UNIVERSITY POLITEHNICA OF BUCHAREST
FACULTY OF POWER ENGINEERING
DOCTORAL SCHOOL OF ENERGY ENGINEERING

PHD THESIS SUMMARY

STUDY OF RADON CONCENTRATION AND METHODS OF REDUCING IT INDOORS

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PhD:

Eng. Marina Ionela CUCU

- BUCHAREST 2022 -

Abstract

Radon is a naturally-occurring radioactive, invisible gas that is present nearly everywhere, and everyone breathes it. Radon released from the ground can enter inside buildings through cracks, other openings in the dwelling's foundation or through the water supply system. That being said, the radioactive gas Radon can be found everywhere, in all possible environments: soil, water, and air. Radon is carcinogenic and has recently been declared the number 1cause of lung cancer in non-smokers. Radon measurements are performed with different types of detectors (passive/active).

The current legislation in force in Romania recognizes the measurements performed with passive detectors. Romania, as a member of the European Union, must impose a series of measures to protect against radon exposure inside homes and workplaces. Both individuals and employers are obliged to take several measures to protect the population and staff against exposure to high levels of radon inside buildings. These requirements are based on Directive 59/2013.

The thesis presents in the first chapter the current stage of the radon issue (history, importance, impact), while the second chapter presents the legislative framework for the radon issue. Chapters 3 and 4 present both means of determining radon concentrations in various environments, the measurement results performed in apartment-type dwellings, as well as in old houses, from rural areas in various parts of the country, and also at working place. Chapters 5 and 6 harmoniously structure elements for assessing the impact of radon concentration on the human body by calculating the dose induced by it, as well as protection against exposure caused by radon inside buildings/enclosures, gamma radiation from building materials, methods prevention, and mitigation. The results of radon concentration measurements when using an anti-radon membrane in the construction of a house versus its lack are also presented.

Keywords: Uranium, Radium, Radon, water, air, soil, decay chain, Radon concentration, Bq/m^3, passive detector, active detector, CNCAN, PNAR, EURATOM Directive 59/2013, construction materials, energy efficiency, attenuation methods, effective assigned dose, professionally exposed to ionizing radiation.

Summary

1. Brief introduction to radon issues

With the aim of producing the X-rays previously highlighted by Wilhelm Roentgen, Henry Becquerel discovered in 1896 the phenomenon of radioactivity. After the separation of the radium by the Curie couple, who processed large quantities of uranium ore (pechblende) from Joachimstal (Czech Republic), Robert F. Dorn discovered in 1902 the emanation of **radium** (a radioactive gas generated by this element). **Radon** is a radioactive gas from radium decay, the latter from uranium decay. It should be noted that radon is present in all types of **soils, waters**, regardless of the depth at which they are found, building materials and can be transported through porous media, especially by the phenomenon of convection, as well as in airborne particles. Radon is classified as a **dangerous/radioactive** gas: it can cause human death, causing lung cancer, and has been mentioned in the latest scientific publications as the second factor after smoking. It is used in medicine and science, it is **odorless, colorless, tasteless**. Research on radon in uranium and neuroaniferous mines in Romania was carried out by the Radiation Laboratory in Ştei (Petru Groza) by Gh. Sandor, G. Dinică, T. Peic, this laboratory being under the wing/protection of the Institute for Rare and Radioactive Metals Bucharest.

Also, the Faculty of Physics from Cluj-Napoca, together with the University of Ghent (Belgium) and the University of Oradea started in 1995 a pilot study in Romania, related to the lung cancer risk due to radon. The study was funded by the CCE within a program PECO. This epidemiological study took into account deaths from primary bronchopulmonary cancer in Bihor and Cluj counties based on an appropriate questionnaire which resulted in other risk factors (smoking, chemical toxins etc.). Constantin Cosma (UBB Cluj), T. Jurcuț, and the researchers Dr. D. Ristoiu, associate professor Dr. T. Vaida and Dr. D. Drăgoiu. Currently (2017-2020), in Romania, the pioneers in radon research are the full members of the Radon Testing Research Laboratory "Constantin Cosma" **-** LiRaCC, among which we mention CS Dr. Alexandra Cucoş Head of Laboratory, Prof. Dr. Carlos Sainz, UC Spain / UBB, Lect. Dr. Tiberius Dicu Technical Coordinator and many others. It should be noted that LiRaCC is designated by CNCAN to conduct investigations and measurements of radon concentration in samples from environmental factors (air, water, soil) by adopting national and European standards in current practice.

According to an assessment emitted by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) on the environment, ionising radiation account for half of human exposure from natural sources. Radon has been recognized as a cause of excess lung cancer among miners. Consequently, radon has been classified as a **carcinogen**. Since radon represents on average about half of all human exposure to radiation from natural sources, more attention has been paid to radon exposure and its associated health risks, both in industrialized and developing countries. There are at least three aspects of major importance regarding studies/research related to radon, its spread, migration, its inhalation. First mentioned: it is related to the determination of radon and radium in groundwater (wells, geothermal waters, reservoir waters, lakes, wells, etc.). The second aspect: it is related to the potential of radon in the soil and the exhalation or flow of radon from the earth's surface. One last aspect, the third, but of equal importance, is related to radon inside buildings / halls / workspaces. If the radon concentration in the outside air is on average **4-8 Bq/m^3**, depending a lot on the geological and meteorological conditions, inside the dwellings / enclosed spaces, by accumulation, the measured values are of the order of 20-80 Bq/m^3, and in some cases, values of the order of 2000-4000 Bq/m^3. Taking into account the 3 aspects above detailed, the research and studies carried out in the area of radiation protection are expected to be extensive, with multiple topics debated from several points of view, at national and/or international levels.

