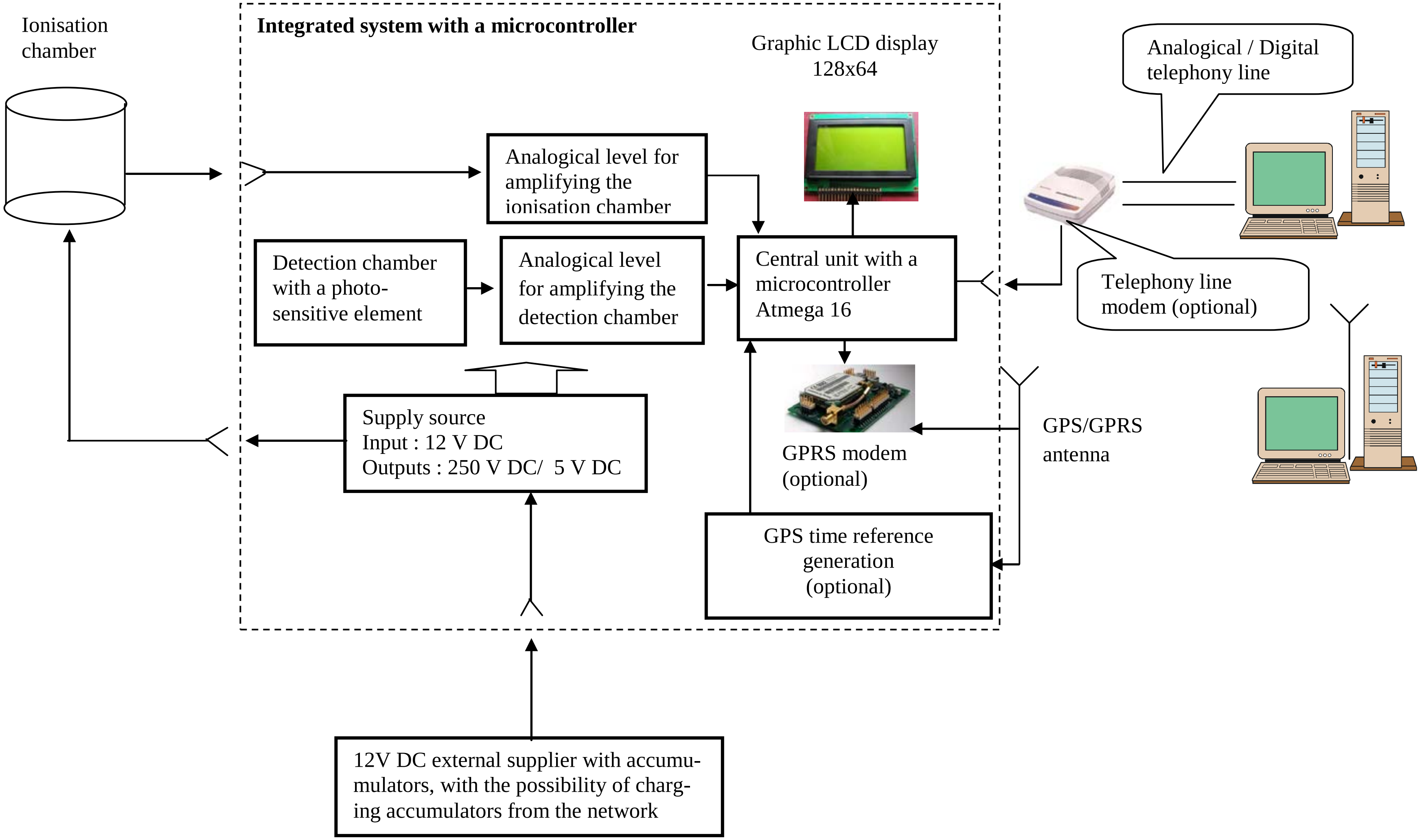


Fig. 2.1. The block diagram of the radon measuring device (original diagram)

The detection chamber is presented in figure 2.2 :

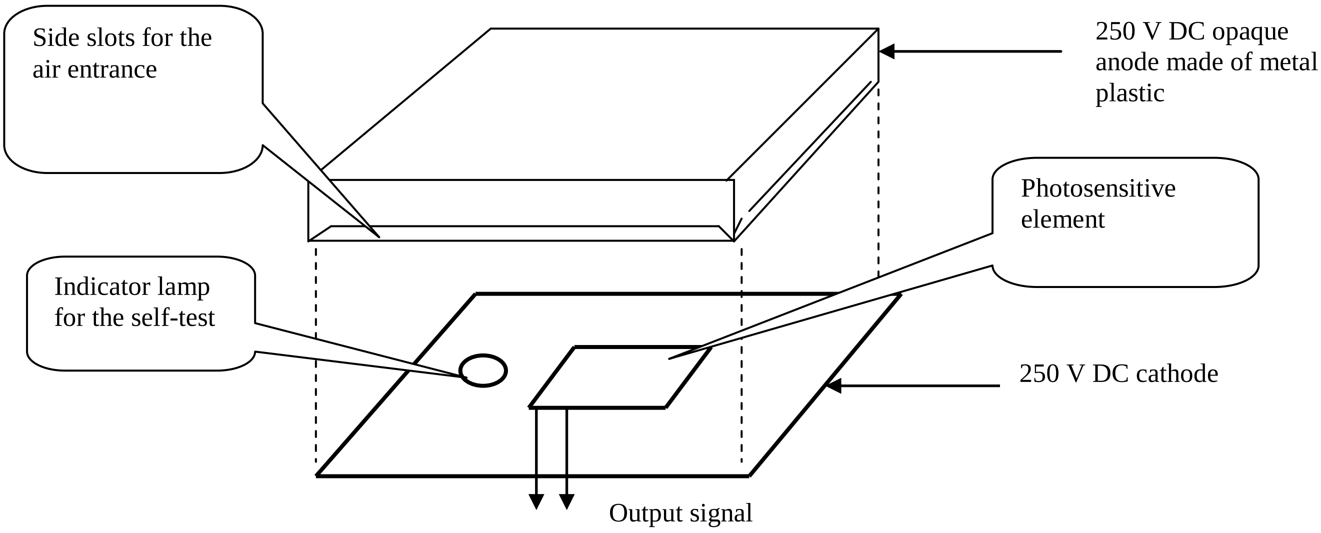


Fig. 2.2. Detection chamber (original drawing)

A powerful electric field is generated inside. The radioactive particles hit the photosensitive surface and give birth to an electric signal upon getting out (Noto et al, 2002). An operation self-test is made prior to utilisation, by turning on an indicator lamp (with a very low luminous intensity), and the output signal is measured. The read values are compared to the reference ones and if they are within the accepted accuracy range, measurement begins, otherwise an error code is displayed. In the absence of lighting, the read signal must be close to zero (in a scheduled time frame), otherwise the noise that appears can be due to the electromagnetic interferences. An error code is displayed and the user is directed to remove the sources of electromagnetic field.

The equation for the electrons movement in an even electric field (Sandu, 1973) is described below :

$m\frac{dv}{dt} = qE$ where m is the electron weight and q the electric charge (2.1)

Upon calculating, the electron trajectory is obtained :

$$y = -\eta.E\frac{x^2}{2.v_0^2.\cos^2\theta} + x.tg\theta \tag{2.2}$$

In order to simulate the electron behaviour in an electric field we take into account : the elementary load : $q = 1.602\ 176462(63) \times 10^{-19}$ C, the electron weight : $m = 9.10938188(72) \times 10^{-31}$ kg, the electrons speed : approximately 104 m/s, the intensity of the electric field in the ionisation chamber : around 2500 V/m. These data can be used to make a Matcad simulation that shows the trajectory modification depending on the angle of entrance of the electron in the field. The electrons will be directed toward the photoelement / electrode, irrespective of the incidence angle. The simulations stand valid for the behaviour of the loaded particles in the ionisation chamber and in the detection one. In the detection chamber, the field inside orients the loaded particles toward a photosensitive element. A photovoltaic cell is a pn junction with relatively high concentrations of impurities in order to diminish the electric resistance. The region subjected to illumination is thin, in order to enable the light to reach the passage region. If the cell is in the dark, no voltage will appear at its terminals, as the cell is in a thermodynamic balance. If the light falls on the surface of the photon cell, it penetrates the thin area and generates pairs of void electrons, which because of the E internal electric field from the passage region are oriented in the following way : the voids toward the p region and the electrons toward n. If there appear electrons accelerated in the electric field, they too penetrate the n area and will take part in the load accumulation. This one gives birth to a difference of potential at the terminals which when the cell is subjected to short circuits generate a current due to the void electron recombinations. In this case, the voltage at the terminals (V_f) becomes 0 and the thermodynamic balance is restored. The short circuit current (I_f) is pro rata the intensity of the luminous flow or of the electron flow.

The static characteristics enable the execution of a simplified model - figure 2.3:

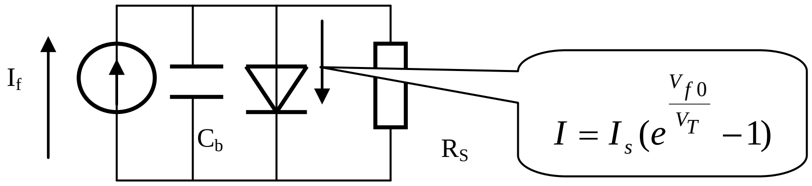


Fig. 2.3. The photovoltaic cell model (classic model)

The photovoltaic cell model will be used for assessing the performances of the two methods taken under discussion for measurements. The measurement of the level of radiation, so of the number of radioactive particles, can be made in two ways :

- by integration : the voltage level upon the exit of an integrator is measured, which is a level pro rata the number of particles from the enclosure
- by counting the voltage peaks, so of the number of particles.

2.2. System of measurement by means of a ionisation chamber

The ionisation chamber is the element sensitive to the presence of radon and is composed, as in figure 2.4, of the chamber enclosure (1), which is a metal cylinder endowed with air inlets and outlets at one end, which could contain radon, and of the chamber adjustment and calibration device (2, 5). The chamber is also complete with fastening electroinsulating devices (10, 11) for the cylinders (8) with grid-disc type electrodes (7) connected to the supply terminals (3) with a high value continuous voltage. The grid-disc type electrodes (6) that are in a galvanic contact with the metal enclosure of the chamber are mounted between the electrodes (7). The cylindrical pipe (4), through which the air is inserted into the chamber, is mounted in the middle of the enclosure (1). During operation, the air is inserted through the cylindrical pipe (4) by a volumetric pump, as per the arrow-marked route, and it reaches the enclosure base, being forced to pass through the disc-grids (7, 6) between whom en electric field optimal for detecting the particle of radon that causes the ionisation of the space between the grids gets formed. The distance between the grids is conveniently selected, according to the energy of the ionised particle and a minimum voltage for supplying the detection grids, which is made by means of the device (2, 5).

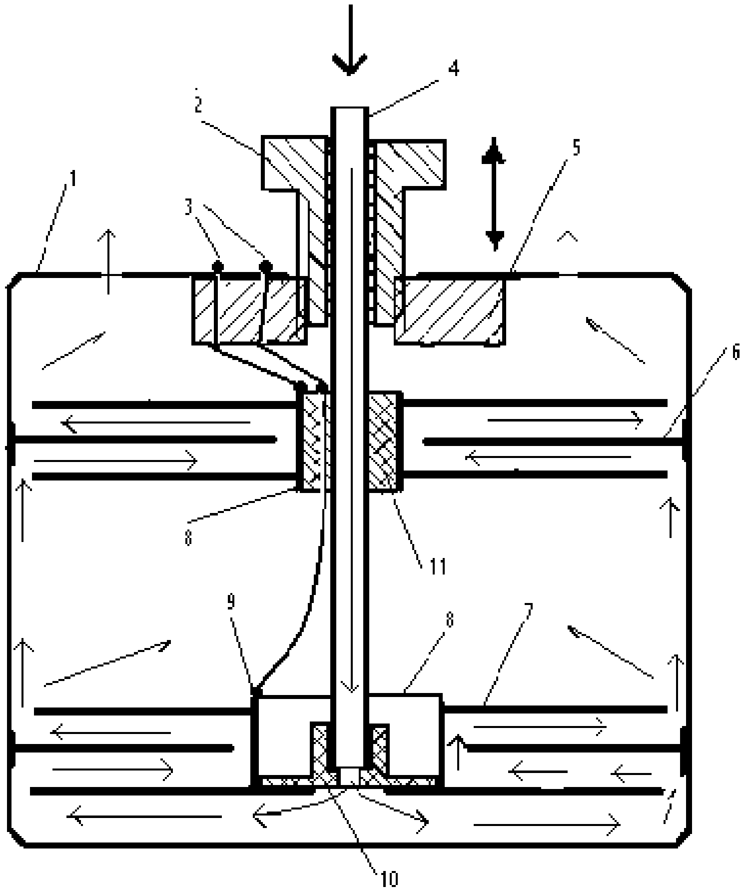


Fig. 2.4. Ionisation chamber structure (original structure)

A high selectivity of the chamber is obtained by a correct calibration, which should consider the amount of air that the pump takes, the distance between the grids and the difference of potential between them. The chamber has two selection levels and is supplied by the connections (3) with different voltages for enhancing the detection sensitivity (optionally, several levels of detection can be attached). After the air covers the route indicated by the arrows inside the chamber, it is evacuated through the peripheral openings in the upper part.

The signal taken by the ionisation chamber is under the form of impulses of discharge by ionisation and it is taken over by an analogical level, then by the microcontroller, which counts the impulses and displays the results.

The measuring procedure was specially made in order to provide a greater immunity to the exterior disturbances and it is specially designed for managing the hardware structure for taking over the impulses through the two channels described above. The measuring procedure has got several steps :

1. The impulse counting procedure

The duration and the amplitude of the impulses for the discharge of one particle of radon are known. The microcontroller checks the received impulse in terms of duration and only counts it if its duration is the expected one, between certain limits, according to the diagram from figure 2.5 :

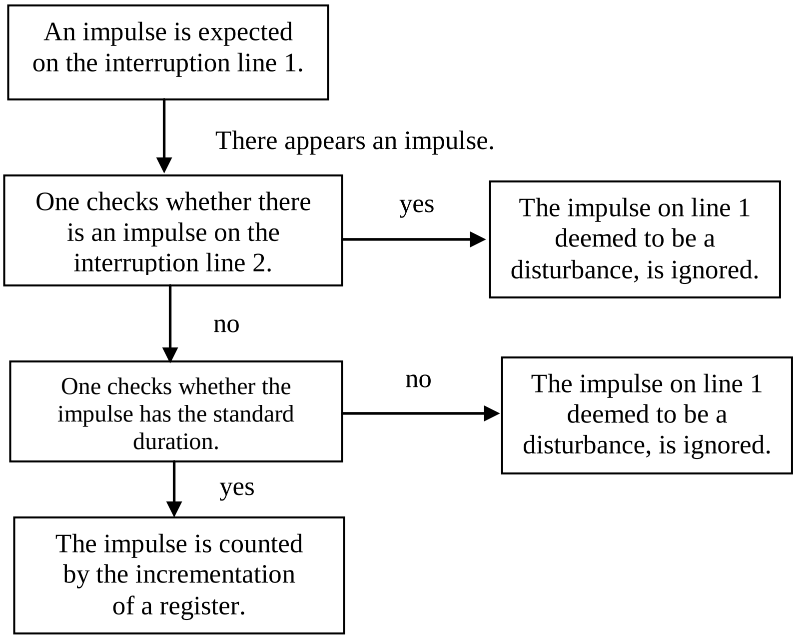


Fig. 2.5. The impulse counting procedure (original logic diagram)

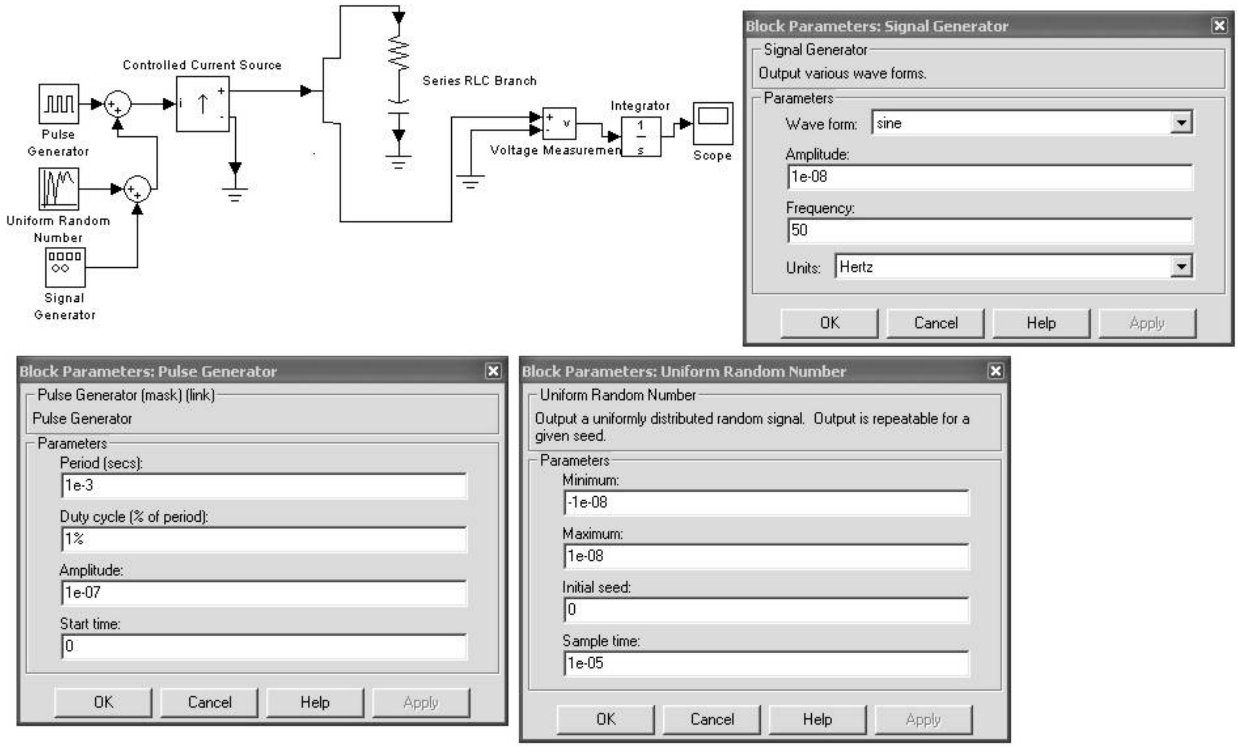
After each incrementation, the register is saved in EEPROM, for an interruption of the supply voltage could not affect the measurement result. If the microcontroller has a lower calculation power, saving is made only after one hour.

The totalisation and display procedure provides the impulses totalisation after each hour, the time being generated by the microcontroller or read by the GPS system. After one hour, the radon concentration obtained by the mediation with the previously measured value is displayed and sent remotedly. The warning procedure is implemented in order to send warning messages if the radon concentration in the air repeatedly exceeds the previous values. The number of readings N1, from which a reference average is made (an average of the radon concentration on N1 hours), the number of readings N2 that exceed the reference average and the excess percentage D for which the warning is issued, are programmed in the microcontroller. N1, N2 and D are set up experimentally.

2.3. Measurement by integration

The model of the measurement by integration made in Simulink is provided in figure 2.6.

An impulse generator simulates the appearance of a radioactive particle, whose frequency is one particle / 10 ms, amplitude 10^{-7} A and duration 0.01 % from the period, that is 10 μs. The noise is simulated by a random number generator, the noise amplitude being 10^{-8} A. The photocell is simulated by a source of current and the load resistance is 10 MΩ.



Block Parameters: Signal Generator
Signal Generator
Output various wave forms.
Parameters
Wave form: sine
Amplitude: 1e-08
Frequency: 50
Units: Hertz

Block Parameters: Pulse Generator
Pulse Generator (mask) (link)
Pulse Generator
Parameters
Period (secs): 1e-3
Duty cycle (% of period): 1%
Amplitude: 1e-07
Start time: 0

Block Parameters: Uniform Random Number
Uniform Random Number
Output a uniformly distributed random signal. Output is repeatable for a given seed.
Parameters
Minimum: -1e-08
Maximum: 1e-08
Initial seed: 0
Sample time: 1e-05

Fig. 2.6. Model of measurement by integration (original simulation)

Figure 2.7 sets out the results after the integration (period : 0.1 ms, namely 10 particles/ms ; impulse duration : 10 μs). The final value of the voltage has a 0.1 % error caused by the noise. On the left there is the entire time frame for the integration and on the right there is the final time frame.

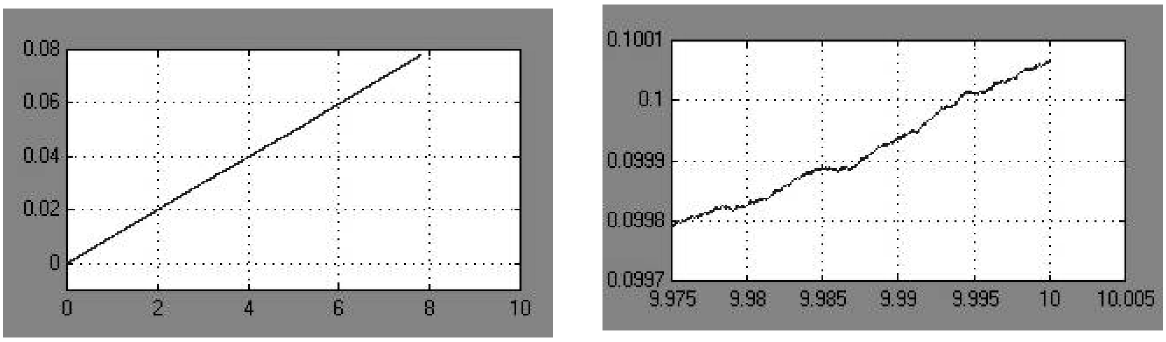


Fig. 2.7. Voltage after the integrator (period : 0.1 ms ; impulse duration : 10 μs) (original simulation)

In case of a low concentration of gas, that is one particle per 100 ms, the error already becomes 60 %, so way too big. The bigger the error, the lower the impulse frequency (fewer particles in time). Moreover, the bigger the error, the lesser impulse duration and amplitude (the error obviously depends on the impulses energy).

In order to ascertain how the influence of the network voltage upon the entrance is manifested, one totals a sinusoidal signal with the 50 Hz frequency and the amplitude of 10 % from the one of the useful signal. The signal is shown with and without integration in figure 2.8 :

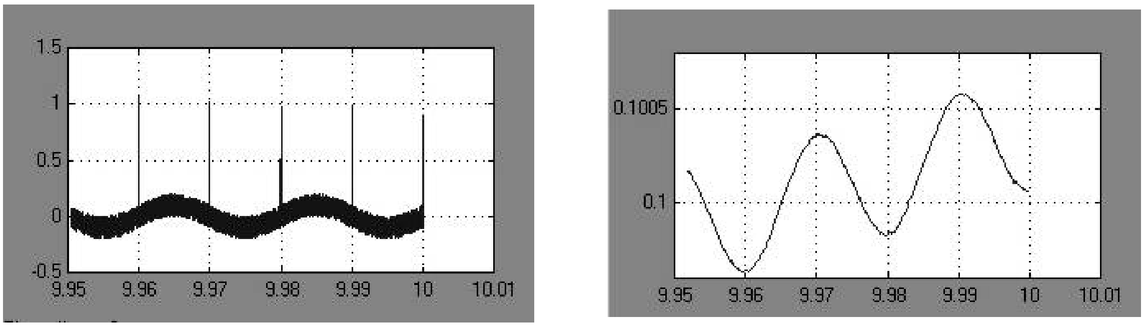


Fig. 2.8. Voltage prior to the integrator (on the left) and after the integrator (on the right) (original simulation)

Upon comparing the signals to those from figure 2.7 (period : 0.1 ms, impulse duration : 10 μs), one notices that the voltage at the end of the integration period has the same value and that the addition of the disturbing sinusoidal signal does not affect the measurement result. If the integration period is chosen as a multiple of the period for the periodical disturbing signal, the rejection of this disturbance is noticed. If the voltage on the integrator had been measured in moment 9.99 s, then the value would have been 0.1006 and the error would have been 0.6 %, 6 times greater than in the absence of such a disturbance.

A model of the integrator by using an integration capacity is given in figure 2.9 :

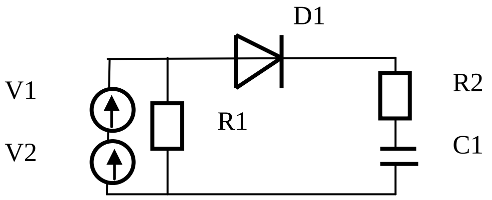


Fig. 2.9. Simplified model PSpice of the integrator (original model)

The voltage source V1 simulates the signal supplied by the sensor, where the appearance of a loaded particle causes the appearance of a 5 ms impulse, once per second at the 500 mV amplitude. The disturbance is a sinusoidal signal with the 50 Hz frequency and the amplitude of 1/10 from the one of the useful signal. The integration condenser C1 is 1 mF and the diode D1 has no threshold voltage. The voltage levels on the condenser in the disturbed situation are 179.5 mV at 500 s and 146.2 mV at 250 s, which means that the difference of amplitude as compared to the undisturbed situation is 20 %. The integrator with a condenser did not reduce the level of the disturbance, unlike the ideal integrator simulated in Simulink.

The running of acquisition tests showed an instability of the values from the exit of the analog/digital converter from the microcontroller composition, which negatively influences the measurements accuracy.

The static testing method consisted in successive measurements of the signal supplied by the converter with its analogical entrance connected to the compound and the transmission of the data to the computer for analysis purposes. The interface with the computer was made by the serial standard RS232, the data being received by a specialised programme for reading the serial port. One monitored the samples obtained and one detected a strong influence from the part of the serial connection. A random noise is overlapped on the useful signal, which should be constant and should equal zero. Deviations from the 7 LSB-sized nil value can be noticed, which is the equivalent of a 7 x 4.88 mV variation, namely 34.16 mV, which is unacceptable in case of a radon measurement. Analogical signal filtration or digital mediation are therefore needed.