The National Commission for the Control of Nuclear Activities (**CNCAN**), Romania's regulatory and control body, must finalize the legislative framework for the implementation of Euratom Directive 59/2013 establishing the basic safety standards for protection against the dangers posed by exposure to ionizing radiation. The Directive provides for the following:

- Calculation of received doses by workers (occupational exposures to ionizing radiation)/ population/medical patients;
- Establishment of reference levels for indoor radon concentrations, as well as for exposure to indoor gamma radiation emitted by building materials;
- Establish an appropriate program for EU Member States to monitor the level of radioactivity in the environment. The National Radon Action Plan (**PNAR** is the romanian acronim) can be discussed as a topic of interest for the radon issue in Romania. PNAR addresses the medium and long-term risks resulting from exposure of the population and workers to radon in homes, public access buildings and workplaces for any source of indoor radon penetration, whether from soil and/or from building materials. The National Radon Action Plan was approved by Government Decision no. 526/2018 published in the Official Gazette of Romania no. 645/25.07.2018. In Romania, the maximum allowed level of ionizing radiation of the natural background is 300 Bq/m^3. According to CNCAN data, at national level, the average radon concentration in the air is about 145 Bq/m^3, and in Bucharest it reaches up to 202 Bq/m^3. There are certain places in the country where this level is exceeded. These are the areas where radioactive ore deposits are found, former mines.

2. Objectives of the doctoral thesis

Considering the topics presented in the previous introductory chapter, I wanted that the objectives of the this doctoral thesis to include at least the following aspects:

- Measurements of radon concentration using proper detectors that are adequate from the legislative and metrological/calibration point of view. The measurements (regardless of their type) were performed with metrologized/calibrated equipment (dosimetric laboratory equipment/radiation protection).

-Measurements of radon concentration in various environments (air/water/soil) in various areas of the country. Performing those I wanted to highlight the importance of the soil in this type of measurements. Regardless of whether we are talking about air/soil/water measurements, the main “source” of radon is in the earth's crust.

- Radon concentration measurements performed both open environment, but mainly indoors. Closed spaces means: apartment type, private houses and workspaces.

-The measurements of the radon concentration at the workplace (FCN Piteşti) were performed in accordance with the legislative requirements in force, my involvement in this proccess being a great one, detailed during the chapters of this thesis.

- In addition to the actual experimental part, the one through which the radon concentration measurements were performed, it was wanted to correlate these values with the “reality in the field”. We correlated the values found experimentally with: the geographical area, the soil on which the site is located (whether we are talking about the block of flats/apartments or the house), the behavior of the inhabitants of these buildings, the structure of the house (construction materials, ventilation systems, cracks, leaks).

- Implementation of solutions for attenuation/reduction of radon concentrations in new constructions, such as houses. I have successfully implemented a small part of what these solutions as follows: I have introduced in the structure of my own house (under construction), the anti-radon membrane, on its ground floor. I performed comparative measurements of radon concentration in our own house and a house (of approximately identical size and structure) without this type of membrane.

- Development of a radon detector prototype with household objects, without major investments. I published a scientific article regarding this subject in UPB Magazine.

-Personal training, by performing internship in a laboratory designated by CNCAN for radon concentration measurements. The training consisted in exchange of experience, research of the laboratory equipment, development of the CR-39 detectors used in the screeening proccess analysis performed for FCN Pitești.

3. Summaries of chapters

This doctoral thesis is structured in 7 chapters, as follows:

Chapter 1 presents the history, importance, and impact that radon gas has on humans, regardless of population or occupational exposure to ionizing radiation. This chapter presents some theoretical aspects regarding the discovery of this gas, the theoretical/practical studies performed on it, as well as the impact that this odorless, colorless, tasteless gas can have on the body if it is inhaled/ingested in quantities that exceed international limits, but not only. Inhaling /ingesting it in small amounts can be harmful to the body.

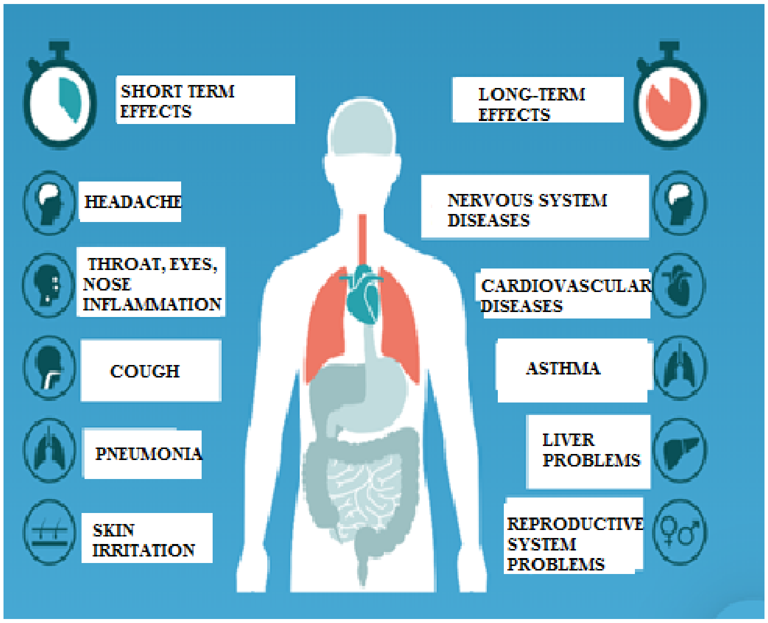


Figure 1 - Adverse effects of inhalation / ingestion of radon concentration

The answers of the occupational exposures to ionizing radiation within FCN Pitești to a questionnaire on the minimum knowledge about radon gas are also presented. The answers were vast, the general conclusion being that people have no (good) knowledge of the negative impacts of radon. Throughout the chapter I tried to explain, for everyone's understanding, the properties of radon gas, its route in the open environment, whether we are talking about air, soil, water, as well as indoors.

I have brought into question methods by which it can accumulate indoors. It should be borne in mind that this gas has been present in people's lives since time immemorial, but this issue has gained momentum in our country (2018-2020 and will continue) with the need to transpose Directive 59/2013 into national law, as well as future normative acts. This chapter also presents aspects related to the traceability of radon gas in environmental factors (atmosphere, water, soil), as well as enclosed spaces, whether it is about of their home places or working places. **Radon in the atmosphere -** The warming of the soil (coming fron the Sun) surface during the day and the cooling during the night cause large changes in the temperature of the air layer on the soil surface. Thus, during the night, the cold air will accumulate radon from the soil and it will be transported during the day (morning) by the hot air, vertically. **Radon in Water** – In depth discussions about the contribution of radon in water to radon in indoor air have been carried over time, concluding that radon in water cannot contribute as a major source of indoor radon. **Radon in soil -** Radon atoms formed on the surface of soil or mineral particles will migrate through the soil capillaries, with the air in the soil generally having a high radioactive charge (approximately 55 000 Bq/m^3). Particular attention should be paid to radon concentrations in large underground cavities, which can still be categorized as closed spaces: mines, caves, underground deposits, tunnels. **Radon in enclosed spaces** - Whether we are talking about office buildings, industrial buildings, residential buildings or enclosed spaces such as caves, various underground galleries, it is very important to analyze the impact that radon has on people who spend (more much) time inside them. WHO reminds in specialized publications that man spends about 80% of his time inside buildings / enclosed spaces, regardless of their nature (office, home, cinema, theater, etc.). An average value of radon concentration of about 8 Bq/m^3 is allowed in the continental air. The values measured by researchers inside the buildings far exceed this value, depending on its typical and many other parameters of interest, the values can reach the order of thousands of Bq / m3, but as an accepted average value: 100-300 Bq/m^3.

This chapter also discusses the issue of **energy efficiency** of buildings that have high concentrations of radon inside the measurements. Energy performance is desired both in old houses/constructions, performing thermal rehabilitation based on watertight insulation systems, replacement of old windows, with wooden frame with some of the double-glazed type, of old wooden doors (high porosity, cracks / cracks in the material), but also for newly built buildings. For new buildings, high-performance air ventilation systems, radon protection membranes etc. are used from the beginning.

In **Chapter 2**, I discussed (in detail) what the legislative framework means, both nationally and internationally. Member States of the European Union (EU) had established basic rules for the protection of the health of workers and the general public against the dangers posed by ionizing radiation, which were most recently revised by Council Euratom Directive 59/2013 of 5 December 2013 by the Scientific and Technical Committee suggested that the basic safety rules take into account the new recommendations of the International Commission on Radiological Protection (ICRP), in particular those mentioned in Publication no.103 of the ICRP and be reviewed in the light of new evidence/measurements/scientific information. According to the specialty literature, the latest epidemiological findings of residential studies demonstrate a statistically significant increase in the risk of lung cancer due to prolonged exposure to radon in enclosed spaces. It is recognized that smoking increases the risk of radon exposure. For this reason, both risks must be taken into account when assessing the health of individuals. Having the status of an EU member state, Romania has taken over the recommendations of the directive in the Rules on Basic Radiological Safety Requirements (NBSR). The reference level set by Directive 59/2013 is 300 Bq/m^3, but EU Member States may take decisions to set a national reference level below this value, if justified by geological circumstances etc. There are countries, such as Norway, where this threshold is set at 100 Bq/ m^3. Chapter 2 also discusses the issue of the impact that Directive 59/2013 has on various social categories.

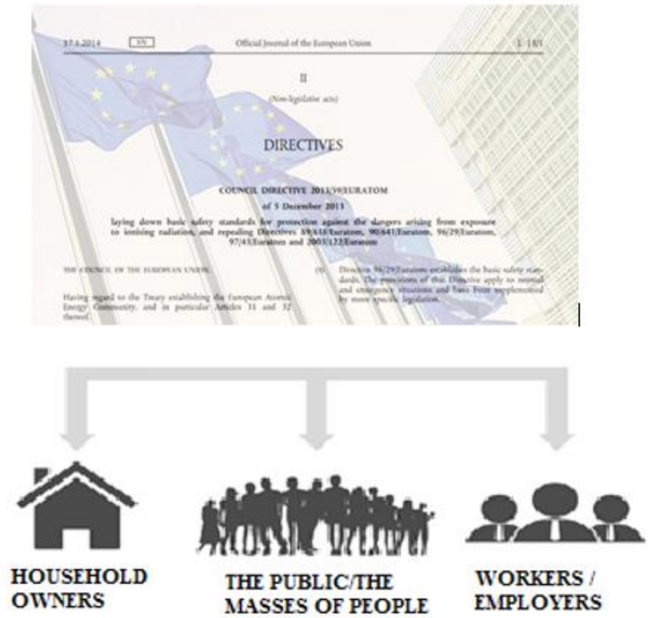


Figure 2- The impact of Directive 59/2013 on various categories of persons

In the case of working places (regardless of their specificity: mines, factories etc.) where the above-mentioned reference level is exceeded, it is necessary to declare/report it to the Commission of the European Union. In the case of working places where there is a high probability that the dose that a professional exposed to ionizing radiation will receive is higher than 6 mSv/year (origin of radon and its descendants), it will be managed as a planned exposure situation to which dose limitations must be applied and also the classification of professionally exposed personnel in A/B work categories according to the specifications of the legislation in force. Also in this chapter, various aspects regarding the PNAR were discussed, the synthesis being the following:

Building permit practices:
- Radon measurements on the construction site;
- Use of materials with a low level of radon concentration.

Measurements:
- Measurements performed in all public spaces of major interest: kindergartens, hospitals, police stations and any space on the ground floor / basement;
- Identification of areas / spaces with a high level of radon concentration;
- Communication of this information to the authorities (CNCAN);
- Monitor these levels and take the necessary measures to reduce them.

Awareness of the general public/masses of more or less educated people:
- Strategies for communicating the risks of radon inhalation / ingestion

Decreased radon concentration:
- Implementation of mitigation methods;
- Discovering other new methods.

Throughout **Chapter 3** I discussed the issue of detecting and measuring radon concentration. Alpha particles emitted by thoron and radon decay products are more difficult to differentiate from those emitted by radon. Radon detection can be performed both by direct and indirect methods. Of all the methods and types of equipment used to performe measurements are presented throughout this chapter. I used the following types of detectors to perform experiments/measurements: DURRIDGE RAD7, an active detector that uses a solid state alpha detector. This type of detector is a semiconductor material (usually silicon) that converts alpha radiation directly into an electrical signal. An important advantage of these devices is the resistance. Another advantage is the ability to electronically determine the energy of each alpha particle. An overview of this type of detector can be found below.