The analysis of the analogical signal supplied by the sensor shows that the noise appeared upon the entrance of the converter can be diminished by screening the entrance route. The size and the frequency of the unwanted impulses are noticed to be considerably reduced. The placement in the close vicinity of the transducer with the integrator and the microcontroller is essential in this type of application.

In terms of software filtrations, the simplest one is the filtration by mediation, which consists in sampling the signal with a high frequency and in calculating the current test specimen by mediating several test specimens taken for one millisecond.

$$y_j = (x_{j*N+1} + x_{j*N+2} + x_{j*N+3} + \ldots\ldots\ldots + x_{j*N+N}) / N \qquad (2.3)$$

where :

N – the number of test specimens taken for one millisecond

Y – the signal for exiting the mediation filter

X – the signal for entering the filter

The output signal is calculated from N test specimens taken previously by an arithmetic average. For great values of N, the algorithm needs a great power of processing. For instance, for the value N=50 the error rate is much reduced : only 4-5 erred samples. Of course, this performance can only be attained by the maximum utilisation of the processing system resources, which is inacceptable in most applications, as the system also has some other tasks to execute in parallel. One may say that the principle of measuring by integration is superior from the anti-disturbing point of view and by the fact that it enables a slow acquisition, therefore the microcontroller does have time to perform the mediation operation.

2.4. Measurement by impulse counting

Another variant of measurement involves counting the particles that are deviated toward the semiconductive detection element. The signal generated by the sensor upon the contact of a ionised particle is low, important amplification being therefore necessary. Additionally, the electromagnetic noises from the environment may affect counting.

The block diagram of the measuring system by a microcontroller is set out in figure 2.10. The detection chamber (with an electrostatic capture) contains a photoelement in an enclosure where the air can get. The enclosure is in a high value electric field obtained by the application of a 250 V DC voltage.

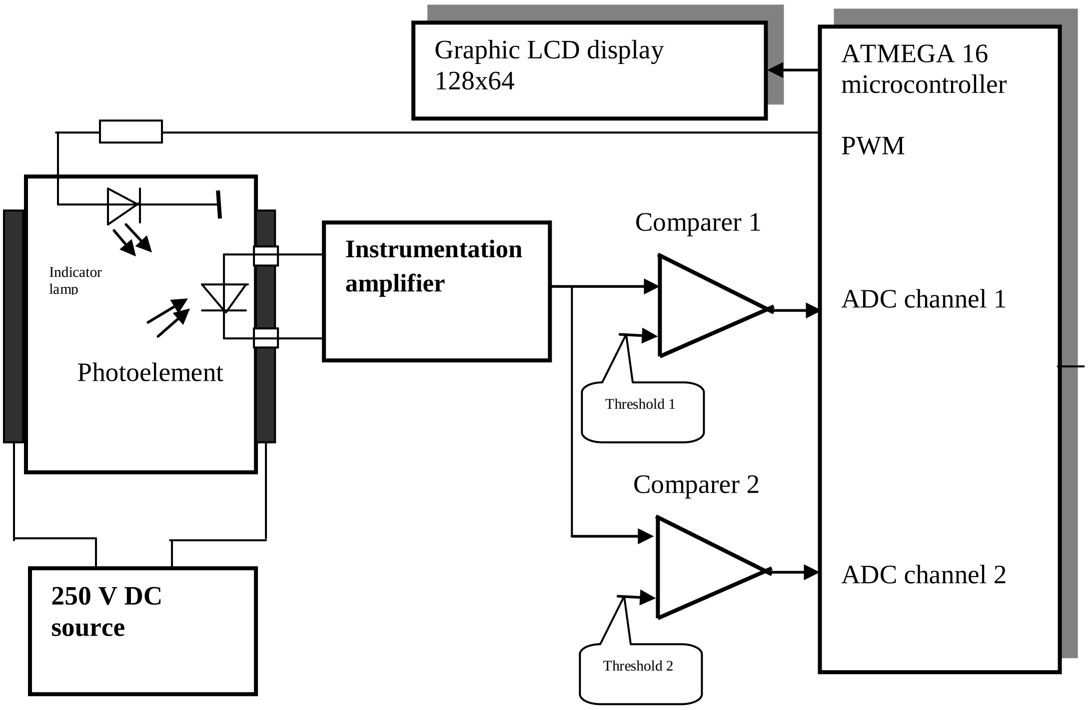


Fig. 2.10. Block diagram of the measuring system by impulse counting (original conception and implementation)

The particles ionised by incidental hitting onto the photoelement give birth to a small current, amplified by an instrumentation amplifier. The level of the output signal will be greater than that of the noise and a comparative circuit 1 detects when the thershold is exceeded. The output signal is taken over by the microcontroller on an analogical input of an analogous digital converter or on a digital input for external interruptions. The input level can also be used in case of using the ionisation chamber, except for the calibration part.

The duration and the amplitude of a current impulse depend on the energy of the incidental particles on the photelement. The amplitude is increased by the instrumentation amplifier, but the duration remains small. In order to be able to make a portable measuring device at a low cost, a cheap microcontroller must be used, therefore the impulses width needs to be extended by differentiation RC circuits. The variation of the parameters of the environment where the measurement takes place and the variations of the electronic components parameters make the measurement be affected by errors and the device operation be disturbed. The electromagnetic environment is one of the main possible causes. A way of checking the calibration, which consists in an indicator lamp placed in the measuring enclosure (inside the transducer), supplied by a PWM channel of the microcontroller, was implemented. The comparer 2 compares the output impulse to a greater threshold, which can only be attained when the indicator lamp has a bright intensity. The lamp is directed to light strongly at the beginning of the measurement in order to check the calibration. If an impulse coming from the comparer 2 is detected during measurement, this is deemed to only originate from an electromagnetic disturbance and the measurement is abandoned by the display of an error message.

The measurement simulation diagram is given in figure 2.11 :

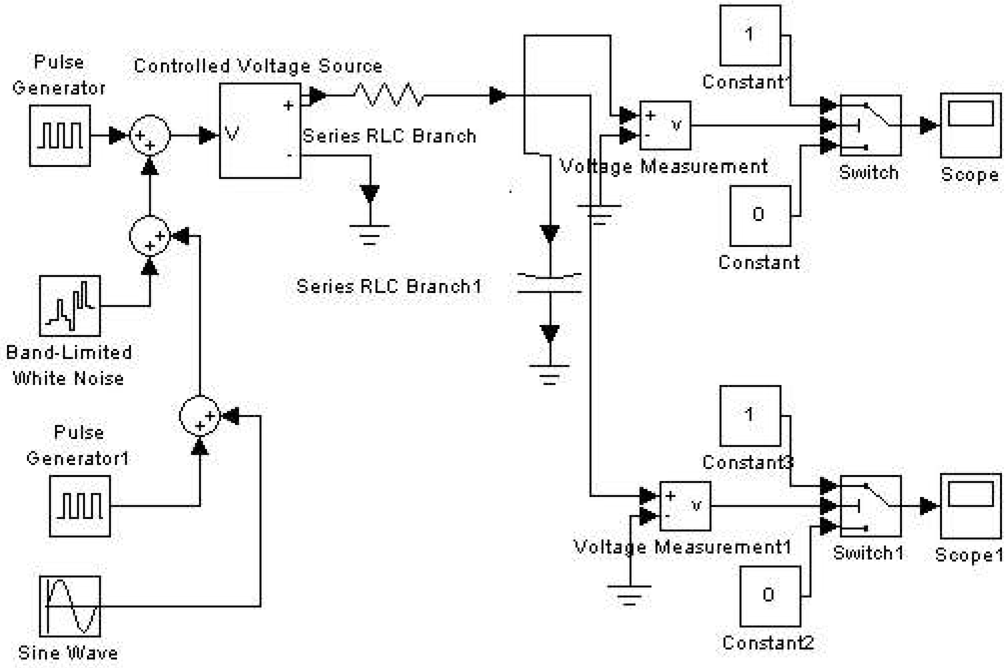


Fig. 2.11. Measurement simulation diagram by impulse counting (original model)

Like the measurement by integration, the one by impulse counting is usually disturbed and the sources of useful impulses are added a source of random noise, which simulates the internal noise of the photoelement, and a sinusoidal source, which simulates the 50 Hz disturbance that comes from the alternating current industrial network. An impulse generator simulates the low amplitude impulses that derive from a discharge and an impulse generator simulates the great amplitude impulses generated upon calibration by the indicator lamp illumination. The input signal is like in figure 2.12.

The differentiation circuits increase the impulse duration and the threshold circuits select the impulses according to the amplitude. The output impulses from the comparers 1 and 2 are given in figure 2.13, on the left and on the right, respectively :

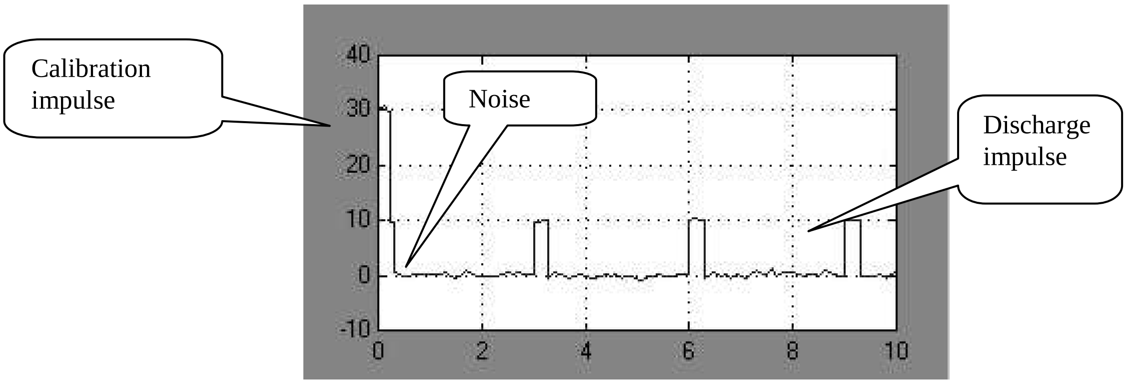


Fig. 2.12. Input impulses (original)

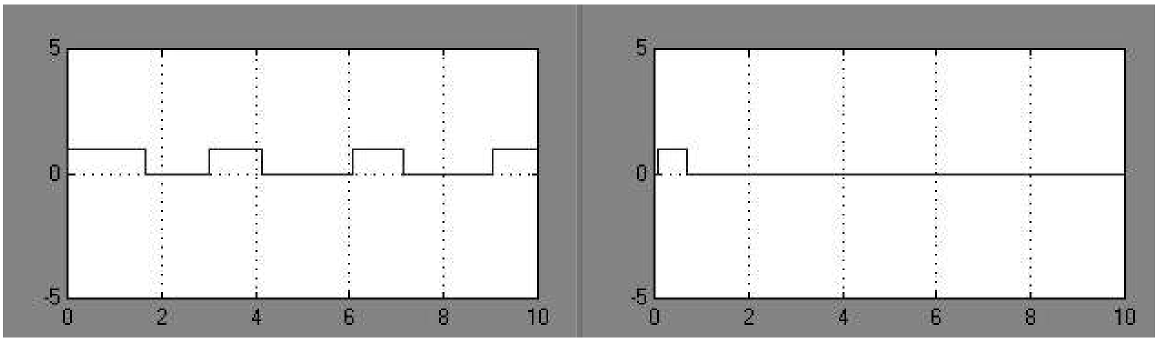


Fig. 2.13. Output impulses (original)

One notices that the discharge impulses and the calibration one appear upon the exit of comparer 1 and that upon the exit of comparer 2 there appears only the calibration impulse.

Special attention must be paid to the entrance level, whose task is to amplify small signals in the presence of the electromagnetic disturbances.

The amplification circuit is located near the detection chamber / the ionisation chamber. Upon entering, the circuit has an operational instrumentation amplifier AD712, which is followed by two levels built by means of the quadruple operational amplifier LM324, which provides the necessary signal for the level entrance to be connected to the digital entrance of the microcontroller. The amplification level with LM324 is a non-linear one, composed of an upper branch, which gives birth to a number of impulses pro rata the signal amplitude, and of a lower branch, which only issues signals if the signal amplitude is greater than a threshold value. The threshold value can be selected in such a way as to enable the amplifier to signal an error by means of an impulse issued by the lower branch, namely the appearance of an impulse with an abnormally great energetic value, which cannot come from a discharge, but because of an electromagnetic interference. The results of the simulation in SPICE show that at a low amplitude of the input impulse there appears an impulse upon the exit of the upper branch and no impulse upon the exit of the lower branch.

2.5. Composing parts of the radon measurement device

The central unit with a microcontroller has a clasic structure, which besides the microcontroller ATMega 16 includes the tact generator, the RESET circuit and the MAX232 level modification circuit for the serial interface RS232, to which the GPRS, GPS modules and the telephony line modem will be connected.