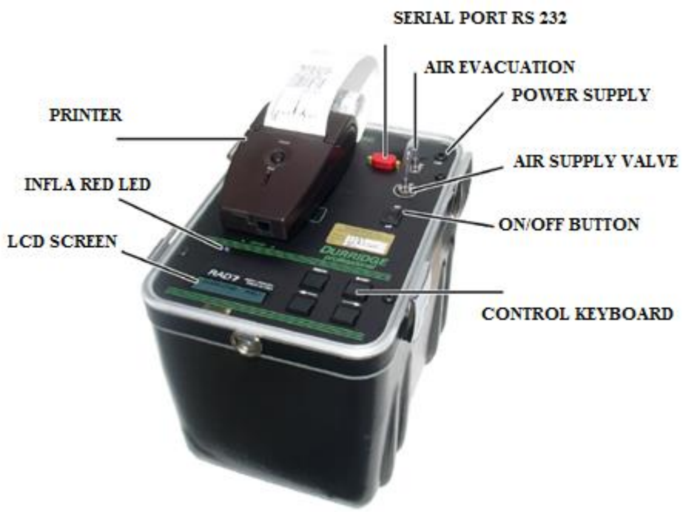


Figure 3 - RAD7 detector

The second detector used was Airthings Wave Plus, a small, compact active detector, an intelligent IAQ (Indoor Air Quality) monitor for radon detection. In addition to the radon sensor, the detector also displays sensors for temperature, air pressure, humidity, TVOC (total volatile organic compounds) and CO_2.

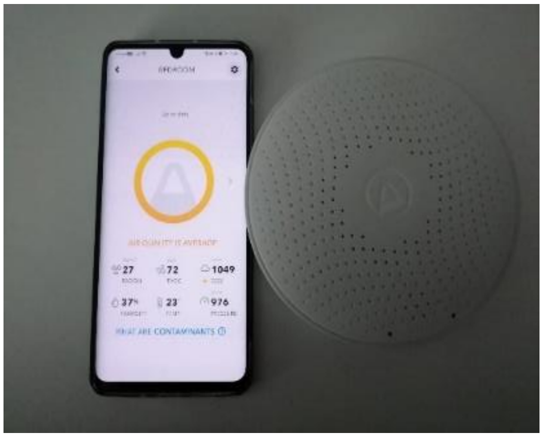


Figure 4- Active Airthing Wave Plus detector and its online application

CR-39 trace detectors are passive detectors made of polymer (alildiglycol) and are sensitive to α radiation with energies in the range of 0.2-20 MeV. In order to visualize the traces resulting from the interaction of the incident particle with the detector material, a chemical development of it is required.

Through the last part of this chapter, we presented our own / innovative project: the detection of alpha particles (from radon source) with a home-made detector, made by reusing a webcam.

Figure 5 - CR-39 Detector

The principle of the experiment of the “home-made” detector for detecting alpha particles (radon source- Am^{241}) consisted in modifying a webcam in order to be able to visualize the “traces” left by the alpha radiation. Changing a webcam is a cheap, easy and affordable way for anyone, with the ultimate goal of gaining experience with CMOS image chips. The fact that the chip is integrated into the motherboard, accessible to those who want to experiment, makes webcams usable in detecting radioactivity, especially alpha radiation emitted by the radioactive element Ra^{226}, which is the "parent" of the isotope Ra^{222}. An ordinary webcam (mass-market) can detect high-energy particles. With regard to the detection of low-energy particles, such as alpha particles, they must undergo certain changes. Minimal change means removing the protective glass filter from the sensor for maximum efficiency. Removing the filter makes the webcam sensitive to infrared and UV light. For some older webcams, the filter and sensor glass are separate, making them easy to change / separate. In the case of the Logitech C270 webcam used for this experiment, the two are combined, making it much more difficult to separate them (without damaging the sensor).

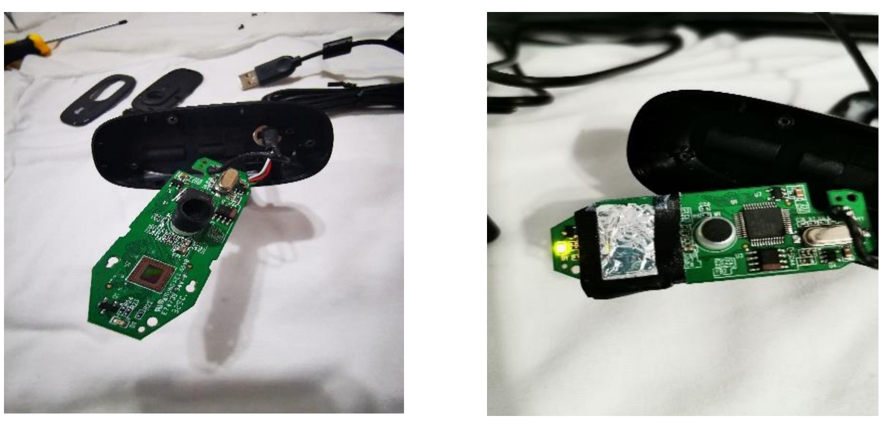


Figure 6 - Logitech C270 webcam

Chapter 4 presents the results of radon concentration measurements in air for various locations. We have carried out numerous monitoring/measurements of various types of housing in 3 counties (Argeș-Mioveni and Oarja locality, Olt-Stoborăşti locality and Galați-Cuca locality). I analyzed the geographical and geological factors, highlighting the most important aspects in correlation with the radon concentration.

We presented in detail these measurements, on time intervals, graphs, as well as interpretations of the results. The measurements performed in all types of locations in the 3 counties were performed using the active detector RAD7. Radon concentration measurements in air at locations were performed in sets of 10 measurements, at 3 different time intervals, as follows: 7: 30-16: 00, 14: 30-1: 00, 19: 30-6: 00. We chose this method in order to be able to observe the influence that the measurement time has on the increase / decrease of the value of the radon concentration in the air. Also, the radon concentration measurements were performed in 4 different calendar months of the year: September, December, March, June. These calendar months are benchmarks for the 4 quarters of interest. Through this distribution of the measurements we wanted to highlight the fluctuations of radon concentration at different atmospheric temperatures and their inclusion in different seasons: September-autumn, December-winter, March-spring and June-early summer. For each of the 3 sets of time intervals, the measurement results were arranged in tabular and graphical form. I will present below excerpts from what is presented in the thesis, this is due to the large volume they have.

Table 1 - Summary of measurements _2

Nr. Crt.	Place of measurement Codification	Details (construction materials, cracks in the floor/floor etc.)	Set	Measurement	Hour of measurement	Month of the year			
						September 2019 CmedRn [Bq/m^3]	December 2019 CmedRn [Bq/m^3]	Mach 2020 CmedRn [Bq/m^3]	June 2020 CmedRn [Bq/m^3]
1	A	ventilation at 14:00 p.m and at each purge, 10 min, after each set of measurements, recent renovation, year 2019, no cracks in the floors, high tightness due to new double-glazed windows	1	1	14:30:00	44.8	47.2	33.7	12.9
2				2	15:40:00	44	49	33.7	13
3				3	16:50:00	41.1	49	35	15.4
4				4	18:00:00	40.3	48.8	35	14
5				5	19:10:00	40	42.7	33.2	14
6				6	20:20:00	40	40	33	14
7				7	21:30:00	37.8	40	31.6	13.3
8				8	22:40:00	37	40.1	31	13.6
9				9	23:50:00	37	40.1	31	13
10				10	1:00:00	37	40.1	30.7	12.2
11	A*	ventilation at 14:00 p.m. and at each purge, 10 min, after each set of measurements, recent renovation, year 2019, no cracks in the floors, high tightness due to new double-glazed windows	2	1	14:30:00	39.7	42.2	38.3	26.5
12				2	15:40:00	39	42	38	26
13				3	16:50:00	39	42	37.7	26
14				4	18:00:00	39.3	41.5	37	26
15				5	19:10:00	38.7	41	37	21.4
16				6	20:20:00	38.7	41.3	37	21
17				7	21:30:00	38	40	31.8	20.5
18				8	22:40:00	36.6	40	31	20
19				9	23:50:00	36	39.4	26.7	20
20				10	1:00:00	35.8	39	26	20

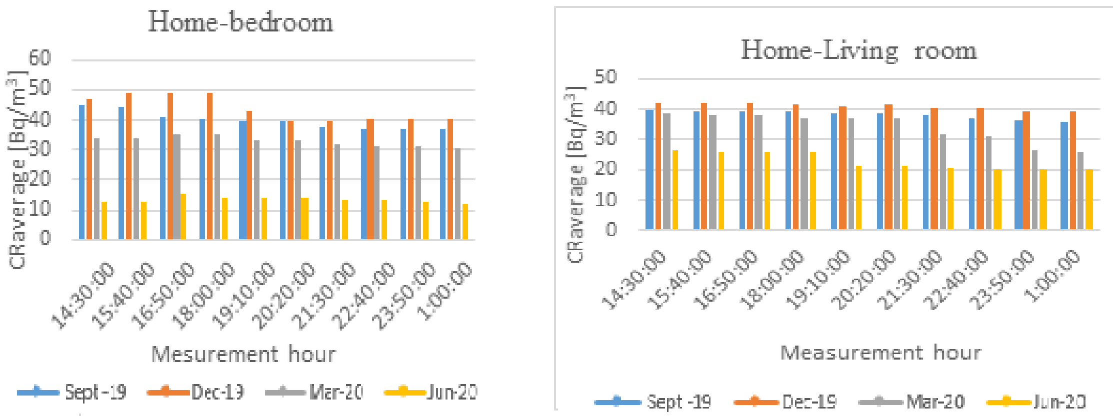


Figure 7 - Graphical representations of measurements

Table 2 - Synthesis of measurements_14: 30_Average

Nr. Crt.	Place of mesurement	Monthly average September [Bq/m^3]	Monthly average December [Bq/m^3]	Monthly average March [Bq/m^3]	Monthly average June [Bq/m^3]
1	Acasă-bedroom	39.9	43.7	32.79	13.54
2	Acasă- livingroom	38.08	40.84	34.05	22.74
3	Acasă- kitchen	48.96	57.71	46.52	31.31
4	Argeș/Oarja 1-room1	83.45	87.28	65.63	63.21
5	Argeș/Oarja 2-veranda	74.29	56.07	50.35	33.33

These measurements were not strictly limited to the resulting numerical values, lower or higher than 300 Bq/m^3, I also wanted to draw out some conclusions and observations, which would help the inhabitants of these enclosed spaces (apartments/houses) to attenuate/decrease radon concentrations. .

Taking into account the legislative provisions that stipulate the obligation to measure and remedy the concentration of radon in buildings, both residential and in the workplace, being mandatory measurements in all public buildings with high occupancy in Romania, including public institutions, Combustibil Nuclear-FCN Pitești has carried out since 2019 a series of actions to synchronize with the regulations in force, which provide for the observance of radon concentration measurements at workplaces. In this sense, 2 contracts were concluded: one for “field” analysis of specialists in the field (laboratory designated by CNCAN for performing radon measurements), and the second contract involved performing screening measurements of radon concentration in all the spaces of interest of FCN Pitești. During this chapter, I detailed how these measurements were performed, methodology, personal involvement in the field placement of detectors, development at the provider's premises (short internship through which I developed CR-39 detectors) etc. Various documents of interest were issued, including the analysis bulletin of the exposed CR-39 detectors (excerpt from it shown in the image below).

Table 4 – Dosimetric bulletin

Nr. crt.	**Buiding**	**Level**	**Detectors numeber**	**Detector code**	**Date of location**	Data of gather	Concentration (Bq/m3)	Annual Concentration (Bq/m3)
1	Administrative pavilion	basement	1	5K2718	6/11/2020		90 ± 10	148
2	Administrative pavilion	basement	1	5K2847	6/11/2020		104 ± 11	170
3	Administrative pavilion	basement	1	5K2686	6/11/2020	9/14/2020	114 ± 12	187
4	Administrative pavilion	basement	1	5K2674	6/11/2020		85 ± 9	140
5	Administrative pavilion	basement	1	5K2731	6/11/2020		67 ± 8	110

I want to bring it to your attention that for one room in my apartment I used for performing measuremnts an active Airthings Wave Plus detector and a CR-39 detector. The resulting values were compared with those resulting from usingof the RAD7 detector, values are presented in table 5 below.