The implementation of the system-user interface was performed by a liquid crystal graphic display big enough to view the working menus and the results in the graph and test modes. For the implementation, the DEM128064ASYH-LY module was selected, which has 128 columns, 64 lines and as many as 8192 pixels, enough for the current application.

The source of supply aims at creating a 250 V continuous voltage, which generates the electric field in the detection chamber and in the ionisation one. The integrated circuit on which this application is based is LM 3524, a PWM signal generator.

The transmission at exact times can be made by using a timer from the microcontroller. The position of the device is not notified in this case. The position and the time can be found out very exactly by using the GPS system. The GPS module is optional in this device and can be mounted upon request. The interface for the coupling with the microcontroller is the serial interface RS232.

Where the radon concentration measuring device can be connected to the server by a telephony line for data transmission, the microcontroller can send data by means of a modem. In general, direct transmission by cable and cable telephony are used less and less, because of the high installation costs. In case of the connection of the radon measuring devices, this method can only be profitable if there is no GSM signal in that area.

The best method in terms of flexibility and costs is the method of transmission by GSM telephony. The GPRS module used was at first of the GM862-GPRS type, then it was the EZ10 model, both of them made by TELIT. The GPRS (General Packet Radio Services) standard enables a direct connection between the GPRS modem and the Internet, by data packages. The maximum transfer speed can be maximum 171.2 kbps.

The author coordinated the group that made a software system called Radon Data Manager. This enables the taking over of predefined messages from the pieces of equipment involved in the measurement of the radon concentration connected within the GPRS system made, their interpretation and the transmission of the resulted data to an MySQL server, with a view of their storing in a database. The software system includes three interfaces interconnected by means of the application methods :

- the graphic interface, which enables the user to communicate with the software system ;
- the server interface (the server), which represents the connection of the application to the pieces of equipment that send predefined messages to the server by using the TCP-IP protocol pile and various technologies of access to the Internet ;

- the MySQL client interface, which provides data recording and updating in the database by transactions between the interface and an MySQL 5.0 server.

At the level of a graphic interface, Radon Data Manager 1.0 enables operations of server control and of the connection with the MySQL server, the management of the equipment involved in the measuring process and the monitoring of the activity of the software system by messages provided by the application methods.

The MySQL client provides the transactions between Radon Data Manager and the MySQL server by using several methods implemented in the software system. The authentication at the MySQL server is made by a complex method, which provides at the same time the creation of the database in case such base does not exist, the taking over of the authentication data from a binary file, thus enabling the automated authentication to the MySQL server the moment when the software system is turned on, without the necessity of the user’s intervention. Upon the first utilisation of the RadonDataManager system, the user needs to enter the authentication data. Should the data be incorrect, the window for setting the authentication data will remain open for the entering of other data. The structure of the software application and the place within the radon measuring and managing process is shown in figure 2.14 :

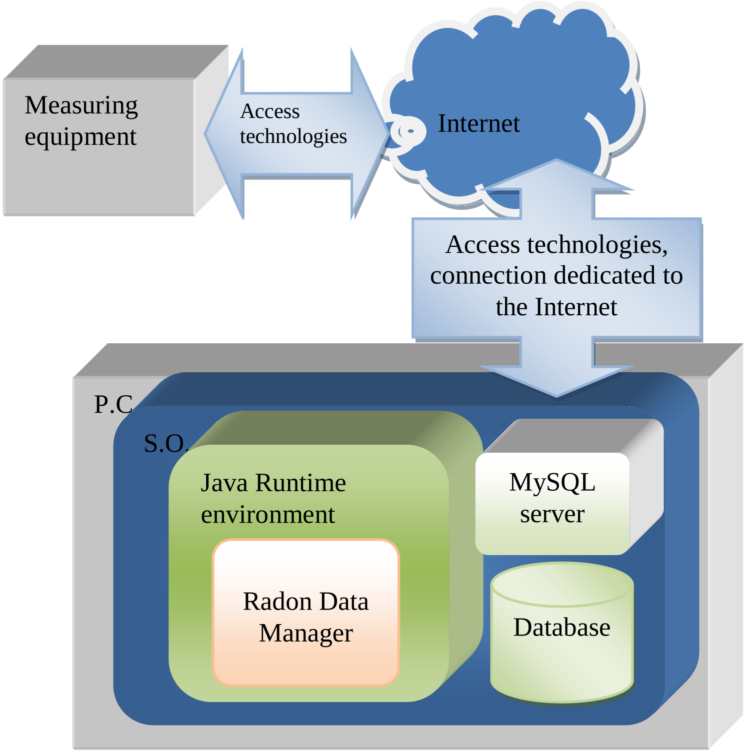


Fig. 2.14. The place of the software application
within the radon measuring and managing process (original scheme)

For the system to run, the software application needs to run on a computer permanently connected and dedicated to the Internet by various access technologies offered by the service providers. A connection dedicated to the Internet involves a fixed IP address offered by contract by an Internet Service Provider. The permanent connection may be supported by an Internet access service by means of an optimal QoS (Quality of Service) parameter. The main screen of the application contains several windows, by which the connected equipment can be identified and managed. The measuring devices show the time, the geographical coordinates and the radon concentration.

2.6. Experimental results

A picture with an overview of the portable device with a detection chamber is presented in figure 2.15 :

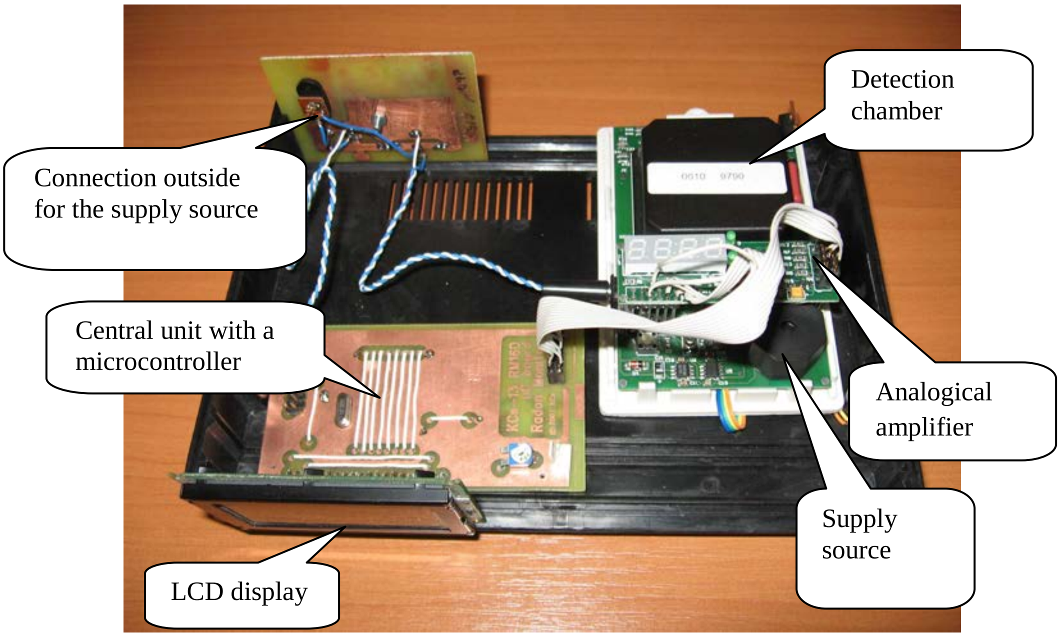


Fig. 2.15. Device with a detection chamber for measuring the radon content in the air (overview) (original)

A front view picture is given in figure 2.16, with the indication of the graphic LCD display for the radon concentration in the air.

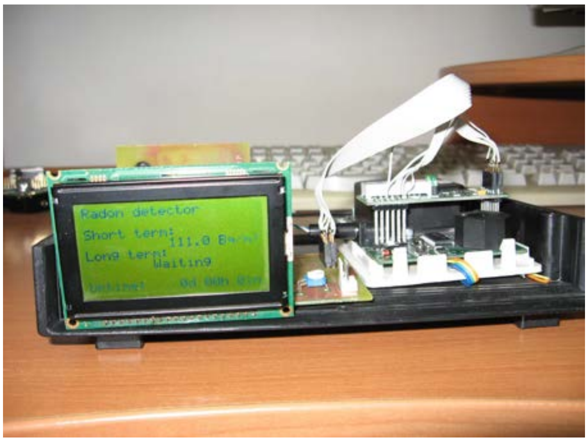


Fig. 2.16. Device with a detection chamber for measuring the radon content in the air (front view) (original)

The measuring device with a detection chamber, equipped with the GPS/GPRS Telit EZ10 module, looks like in figure 2.17 :

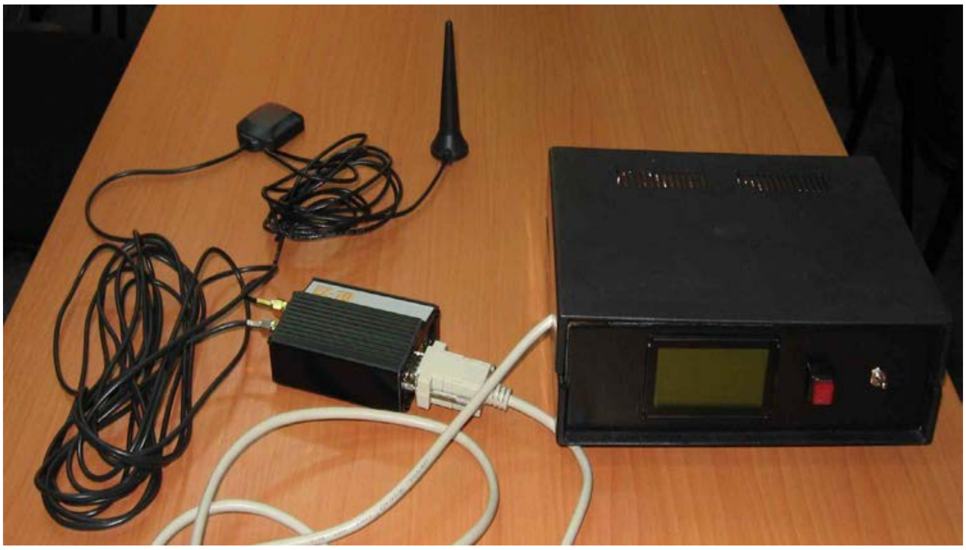


Fig. 2.17. Measuring device with a detection chamber

Determinations by means of the ionisation chamber from IFIN-HH have been carried out, too, the stand being shown in figure 2.18 :

Fig. 2.18. Laboratory stand for tests by means of the ionisation chamber

The device made by means of the suggested ionisation chamber is in the calibration and testing phase, the inside being provided in the picture from figure 2.19. The tests performed on a longer period of time (2 months) aimed at the relationship between the values given by the suggested device and an electronic detector Safety Siren 2 - figure 2.20 :

Fig. 2.19. Device with a ionisation chamber for measuring the radon concentration – inside view (original)

Fig. 2.20. Device with a ionisation chamber for measuring the radon concentration, during tests, alongside a Safety Siren 2 device and a Geiger Muller meter (original)

Chapter 3

Methods applied for mitigating the radon concentration in the air

3.1. Dwelling building and reconditioning for providing the reduction of the radon concentration in the Băiţa area

3.1.1. Radon concentration measurement prior to the remedy

The **Fânaţe 116 A** house was selected for remedying according to the integrated radon measurements carried out in two campaigns in 2011, which show a high concentration of radon, above the allowed limits. The measurements results are set out in table 3.1.

Table 3.1. Results of the integrated radon measurements in the two campaigns from 2011, namely the yearly average concentration at the Fânaţe 116 A house

Room	Radon concentration (Bq/m^3)		
	Campaign 1 (Dec.-Feb.)	Campaign 2 (Mar.-Apr.)	Yearly
Bedroom 1	**1013**	**601**	**680**
Bedroom 2	**1600**	**1590**	**1395**
Living-room	**-**	**649**	**649**
Bathroom	**-**	**726**	**726**

The Fânaţe 116 A family house was built between 1976 and 1978 and it has a ground-floor and a basement underneath bedroom 1 - figure 3.1. The building materials used were brick, stone, sand and ballast from the Criş river, stone from the old mine area (Băiţa-Plai) and brick. The entire house had been recently renovated.

In order to identify the radon leaks between the basement and the building, radon concentrations measurements were performed from air samples taken from the cracks in the floor. The results of the continuous measurements carried out by means of radon devices in the investigated rooms are represented in fig. 3.1 and the descriptive statistics of the results is shown in table 3.2.