Table 5 - Comparison between the 3 types of detectors

		September	December	March	June
min	RAD7	22	35	21.6	12.2
	AW	5	5	1	1
	CR-39	45	45	45	45
average	RAD7	36	45	37	21
	AW	21	45	14	15
	CR-39	45	45	45	45
max	RAD7	45	55	52	38
	AW	55	110	47	57
	CR-39	45	45	45	45

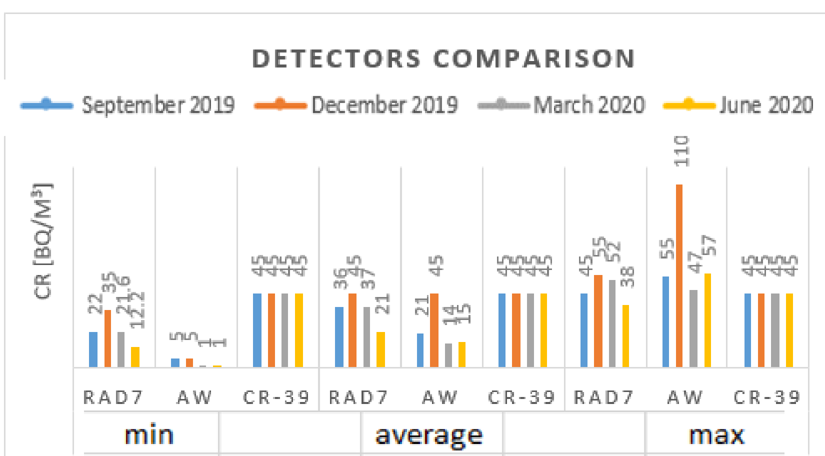


Figure 8 – Detectors values comparison

Radon gas can come from enclosed spaces from 3 sources: water, soil, air, so in the last part of the chapter I presented the results of radon concentration measurements performed in soil, as well as in various water samples from the counties where we performed the radon concentration in air measurements. For all the types of measurements I did not find any results that exceed the limits established by the leasing regulations in force, respectively: 300 Bq/m^3 for air, 100 Bq/Liter for water.

Chapter 5 assesses the impact of radon concentration on the human body by calculating and assigning the total internal/effective dose. The radiation that enters the body is absorbed to a greater or lesser extent by it. The mechanism of radiation absorption varies according to its nature. A radiation is completely absorbed by plant and animal organisms to a depth of 0.1 mm. Consequently, the radionuclides that emit it are not dangerous, unless they are incorporated into the body by ingestion and / or inhalation. The process of inhaling radon and its descendants is the main process that leads to the radiation dose received throughout the respiratory tract and can cause, in case of high doses, a primary broncho-lung cancer.

I have detailed the model for calculating the effective dose for both occupational exposures to ionized radiation and the population. The results of radon-to-air measurements performed in the context of the possibility of lung cancer will also be discussed. For many people (from the category of non-occupational exposure to ionizing radiation), radon is the main contributing factor to exposure to ionizing radiation throughout life. The United Nations Scientific Committee on the Effects of Atomic Radiation has concluded in two comprehensive reports (from 2000 and 2006) that inhalation/ingestion of radon and its disintegrants are carcinogenic to the lungs (doses for other organs and tissues were In 2009, the World Health Organization (WHO) published a “Handbook on Indoor Radon” WHO Review of Recent Studies on Indoor Radon and Lung Cancer in Europe, North America and Asia have provided strong evidence that radon causes a substantial number of lung cancers in the global population.The WHO estimates that the proportion of lung cancers attributed to radon exposure varies from 3 to 14%, depending on the radon concentration in the country and the method. IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Rad iation Sources: International Basic Safety Standards sets requirements for the protection of the public against indoor radon exposure. In particular, para. 5.20 of the GSR Part 3, establishes this responsibility as the responsibility of national authorities to “ensure that an action plan is established that includes coordinated actions to reduce radon concentrations in both existing and new buildings. builded". In the last part of this chapter we presented the results of measurements of radon concentration in the air made in the context of the possibility of lung cancer. To compare the model predictions with epidemiological data for indoor exposures, we used the data reported by S. Darby.

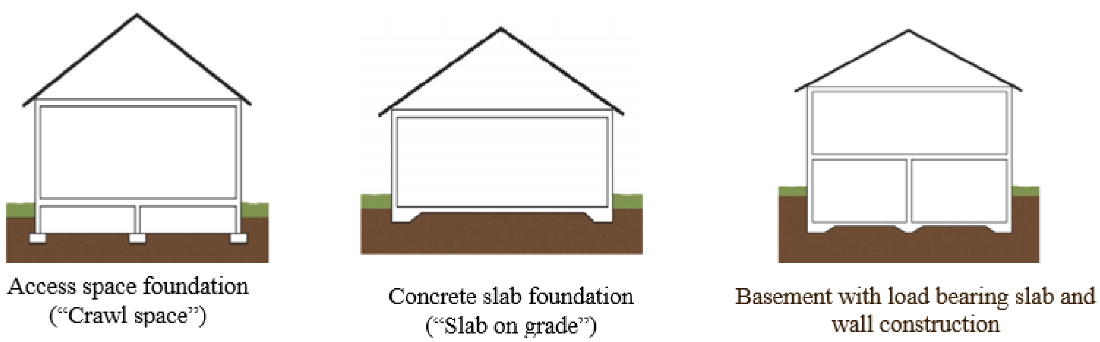
Table 6- Relative risk of lung cancer cases – Mioveni

Nr. Crt	Codification	Measured value of radon concentration [Bq/m^3]	Relative risck-RR [%]	$N_{Rn,a}$	Average concentration value [Bq/m^3]	Medium relative risk [%]	$N_{Rn,a}$ med
1	C1	67	1.0536	3.87	77.88	1.0623	4.46
2	C2	121	1.0968	6.71			
3	C3	56	1.0448	3.26			
4	C4	59	1.0472	3.43			
5	C5	74	1.0592	4.25			
6	C6	51	1.0408	2.98			
7	C7	101	1.0808	5.68			
8	C8	79	1.0632	4.52			
9	C9	93	1.0744	5.26			

The purpose of **Chapter 6** is to provide an analysis of the technical solutions for both corrective actions and preventive measures that may have the effect of reducing the risk of radon penetration (regardless of manner) inside closed buildings/spaces. The following will be considered: description of methods, design, implementation of measures and actions to reduce the penetration of radon into buildings, materials, and equipment used in these solutions. The chapter presents the values of radon concentration measured in various locations, various constructions (rooms/buildings) that used various types of construction materials/materials for redevelopment / rehabilitation of spaces. It will be noted that the values of the radon concentration presented are closely related to the construction materials used. This chapter discusses both measures to mitigate/reduce radon concentrations in existing buildings and protection measures to reduce radon concentrations in new buildings from the outset (starting from the design phase). I discussed the topic of diagnosing radon problems for a number of common types of construction, ventilation and their influence on the penetration of radon into a building/enclosure. I also presented a comprehensive selection of mitigation/mitigation methods, as well as protection / prevention measures for new buildings. There is no magic solution, generally usable/valid for all types of buildings. Some homes may need a combination of several methods, so that the radon level is reduced below the national reference level (300 Bq/m^3 in the case of Romania).