Table 3.2. Descriptive statistics of the continuous inside measurements results (minimum, maximum and average)

Room	Radon concentration (Bq/m^3)		
	minimum	maximum	average
Bedroom 1	**67**	**578**	**330**
Bedroom 2	**188**	**1425**	**889**
Living-room	**100**	**546**	**333**
Bathroom	**56**	**731**	**395**
Basement	**25**	**2874**	**1131**

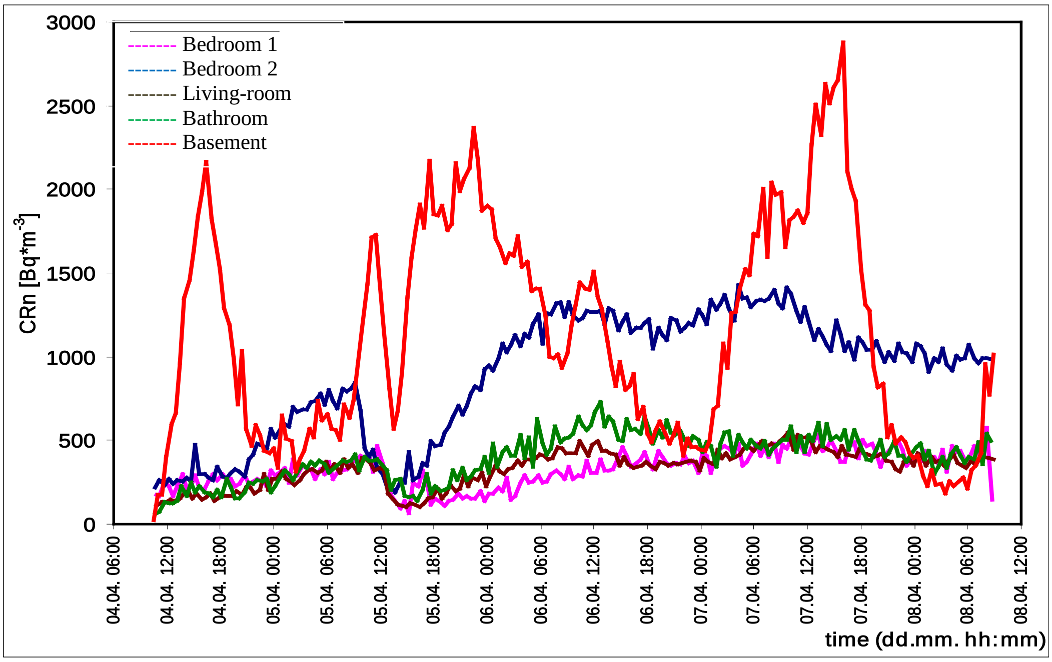


Fig. 3.1. Results of the continuous radon concentration measurements in five rooms at the Fânaţe 116 A house (bedroom 1, bedroom 2, living-room, bathroom and basement) (original)

The radon leaks at the contact between the basement and the building (with values of the radon concentration above 1 kBq/m3) were identified in bedroom 2 (11 cases, the maximum being 6.7 kBq/m3) and in the living-room (2 cases, the maximum being 4.7 kBq/m3). The integrated radon measurements showed high concentrations (with averages above 889 Bq/m3 in bedroom 2, more than 330 Bq/m3 in bedroom 1, living-room and bathroom) and very high concentrations in the basement (the average exceeding 1131 Bq/m3). The results of the simultaneous continuous measurements show that the most important way for the radon to enter the house from the basement and the indoor environment is in bedroom 2. In addition, given the very high concentration of radon from point 8 and the high values of radon from room 2, which is the closest to this source, one may say that this piece of soil, which probably was the place for storing the construction material brought from the Băiţa mine, is the main source of radon in the house.

3.1.2. Applied remedy measures

The following remedy methods were implemented and tested within the experiments suggested between 15.10.2011 and 30.03.2013 :

1. the depressurisation and the pressurisation of the soil around the pilot house by means of four radon collectors mounted in the soil from the house foundation and connected to four individual electric fans ;
2. basement ventilation – by means of an electric fan mounted on the basement window ;
3. the application of an extraction wind head mounted on the roof of the house and connected to two radon collectors mounted in the soil from the house foundation ;

4. the testing of the combination made of the extraction wind head and an electric fan connected to four radon collectors mounted in the soil from the house foundation ;
5. the application of the anti-radon barrier membrane in one of the bedrooms ;
6. the testing of the combination made of an anti-radon membrane and the soil depressurisation system by means of two radon collectors connected to one electric fan and an extraction wind head ;
7. an automated system for monitoring and controlling the radon concentrations in the house.

In the first remedy stage (15.10.2011 to 15.03.2012), two remedy techniques based on the depressurisation and the pressurisation of the soil around the house by means of four radon collectors mounted in the soil from the house foundation, were experimented and tested. Thus, three radon collectors were mounted outside the house and one in the middle of it, in bedroom 2. The radon collectors are made of a Φ □400and 80 cm long PVC pipe, where several series of Φ 150 / 8 slots were made on a 60 cm length and Φ □12holes were made on a third from the collector circumference in order to facilitate the radon circulation. The collector is lid-free at its lower part and at its upper part it is complete with a tight PVC lid with a hole through which a Φ □110and 3-4 m long PVC passes till close to the house roof. In its upper part, this tube has a 14 W / 220 V – 110 mc/h electric fan, whose extraction direction can be changed by depressurisation / pressurisation. The collectors no. 1, 2 and 3 are placed in a pitch dug in the soil from the house foundation at a 1 m depth. A thin Φ □8~16 mmlayer of variety gravel was placed on the bottom of the pitch until the 60 cm depth, after which a layer of clay was poured, above which around 20-25 cm were cemented. The collector no. 4 is located in the middle of the house, inside bedroom 2, in an approx. 1 m deep pitch. The upper part of the collector tube is extended till the house attic, where there is a 14 W / 220 V – 110 mc/h fan. Constructive details are provided in the pictures from figures 3.2. and 3.3.

Fig.3.2. The radon collector : a 40 cm diameter and 80 cm long thick PVC tube, endowed with slots and holes for the radon gas passage (on the left) and the radon collector inserted in the house foundation, extended by a long PVC tube fastened onto the exterior wall of the building (on the right) (original).

Fig.3.3. The electric fan at the upper end of the PVC tube (on the left) and the electric fan no. 4 installed in the house attic and connected to the radon collector mounted in bedroom 2 (on the right) (original).

Four active collectors were made by the coupling of the radon collectors with the fan ; these collectors were tested at the pilot house in two operating ways :

1. depressurisation by extraction, which makes the air flow underneath the floor increase, whereas the fan helps reducing the amount of radon that enters the house. This method supposes the additional installation of ventilation ways underneath the floor (drain tubes).
2. positive pressurisation, which involves the insertion of air in the house by means of a fan mounted in the attic, thus giving rise to a slight pressure increase versus the atmospheric pressure. This forces the air to get out through cracks, windows, other openings and mitigates the entrance of radon.

In the second stage (09 to 24.05.2012), the remedy technique based on ventilating the basement by a 14 W / 220 V, 110 m^3/h electric fan mounted on the basement window, was subjected to experiments and tests. This fan is installed in an position that enables the extraction of the air from the basement.

In the third stage (01 to 10.06.2012), the application of an extraction wind head mounted on the house roof and connected to two radon collectors mounted in the soil from the house foundation, was experimented. Two radon collectors were thus united in the house attic and then got connected to an extraction wind head mounted on the house roof – figure 3.4.

Fig. 3.4. The connection of the two Rn collectors (1 and 2) in the attic of the house, which continues by the electric fan in the attic and toward an extraction wind head in the direction of the house roof (original)

In the fourth stage (29.10 to 19.11.2012), the remedy technique based on the combination of the extraction wind head (placed on the house rooof) and the electric fans from the house attic, connected to two radon collectors each, was experimented and tested. The aim of these experiments was to test the effect of the extraction wind head in combination with the electric fan, by monitoring the radon concentrations in the two rooms – bedrooms 1 and 2. First of all, the goal was to monitor the effect of the wind head and of the electric fan connected to the radon collectors 1 and 2. The radon collectors were thus united to one electric fan extended by an extraction wind head on the house roof. Secondly, the goal was to monitor the effect of the wind head and of the electric fan connected to the radon collectors 1 and 3. Thus, the collector 2 was disconnected from the electric fan, so that only the collector 1 remained connected to the electric fan with the wind head, whereas the collector 3 was connected to its own fan.

In the fifth stage, the application of the anti-radon barrier membrane was experimented in one of the rooms (bedroom 2). Thus, a parquetry film, an anti-radon membrane, 30 mm extruded polystyrene and three-layered oak parquetry were put over the concrete mount-ing bed. The anti-radon membrane of the Monarflex RMB 350 type was stuck onto the walls by a double layer anti-radon insulating strip upon the contact of the floor with the wall (fig. 3.5).

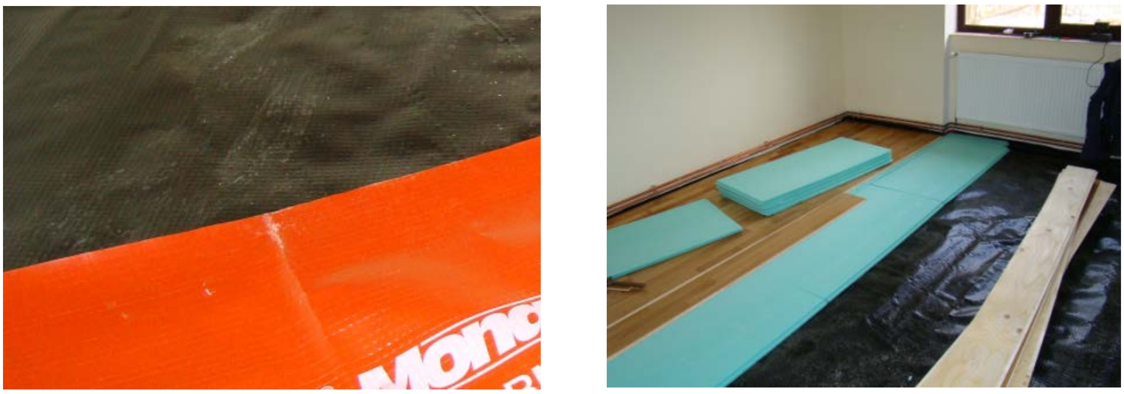


Fig. 3.5. Anti-radon barrier membrane of the Monarflex RMB 350 type (on the left). Anti-radon barrier membrane application on the room floor. Over the membrane – extruded polystyrene and three-layered oak parquetry (on the right) (original)

In the sixth stage (20.02 to 10.03.2013), the remedy technique based on the combination of the anti-radon membrane and the soil depressurisation system, composed of two radon collectors connected to one electric fan in the attic of the house and an extraction wind head (on the house roof) was experimented and tested. The aim of these experiments was to test the anti-radon membrane in combination with the effect of the electric fan and the extraction wind head, by continuously monitoring the radon concentrations in bedroom 2.

The first goal was to see the effect of the anti-radon membrane mounted in bedroom 2. The electric fan and the wind head were thus (obturated) disconnected from the radon collectors 1 and 2. The following goal was to monitor the effect of the anti-radon membrane in combination with the effect of the electric fan and of the wind head. The collectors 1 and 2 were therefore united with the electric fan from the attic extended by an extraction wind head placed on the roof of the house.

The remedy technique by means of an ‘Automated System for Monitoring and Controlling Radon Concentrations’ was also experimented and tested in the sixth stage. The system is composed of three main parts : the electrical power supply block, the radon detection block and the data processing & control block.

The entire system is designed independently from the consumption from the electrical network. The system is supplied by a solar system made of a 1480 x 680 x 35 mm and 12.5 kg solar panel, a voltage regulator and an accumulator meant to 90 Ah solar systems.

3.1.3. Radon concentration measurement after the remedy

Within the experiments of depressuring and pressurising the soil around the house by means of four radon collectors mounted in the soil from the house foundation, 12 experiments were carried out in the soil depressurisation (ventilation) and pressurisation mode, by using a radon collector each time and in combination. These two remedy techniques were tested by continuously measuring the radon concentrations in the following rooms : bedroom 1, bedroom 2, living-room and bathroom, prior to and after the electric fans were turned on (the accumulation and ventilation period). The results of these experiments measurements are set out in Appendix 1 and in table 3.5. from the thesis, which is a large-sized centralising table.

The extraction from the basement by means of the electric fan mounted in the basement window was tested by monitoring the radon concentrations from the bedrooms 1 and 2 by RADON SCOUT devices. The radon concentrations before turning the fan on (the 5-day accumulation period) and after that (the 10-day period of ventilation in the basement) were measured – table 3.3. and figure 3.6. This procedure only leads to a very slight diminishment of the radon concentrations in the target rooms (bedrooms 1 and 2), one of the explanations being that the fan is not able to induce enough depression likely to bring forth a flow from underneath the house toward the basement, therefore a reduction of the radon concentration in the rooms.