Are presented the following:

- Types of foundations for buildings/dwellings/enclosed spaces:



- Types of ventilation:

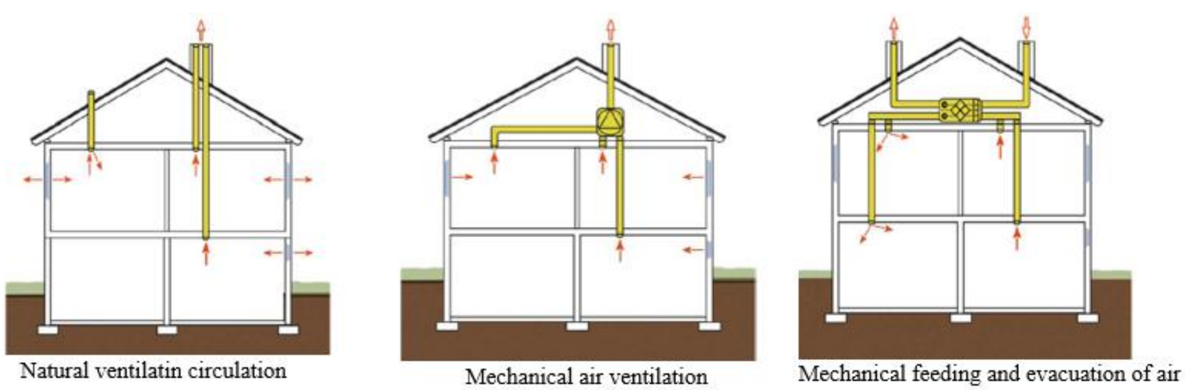


Figure 9 - Types of foundations / ventilation

In one of the subchapters I discussed the issue of residues NORM - Naturally Occurring Radioactive Materials: radioactive waste or construction material?! The use of radioactive building materials (more or less) rich in natural gamma emitting radionuclides can cause significant exposure of those who spend time/living in buildings constructed with such products. Radioactive building materials have been used in many parts of the world for generations. The main (possibly) radioactive materials are concrete, mortar, by-products and industrial waste used as ballast. (Higher) radioactive concentrations have been found in acidic magmatic rocks, especially in magmatic granites and in some metamorphic rocks. Concrete is one of the most commonly used radioactive building materials. The variation of natural radionuclide concentrations in concrete depends on the radioactive materials in the ballast and additives. Usually the radioactive materials used as ballast are sand, gravel, macadam and gravel, which do not normally increase the radioactive content of concrete. However, other radioactive ballast materials such ponce rock with high Ra^{226} concentration are also used. The table below shows some of the most used construction materials in country.

Table 7 - The most used construction materials in Romania

Type of material	Average specific activity			Index/ Category
	K^{40}	Ra^{226}	Th^{232}	
Currently used building materials				
Sand	176 ± 190	24 ± 18	20 ±22	0,242/ I
Gravel	137± 108	25 ± 10	13 ± 4	0,200/ I
Cement	281 ± 148	70 ± 59	27 ± 8	0,2-0,8/ I-II
Concrete	918 ± 519	69 ±51	77 ±69	0,921/ II
Mortar	313 ± 168	43 ±19	44± 25	0,467/ I
Bricks / red bricks	1038 ± 170	56 ± 25	51 ± 24	0,661/ II
Bricks / red bricks	725 ± 376	51 ± 34	45 ± 21	0,732/II
Natural gypsum	199± 100	41 ±16	40 ± 19	0,410/I
chalk	343± 270	43 ± 11	31 ± 17	0,433/I

The last subchapter presents the experimental measurements of the radon concentration in enclosed spaces (new constructions/house type) using the anti-radon membrane as a means of reducing/attenuating the internal radon concentrations. It has been shown that the use of the membrane can reduce the concentration of radon in an enclosed space up to 88%.

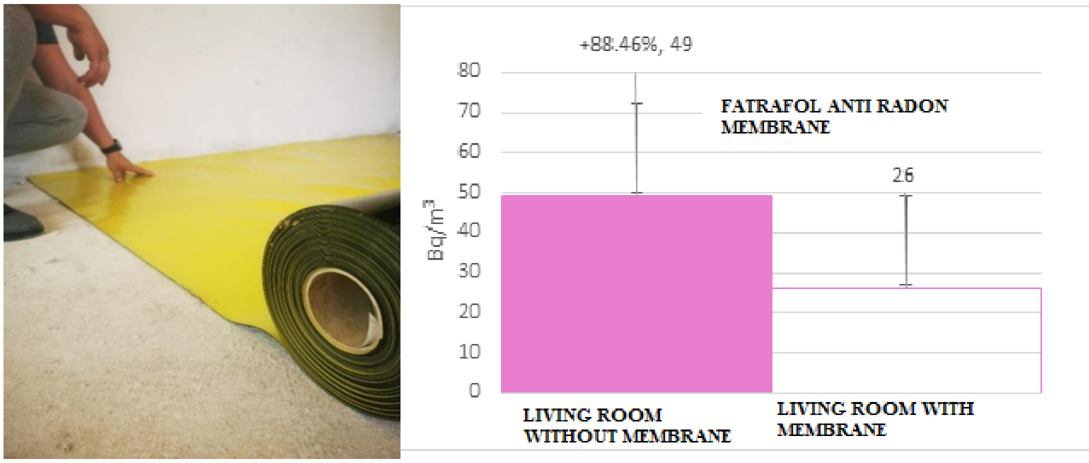


Figure 10 - FATRAFOL anti-radon membrane

The last chapter, **Chapter 7**, presents the observations, general conclusions, and personal contributions to the paper. Throughout the chapter, the values resulting from the measurements of radon concentration in all 3 environments were analyzed: soil, water, air. These values did not indicate inconsistencies. In the case of measurements made on water samples, the value sets did not indicate increases, the highest value being about 20 Bq/Liter, one fifth of the imposed legislative limit of 100 Bq/ Liter. For the measurements performed in the air, regardless of the chosen location, the time of the measurements, of the detectors used, I can say that the dependence of the temperature / pressure-radon parameters has been observed. Depending on the detector used, its sensitivity (technical constructive characteristics), the recorded values fluctuated, but there were no extreme cases, of major differences recorded in the same conditions by 2 different detectors.

It should be noted that the easiest way to reduce the concentration of radon inside rooms/enclosed spaces is by simply opening a window and/or door (where possible). The window/door must be open / wide to allow the exchange of air currents, not folded or very slightly open. This aspect was found experimentally in one's own home, coding A, according to the tables presented in the theses. For the room of interest "Bedroom" it was found that for a ventilation (window opening) of about 15 minutes, in the warm season, June, the radon concentration decreases by about 17% (from 28.44 Bq/m^3 to 23.6 Bq/m^3), and for the cold season, December, the radon concentration decreases by about 29% (from 53.34 Bq/m^3 to 37.87 Bq/m^3).

It has been found out that indoor air recirculation/exhaust systems (kitchen hood, bathroom fans, AC-air conditioning systems) can play an important role in accumulating high concentrations of radon in cracks/cracks in floors/floors. During their operation, radon gas accumulates inside the room. This negative impact was demonstrated by measurements with the active Airthings Wave Plus detector. The values related to June are a phenomenon of interest: in the days of 07-08 the values of the radon concentration were slightly increased (50 Bq/m^3). In the hot season, this value was high, the measured values should have been lower and lower! At a first (minimal) analysis, the answer lies in the excessive use of AC (air conditioning). The high capacity of such a ventilation system, as mentioned above, can extract radon from existing floors and / or cracks.

Measurements of radon concentration in soil have indicated values of thousands of Bq/m^3 (the maximum value found was about 4 thousand Bq/m^3 in the cold season, in December). These values are not abnormal, the earth's crust being the place of formation of radon gas. Radon concentration measurements in soil were performed for a single location, location A (according to Table 11, presented in thesis). Soils characteristic of Mioveni are: brown clay-alluvial soils, luvic brown soils, regosols, erodisols.

The comparison between the values of radon concentration found in living spaces versus workplaces during the warm season led to the conclusion that they are comparable to those in location A (own apartment): 44 Bq/m^3 compared to an average of 30 Bq/m^3.

4. Original contributions

The original contributions to this paper are as follows:

• Carrying out radon concentration measurements in all 3 environments of interest (air/water/soil) using various dosimetric equipment (calibrated and metrologized), active detectors: RAD7 (standard air measurement kit to which either the water or soil), Airthings Wave Plus, passive detectors: CR-39 trace detectors.

• Correlation of radon concentration measurements performed with ambient dose rate measurements (measured with professional laboratory dosimetric equipment - Flowmeter FH-G-10 Thermo Fisher).

• Personal development of CR-39 detectors used in the screening / detection process in FCN Pitețti in an ODD (Designated Dosimetric Body) laboratory.

• Carrying out measurements for various types of homes/dwellings, various sources of water supply (both at the centralized distribution system and at the wells/wells in the courtyards of the respective houses) and identifying possible access routes for radon gas.

• Processing of measured experimental data and identification of sources and factors that contributed to the indoor radon source.

• Validate the efficiency of using an anti-radon membrane to reduce the concentration of radon indoors.

• Development and validation of a "home-made" detector - based on the detection of alpha particles (source-radon source).

• Carrying out the first study on the level of radon concentration from FCN Pitețti. The study consisted of the elaboration of the measurement methodology, the effective measurement of the radon concentration, the processing of the experimental data and the elaboration of some conclusions and recommendations. Some of these recommendations have already been implemented, while others are being implemented.

• Calculation of the actual doses received from radon exposure, both by the population and by the professionally exposed personnel (regardless of the classification category A or B, according to the legislation in force) of FCN Pitești.

5. Prospects for the future

The issue of radon is a vast one, with many areas of interest. This paper briefly discusses the general notions of radon gas, its detection / measurement methods, the importance of construction materials, protection against radon exposure inside buildings / enclosures, as well as gamma radiation from building materials, methods prevention and mitigation, the calculation of doses received by the population and / or occupational exposures to ionizing radiation.

This paper can be extended / continued through various scientific papers, such as articles in journals of interest, national / international conferences on radiation protection / radiological protection, but not only. Topics of interest in future (personal) scientific papers include:

- Measurements of radon concentration in the N-V part, as well as in the center of the country and comparison with the measurements performed in the S and S-E part of the country. These measurements should be performed with the same types of detectors as in similar types of dwellings. If the same measurement "bases" are maintained to a large extent, these measurements can show the importance of geological as well as geographical factors on radon concentration measurements.

- Detailed measurements on various types / categories of construction materials that emit the range and that contribute to the actual dose. Detailed research can be done on the construction materials market.

- Thermal efficiency of buildings / spaces versus buildings, analysis from an economic point of view. In an article of this type, calculations can be made to establish the extra initial costs to be planned for a new construction that would have in its structure all the effective means of attenuation / reduction of radon concentration.

- Negative / destructive effects from a medical / biological point of view. The literature confirms that radon gas is the second leading cause of lung cancer. It may be a topic of interest in a scientific paper to correlate the data in the literature with what is happening in reality. It would be of great interest for this study to be conducted in an area of interest, for example housing near former processing mines, former occupational exposures to ionizing radiation, and also smokers, active and / or passive.

- Methods / means to reduce / decrease / attenuate the radon concentration in various environments and / or in various types of buildings / spaces in case of high radon concentrations (exceeding the national maximum permitted level). The economic effects can be traced over time, as well as those with a medical impact. For these studies we can have as a starting point the aspects detaile