Table 3.3. Results obtained after the experiment with the electric fan from the basement

Method	**Room**	**C_m [Bq/m^3]**		***Eff* (%)**
		Before	**After**	
Electric fan - basement	**Bedroom 1**	**338**	**331**	**2.1 %**
	Bedroom 2	**606**	**594**	**2.0 %**

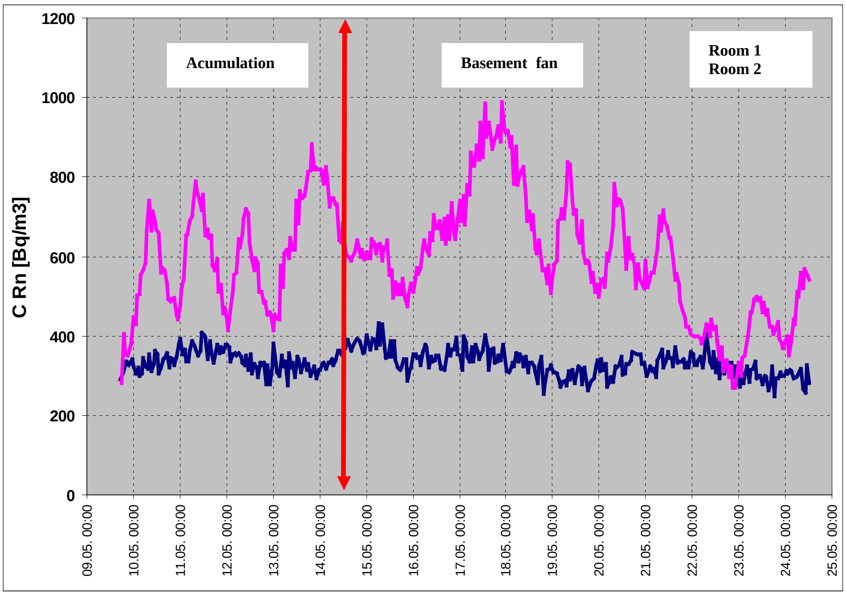


Fig.3.6. Monitoring the radon concentrations in bedrooms 1 and 2 (period : 09 to 24.05). The red line represents the fan start-up (original).

The extraction wind head connected to collectors 1 and 2 was tested by measuring the radon concentrations from the bedrooms 1 and 2 and from the living-room in an integrated way, by means of the RAMON detectors. One measured the radon concentrations with the wind head disconnected from the radon collectors (the 5-day accumulation period) and connected to the radon collectors (the 5-day soil depressurisation period) between 01 and 10.06.2012 – table 3.4.

Table 3.4. Results obtained after the experiment with the extraction wind head

Method	**Room**	**Average C [Bq/m^3]**		***Eff*** **(%)**
		Before	**After**	
Extraction wind head	**Bedroom 1**	**346**	**137**	**60.4 %**
	Bedroom 2	**615**	**223**	**63.7 %**
	Living-room	**167**	**112**	**32.9 %**

The combination of the extraction wind head and the electric fan connected to the radon collectors was tested by continuously measuring the radon concentrations in bedrooms 1 and 2. The radon concentrations were measured by means of the **RADIM 3A** radon monitors. One measured the radon concentrations, plus the effect of the wind head (a 5-day period) and the effect of the electric fan connected to the radon collectors (a 5-day period) - figure 3.7.

The remedy technique by the anti-radon membrane, in combination with the soil depressurisation system, the electric fan and the wind head being connected to the Rn collectors, was tested by continuously measuring the radon concentrations in bedroom 2. The radon concentrations were measured with the help of the RADON SCOUT radon monitor. The radon concentrations, plus the effect of the membrane and the effect of the membrane in combination with the electric fan and the wind head, were measured - figure 3.8. By comparison, the average concentration prior to the application of the remedy technique is 787 Bq/m^3.

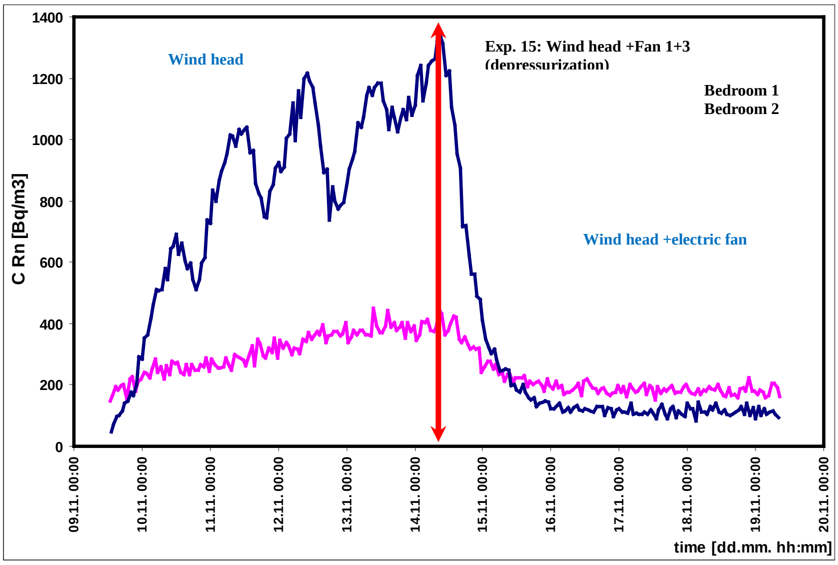


Fig. 3.7. Monitoring the Rn concentrations in bedrooms 1 and 2, with the effect of the wind head and of the electric fans connected to collectors 1 and 3. The red line represents the moment when the electric fans are turned on (original).

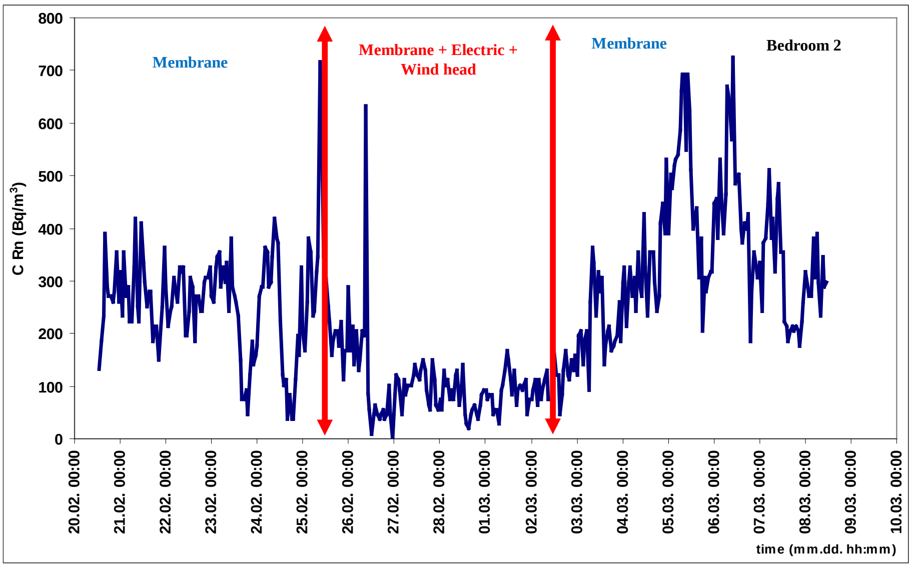


Fig. 3.8. Monitoring the Rn concentrations along with the membrane effect in bedroom 2 (20 to 25.02 and 02 to 09.03), the effect of the membrane with the fan and the wind head in bedroom 2 (25.02 to 02.03). The red line represents the connection / start-up moment of the fan and the wind head (original).

3.1.4. Final experimental results

In the stage of finally checking the efficiency of the methods applied for mitigating the radon concentration there were several experiments and tests at the pilot house, with an aim to re-check the performances obtained by the implementation of a combined method composed of the sub-pressurisation by collectors 1 + 2 and the anti-radon membrane installed in bedroom 2. The results were checked up by André Poffijn (Federal Agency for Nuclear Control) from Belgium between 6 and 13 May 2013. The performances obtained were tested ‘in situ’ and confirmed the previously obtained results. The conclusions are positive, according to the report (Poffijin, 2013).

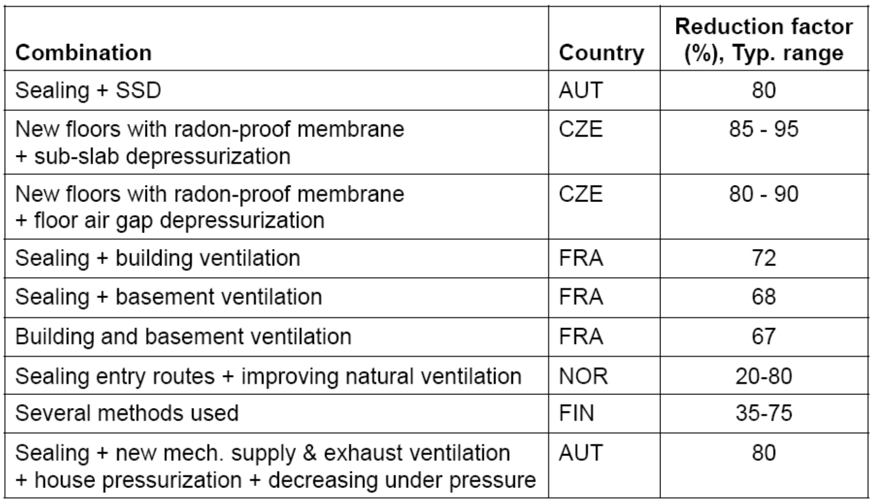
This report highlights the good results obtained both in the studies on the pilot house and in the remedies performed at the 20 houses, as good as those obtained in the RADPAR international programme (2009-2012), in which 14 European countries participated (Holmgren, 2013).

The values obtained by the author and those obtained within the RADPAR project are presented compartively in tables 3.5 and 3.6, respectively.

Table 3.5. Results obtained within the testing operations performed by means of the track detectors at the pilot house

Location / Room	**Detector CR-39**	**C Rn (Bq/m^3)**		**Remedy efficiency**
		Prior to remedy 2011	**After the remedy : Mar.-May 2012**	
Bedroom 2	**V83862**	**1385**	**159**	**88.52 %**
Bedroom 1	**V83762**	**680**	**281**	**58.70 %**
Living-room	**V83744**	**649**	**83**	**87.21 %**
Bathroom	**V84043**	**726**	**119**	**83.60 %**

Table 3.6. Remedy efficiency obtained in the RADPAR Programme



Combination	**Country**	**Reduction factor (%), Typ. range**
Sealing + SSD	AUT	80
New floors with radon-proof membrane + sub-slab depressurization	CZE	85 - 95
New floors with radon-proof membrane + floor air gap depressurization	CZE	80 - 90
Sealing + building ventilation	FRA	72
Sealing + basement ventilation	FRA	68
Building and basement ventilation	FRA	67
Sealing entry routes + improving natural ventilation	NOR	20-80
Several methods used	FIN	35-75
Sealing + new mech. supply & exhaust ventilation + house pressurization + decreasing under pressure	AUT	80

PhD André Poffijn checked the operating manner and the performances of the ventilation system. To this end, the pilot house was aired for half an hour and then everything was closed for one day for accumulation purposes. Sarad-type continuous measuring devices were installed in the 3 rooms : bedroom 1, bedroom 2 and the living-room. The extraction system was turned on after one day of accumulation and the results were recorded - figure 3.9. One notices that right after the ventilation system was turned on the concentration began to drop and reached values below 200 Bq/mc in all the three rooms. The results are synthesised in table 3.7, which shows the efficient operation of the ventilation system and of the membrane, the values obtained being low : 47 and 114 Bq/mc in the living-room and bedroom 1 and 196 Bq/mc in bedroom 2.

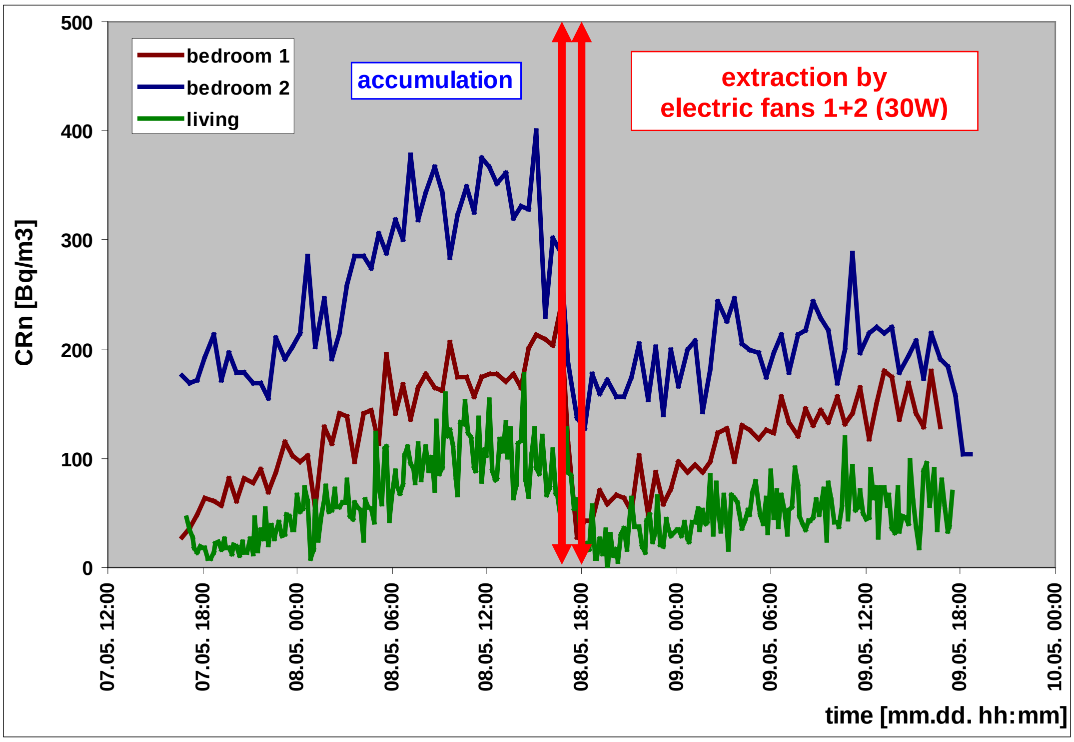


Fig. 3.9. Final check of the extraction system (original)

Table 3.7. Final results for the efficiency of the extraction system

Room	C Rn [Bq/m3]					
	Accumulation			extraction by elect. fans 1+2 (30 W)		
	min	max	mean	min	max	mean
Bedroom 1	**28**	**237**	**132**	**43**	**180**	**114**
Bedroom 2	**155**	**400**	**267**	**127**	**289**	**196**
Living	**8**	**177**	**68**	**0**	**119**	**47**

3.2. Conductive materials for electromagnetic screening and radon concentration mitigation

Departing from the observation that among the radon insulation membranes manufactured by Monarflex there is also a membrane with conductive insertions, this chapter studies the link between the electrically conductive materials and radon measurement.

Researches show that the measurements of the radon concentration can be affected by electromagnetic disturbances (Ogrutan, Suciu et al, 2013). Electromagnetic insulation has a positive effect on the reduction of the electric field intensity in the measuring enclosure, therefore the measuring errors might become scarce.

A preliminary research made by the author about the insulation capacity of the conductive materials against radon penetration did not come out with relevant results, therefore this research direction can be continued in the future.

3.2.1. Errors caused by the electric field upon the measurement of the radon concentration by electronic devices

One analyses the possibility of recording errors upon measuring the radon concentration in the air because of the electromagnetic interference. In this regard, measurements took place in a location with a high level of the electromagnetic field versus a location with a low level and the results of the measurements made both by means of an electronic device and of track detectors are set out.

The origin of these preoccupations was the measurement of the electric field and of the ionising radiation in a location close to GSM antennas. High values of the electric field were recorded in this location as compared to a witness-location, however the measured values were below the allowed limit. An electronic device recorded a level of the radon concentration in the air above the allowed limit, even though the location is at the 1st floor. The increased radon concentration was not confirmed by the measurement by means of track detectors, therefore the hypothesis that there must have come up errors because of the electric field upon the electronic measurement was issued.

Generally speaking, any electronic device is subjected to the influence of the electromagnetic field. The value of this field is higher and higher because of the increased number of mobile telephony equipment, of the wireless transmissions and of the consumption of current from the public supply network. The measurement of the radon concentration in the air is based on the electronic measurement of currents with very low nA order values. The radon mesurements are therefore susceptible to electromagnetic disturbances and the results can be wrong.

Chen', Falcomer's et al's paper from 2007 draws the attention on the errors of certain active devices that measure the radon concentration in the air and presents a few experimental results regarding their behaviour. In the paper, one of the errors causes is deemed to be the electromagnetic interference. This one was also noticed in case of the measurement of the radiation dose (Gilligan, Somerville et al, 2000). The tests showed the appearance of errors at certain dosemeters near cell phones. The Simon, Powers et al, 1989 patent sets out for the first time an amplification on several channels and the comparison of the results obtained. Only one channel is connected to the measuring element, the rest of them being passive. If there appears an impulse on the measuring channel, then it is accepted and if there appear simultaneous impulses on all the channels this means that there is an electromagnetic disturbance in the electronic circuit. The Balmer, Haverty et al, 1996 patent suggests a detection chamber of the electromagnetic field with superior screening performances.

The measurement of the electromagnetic field was made in two frequency ranges, where the value of the field is supposed to be higher, around the 50 Hz frequency and in the high frequency range allotted to mobile telephony.

Figure 3.10 shows the results measured in the 400 MHz - 2100 MHz range, which covers the area of mobile communications. In Romania, the 900 MHz, 1800 MHz (2G) and 2100 MHz (3G) frequencies are allotted for the mobile communications. Cosmote has also the 450 MHz band allotted. One can notice that the measurement in the area close to the antennas (on the left) shows far higher values of the electric field intensity than in a witness-area, far from the antennas, still in the city and with a signal for all the mobile telephony networks.

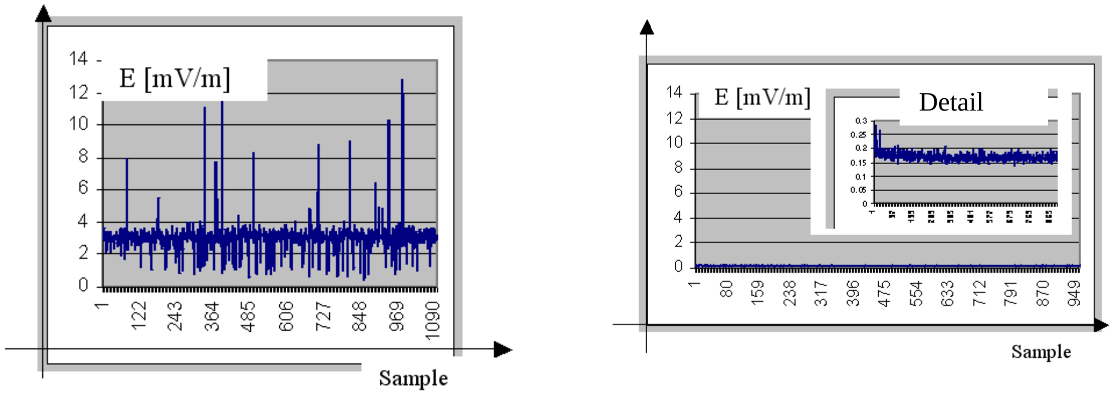


Fig. 3.10. Intensity of the electric field in the 400–2100 MHz range near the antennas (on the left) and in the witness location (on the right) (original)

Figure 3.11 shows the results obtained upon measuring by means of the electronic device on a 12-day duration, by putting down one value per day. The value measured in the location near the antennas (the graph above) is noticed to be much higher than the value measured in the witness-location, reaching the limit allowed in the European Community. This surprising result had to be confirmed by another kind of measurements, therefore track detectors were used subsequently.

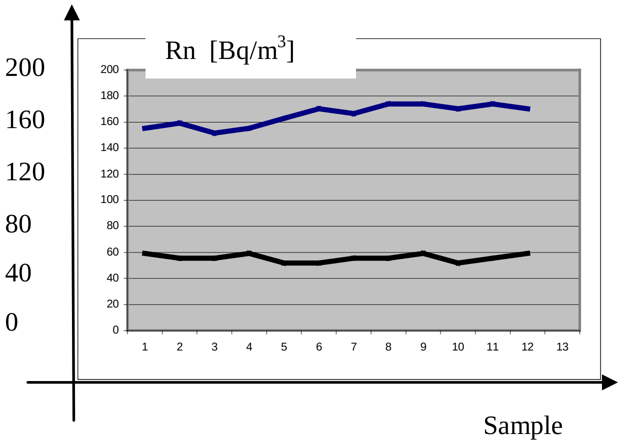


Fig. 3.11. The radon concentration measured by means of an electronic device in the location near the antennas (above) and in the witness-location (below) (original)

The level of the radon concentration measured by means of the electronic device is noticed to be higher than the attention limit and higher than the normal value for the conditions of the measuring location (Cosma, Szacsvai et al, 2009). This result needed measuring by means of track detectors, which showed a normal value of the radon concentration in both locations. One may therefore issue the hypothesis that the value measured by the electronic device was erred because of the electromagnetic interference. The graph from figure 3.12 suggestively shows the values measured in both locations : the one of the electric field (grey) and the one of the radon concentration by means of the electronic device (white) and the track detector (black). The image of the concentration difference measured in the location affected by the electric field is suggestive.

The researches can be continued in this direction by testing the susceptibility of the electronic device in a TEM (Transversal ElectroMagnetic) enclosure.

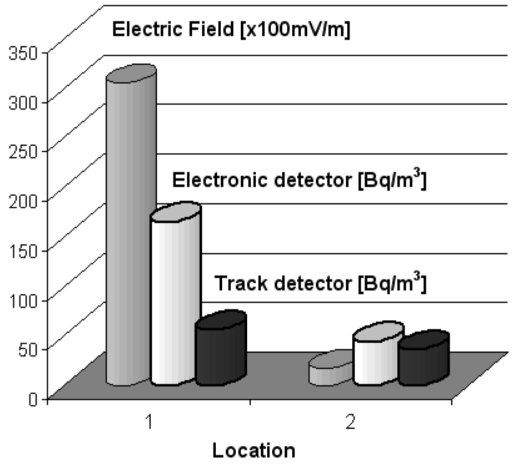


Fig. **3.12**. Radon concentration measured by two methods and the electric field in the 2 locations (original)

3.2.2. Determination of the radiation level mitigation by using materials and nanomaterials with conductive insertions

CR 39 transducers, 4 transducers closed in the materials subjected to the test and one free transducer were placed in the basement - figure 3.13 and materials obtained by nanotechnologies were tested at ICPE from Bucharest (Kappel and Lucaci, 2010). The materials are made of styrene-butadiene with conductive insertions from nanocarbon (TN), graphite (GR), iron (FE) and ferrite (FT).

Fig. 3.32. CR 39 transducers placed in the basement (original)

The CR-39 detectors put in Radapot-type boxes were exposed, the exposure time having ranged between 2007.08.29 and 2007.11.22, then they were developed in Cluj-Napoca, at the laboratory of the Institute of Interdisciplinary Experimental Researches within the University. After developing, they were read by using the Radosys 2000 optical microscope.

The measurement results are given in table 4 :

Table 3.8. Radon concentration measurement results

Material	Free transducer	TN150	GR150	TN300	GR300	FE300	FT300	Transducer in a tin foil
Radon concentration	264	100	87	107	249	160	210	120

The results from table 3.8 show that the transducers wrapped in the tested materials indicate a lower concentration of radon in the air, but the large variation of the concentration for the various materials show that the conductive insertion does not lead to conclusive results for the protection against radon penetration.

The importance of the studies linked to the materials likely to be used for mitigating the radon concentration is also proven by the European projects dedicated to this purpose, such as ERRICA, 2001. According to the W3 goal pertaining to the building materials, one suggests the utilisation of the materials that do not release radon, of building materials with special structures as a barrier against radon and the determination of measurement methods and standards in this field. The goal W4 refers to the establishment of methods for the reduction of the radon concentration at the construction of the new buildings. New researches (Lamonaca et al, 2014) show the importance of the building materials in mitigating the concentration of radon.

Chapter 4. Conclusions and main personal contributions

4.1. Conclusions

This thesis, the material elaboration and the analysis of the experimental results obtained bring forth a few main conclusions. Thus, the most important conclusions of Chapter 2 are :

1. The comparison between the principle of measurement by integration and by impulse counting

The conclusions of the simulation of the two measurement methods show that measurement by integration is superior to that by impulse counting from several points of view :

- the sinusoidal disturbance is totally rejected if the period of integration is a multiple of the period of the industrial network voltage ;
- during integration, the microcontroller can execute some other tasks as well, for instance data transmission ;
- the analogical level is simple.

Still, in case of measuring the radon concentration, the method of integration cannot be applied. It can only be applied to a large number of discharge impulses in the time unit and the measurement of the small concentrations of radon means a very small number of discharges per day. By integration, the measurement noise increases in time and causes the saturation of the integration analogical circuit. The impulse counting method is also suitable to measurements of small concentrations, however by using the microcontroller resources more. This conclusion was drawn after the creation of the analogical chain, the signal acquisition and its monitoring by National Instruments on a longer period of time by means of the acquisition module.

2. The comparison between the detection chamber device and the ionisation chamber one

The devices were tested by comparison with the Safety Siren 2 system and the results are very similar, the difference being less than 10 %. The detection chamber is far smaller in terms of sizes than the ionisation chamber and the bibliography shows that it is more used in the modern applications. Nonetheless, a disadvantage of the detection chamber is the fact that the first results are given with a greater delay than the ionisation chamber. As the sizes are smaller, it takes more time for the air to enter the measuring enclosure. The devices with a detection chamber are suitable to portable applications. Even though there is no theoretical limit of the maximum sensitivity, the minimum measurable limit is assessed to be 0.1 pCi/l (4Bq/m^3) because of the fact that there have not been technical means for checking the device at a lower content of radon. The Nachab (2006) paper sets out a radon measuring device by impulse counting, which also detects a concentration of 18 mBq/m^3 (one discharge/24 hours) by means of a 701 detection chamber polarised by 1500 V and a PIN photodiode. This paper from 2006 shows the correctness of the line chosen in this project for designing the constructive variant with a photoelement.

3. The data transmission systems

For the data pertaining to the radon concentration to be able to be sent remotedly by several devices and for a server to manage a base of received data, several types of transmission have been designed : by a cabled telephony line and by the GSM mobile telephony. Out of these two types of transmissions, one may select the one that corresponds to the position of the measuring device (the existence of the GSM signal or the existence of a telephony line). The measuring device was complete with a GPS reception module, so that at the same time with the transmisison of the data related to the radon concentration, it also sends data about the geographical position and the exact measurement time. The software system for data reception, centralising and storing interprets the data received, signals out when the scheduled limit radon concentration is exceeded and alerts the absence of communication by a measuring device. The programme may be entered by authentication.

The main conclusion of Chapter 3 are :

1. The conclusions of the experiments made at the pilot house all throughout the remedies

12 successive experiments for soil depressurisation and pressurisation were carried out by means of the radon collectors connected to 30 W / 220 V - 110 mc/h electric fans mounted at the upper part of each radon collector (an active remedy system), one by one or in combination. Each experiment was preceded by a period of radon accumulation of approximately 1 week. The results of the experiments show a maximum efficiency of 80 % for bedroom 2 and of 55-65 % for the other rooms (even 68 % for the living-room). In all cases of extraction, even if there have not been remedy efficiencies greater than 60 %, the value of the radon concentration was less than 200 Bq/mc, which is a value that represents the remedy goal pursued.

The remedy techniques were tested by measuring the radon concentrations prior to and after the application of the remedy technique. The testing of the remedy technique by ventilation shows a very weak efficiency (of 2 %, in both bedrooms). This extremely low efficiency was determined to be due to the fact that the primary source of radon was not the basement, but the soil in front of the house (at the road), which was supplying the basement with radon. The testing of the remedy technique of soil depressurisation by means of an extraction wind head shows good efficiency (more than 60 %) in certain situations and a low efficiency in others (10 %), so that the researches need to be continued. The efficiency of the wind extraction was also tested globally within the integrated measurements by means of track detectors for the entire set of houses remedied in 2013 and the immediate 47.4 % result (similar to the efficiency of the membrane at the pilot house) still confirms that the extraction wind head has an acceptable efficiency.

The testing of the soil depressurisation remedy techniques by the extraction wind head – electric fan combination shows very good efficiency in case of the simultaneous connection of the wind head to the electric fan, thus the concentrations drop below 200 Bq/mc in bedroom 1.

The testing of the remedy techniques by means of the anti-radon membrane in combination with the soil depressurisation by using an electric fan and a wind head shows good efficiency in case of applying the anti-radon membrane, so that the average concentration in the bedroom with the membrane drops to 260 Bq/m^3 (a more than 65 % efficiency) and very good efficiency in case of applying the membrane in combination with soil depressurisation, so that the average concentration in the bedroom with the membrane drops to 85 Bq/m^3 (an almost 90 % efficiency).

2. The final testing within an external audit confirmed the remedy results obtained.

The final checks made by a specialist on the occasion of a technical audit showed the good operation of the depressurisation system and of the control and adjustment one. Furthermore, additional checks of the radon concentration from the soil around the collectors and of the radon content in the flow eliminated through the two extractors were performed. The extraction by means of a centrifugal and axial fan were tested alternatively. The preliminary results do not indictae a clear result in favour of one of the two types of fans. The researches can be continued in this direction, too.

Tests at the pilot house regarding the efficiency of the extraction system and of the membrane were carried out within the same final tests. The results show that in all the rooms where measurements were made, the values recorded were below 200 Bq/mc. If a calculation is made departing from the 680, 1395 and 649 Bq/mc initial yearly average values and from the final values, the following efficiencies result : 83.22 %, 85.95 %, 92.31 %, in very good compliance with the values obtained in the RADPAR project.

As additional measurements at the pilot house during the audit one checked and proved that the most important source of radon is the soil near the wall of the house next to the road. What is more, the measurements of the concentration of radon from the extracted flow confirmed once more the localisation of the main source and the fact that, being a very strong source, a reduction in the closest room to this source is difficult to make. The value of the remedy efficiency for this room, i.e. 82.4 %, is a very good result in this situation. The good operation of the radon concentration control and adjustment system was noticed at the pilot house, proving that it acts adequately.

3. The influence of the electric field on the uncertainty at the measurement by electronic radon detectors

The measurement in parallel of the high frequency electromagnetic field and of the radon concentration in the air by two methods proved that the Safety Siren 3 electronic device is susceptible to disturbances. The goal was to obtain results that determine whether the materials obtained by nanotechnologies can be used for mitigating the electromagnetic field and the concentration of radon. As regards the electromagnetic field, the mitigation effect is proven, but as regards the mitigation of the radon concentration, the results are not conclusive, as the determinations are too few. The research can continue in this direction, too.

4.2. Personal contributions

Main personal contributions from Chapter 2

Two devices for measuring the radon concentration in the air were conceived, designed and built with an original structure. Main contributions at the construction of these devices :

1. the simulation in Matcad of the electron trajectory, in order to determine the value of the electric field necessary for orienting the particles charged in the detection chamber ;

2. contributions at the conception and the design of an original type of ionisation chamber and measuring procedure, patented as an invention ;

3. the comparative analysis of two measuring methods : by integration and by impulse counting. The analysis took into account the range of radon concentrations monitored for measuring and the electromagnetic disturbances that affect measurement ;

4. the simulation in Simulink and PSpice of the measurement by integration in the presence of the electromagnetic disturbances ; the design and the execution of an integrating amplifier and the comparison of the results to the simulated ones ;

5. the Simulink simulation of the measurement by impulse counting ; the proposition for the two channel measurement and the design of an entrance level that rejects fake impulses ; the Pspice simulation of the entrance level ;

6. the conception, design and execution of a microcontroller device that takes over the impulses from the entrance level, counts them and shows the result on an LCD display ;

7. the conception and the design of a voltage increase source for polarising the detection chamber and the ionisation one ;

8. the conception and the design of a system for exactly setting up the position of the measuring device and of the transmission time based on the GPS messages ;

9. the conception and the design of a communication system between the microcontroller and a PC by means of the telephony line or directly by cable, by the connection of a dial-up modem ;

10. the conception and the design of a communication system between the microcontroller and a PC by means of the GSM telephony and of the Internet, by the connection of a GPRS module ;

11. the elaboration of the architecture of a software programme for managing the messages sent by several measuring devices located in various geographical points, data storing in a database and the generation of warnings when the maximum value of the radon concentration in a certain location is exceeded ;

12. the conception, design and execution of two experimental models for measuring the radon concentration in the air – one with a detection chamber and one with a ionisation chamber, with the possibility of locally displaying the data and of sending them remotedly by GPRS. The measuring devices were tested, the results were compared and the calibration was performed.

Published papers that contain the original aspects set out in Chapter 2

1. P.Ogrutan, L. Suciu, L. Purghel, C. Cosma *Integrative Method for Measuring Radon in the Air. The Influence of the Electromagnetic Environment*, Eco Terra magazine – no. 12/2007, ISSN 1584-7071 (CNCSIS – D category)
2. P.Ogrutan, L. Suciu, L. Purghel, C. Cosma *Measuring the Radon Concentration in the Air by Impulse Counting*, Eco Terra magazine - no. 13/2007, ISSN 1584-7071 (CNCSIS D)
3. P**.**Ogrutan, Cs. Kertesz, L. Purghel, L. Suciu *System for Measuring the Radon Concentration in the Air in Real Time and Data Transmission from Multiple Locations*, Eco Terra magazine - no. 14/2007, ISSN 1584-7071 (CNCSIS D)
4. P. Ogrutan, L. Purghel, C. Cosma, Cs. Kertesz, L. Suciu, *Aspects regarding real time Radon measurement and GPRS data transmission*, Environment – Essential Problems, 10/2007, Edited by Babes Bolyai University of Cluj Napoca and ICPE Bistrita,, ISSN 1584-6733, pag.297-302
5. Csaba-Zoltan Kertesz, Gheorghe Pana, Petre Ogrutan, Liviu Suciu, *Microcontroller Based System for Radon Concentration Measurement and Data Transmission,* 13th International Conference on Optimization of Electrical and Electronic Equipment, ISBN 978-1-4673-1653-8/12/2012 IEEE, p. 1247-1252, **indexat IEEE**
6. P. Ogrutan, Gh. Morariu, C. Cosma, L. Suciu**,** *Radon concentration measurements. Comparative data*, Environment – Essential Problems, 12/2008, Edited by Babes Bolyai University of Cluj Napoca and ICPE Bistrita,, ISSN 1584-6733, pag.323-330
7. L. Purghel, Gh. Morariu, P. Ogrutan, M. Alexandru, Cs. Kertesz, L. Suciu, *Method and Device for Measuring the Radon Concentration in the Air and Remote Data Transmission*, invention patent no. 125125/2012 **indexed Derwent, ISI Web of Knowledge**

Participation in projects linked to Chapter 2

1. **CEEX 2006-2008 –** Researches on Nationally Mapping Radon (Indoors and in Various Environmental Factors) for the Protection of the Population Pursuant to the Requirements of the International Norms and of EU – RADROM

Main personal contributions from Chapter 3

2. Several new remedy techniques, whose efficiency was assessed, were implemented and tested.
3. The ventilation of the basement by means of an electric fan mounted on the basement window was implemented.
4. An extraction wind head mounted on the roof of the house and connected to the radon collectors was applied.
5. The combination made of the extraction wind head and the electric fan connected to the radon collectors was tested.
6. The anti-radon barrier membrane was applied in the bedroom.
7. The combination made of an anti-radon barrier membrane and the soil depressurisation system (radon collectors connected to an electric fan and an extraction wind head) was tested.
8. An automated system for monitoring and controlling the radon concentrations in the house was implemented.
9. Electromagnetic field measurements in the range around the 50 Hz frequency and in the high frequency range allotted to communications were carried out in two locations : one close to the antennas and the other one remotedly.
10. The radon concentration in the air was measured by the Safety Siren 3 electronic device and track detectors in both locations.
11. On analysing the results, the electronic device was determined to have measurement errors in the presence of the high frequency electric field.
12. In order to determine whether the weakly conductive materials have an effect on the radon concentration decrease, a measurement was made by insulating track transducers in cases built from these materials.
13. The results were not conclusive because the number of experiments was not enough. A mitigation of the radon concentration was noticed. The researches can be continued in this direction.

Published papers that contain the original aspects set out in Chapter 3

1. P. Ogrutan, L. Suciu, G. Morariu, L. E. Aciu, *Susceptibility of Radon Measurement Device to Electric Fields*, Roumanian Journal of Physics, Volume 58, Supplement, pages S202-S209, 2013, **indexat ISI Web of Knowledge**
2. L. Suciu, P. Ogrutan, Gh. Pana, C. Cosma, *Aspects Regarding Building materials with Electromagnetic and Radon Shielding Characteristics*, Eco Terra nr 17/2008, ISSN 1584-7071 pag 28-29
3. Moldovan M., Cucos- Dinu A, Suciu L., Vald G., Cosma C., *Radon from the Soil and the Influence on the Yearly Dose – Absolute Ages by Nuclear Dating Methods,* Quantum publishing house, ISBN 978-973-88835-0-5, p. 181-194, 2008;
4. Cosma C., Szacsvai K., Cucos- D. A., Ciorba D., Dicu T., Suciu L., *Preliminary Integrated Indoor Radon Measurements in Transilvania (Romania),* Isotopes in

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5. Cosma C., Papp B., Moldovan M., Cosma V., Cindea C., Suciu L._ *Measurement of Radon Potential from Soil using a Special Method of Sampling,* Acta Geophysica, Volume 58, Issue 5, pp. 947-956, 2010, **indexat ISI Web of Knowledge**
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8. Cucoş- Dinu A, Cosma C., Dumitru O.A., Dicu T., Papp B., Niţă D.C., Begy R., Moldovan M., Burghele B., Sainz C., Suciu L., *Brief Description of the Remedy Methods for the Radon Concentrations Implemented in 20 Houses in the Băiţa-Bihor (Romania) Mining Area,* Ecoterra, no. 36, p. 17-21, 2013.
9. Cosma C., Cucos Dinu A., Papp B., Moldovan M., Begy R., Dicu T., Nita D.C., Burghele B.D., Fulea D., Cîndea C., Rusu O. D., Maloş C., Suciu L., Banciu G., Sainz C., *Radon Measurements and Radon Remediationa in Baita-Stei Prone Area*, Carpathian Journal of Earth and Environmental Sciences, May 2013, Vol. 8, No. 2, p. 191 – 199 **indexat ISI Web of Knowledge**
10. Cosma C., Cucos Dinu A., Papp B., Begy R., Dicu T., Moldovan M., Truta L.A., Nita D.C., Burghele B.D., Suciu L., Sainz C., *Radiation and remediation measures near Baita Stei pound old uranium mine (Romania),* Acta Geophysica, Volume 61, Issue 4, pp. 859-875, 2013, **indexat ISI Web of Knowledge**

Participation in projects linked to Chapter 3

1. **2008-2011 PARTNERSHIPS –** Experimental and Clinical Studies on Radon in the Counties from the Middle of Transylvania and the Impact on the Morphology of the Breathing Apparatus in Humans and Animals - SERTIR

2. **POS CCE 2009 –** Implementation of the Radon Remedy Techniques in Dwellings from the Băiţa Uranium Mine Area / IRART

3. **2012 PARTNERSHIPS –** Radon Map (residential, geogenic, water) for Center, West and NortWest regions from Romania (*RAMARO*)

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