„BABEŞ-BOLYAI" UNIVERSITY, CLUJ-NAPOCA
FACULTY OF ENVIRONMENTAL SCIENCE

# PH.D. THESIS

(SUMMARY)

# USE OF SOLID STATE TRACK DETECTORS IN RADON STUDY: RESIDENTIAL AND INSTITUTIONAL EXPOSURE

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## Key Words:

natural radioactivity, radioactive equilibrium, radon, lung cancer, solid state nuclear track detector, track density, residential exposure.

# INTRODUCTION

Because in our days the majority of the population spends its life (80%) in indoor spaces, it is necessary to know the indoor air quality.

Radon, a naturally occurring radioactive gas, constitutes the most important natural radiation exposure in many dwellings and contributes more than half of the total natural ionizing radiation dose to world population. Radon and radon progeny are present in the air of dwellings, representing the most important contribution to dose from natural sources of radiation. After smoking, radon represents the second most important risk cause of developing of the lung cancer.

For this reason we proposed an adaptation of one known method for radon measurements in indoor air in dwellings, schools and kindergardens, etc.

Besides the unwanted effects on health radon can have a positive effect too, if the concentration is kept under certain limits.  A possibility to use the therapeutic effect of the radon is in the case of the mofettes where the emanated gas can contain important quantities of radon

The thesis is structured in 7 chapters, which contain a presentation of my achievements in a logic succession both a temporal development and a technical order.

Chapter 1 presents the nuclear radiation.

Chapter 2 presents the properties of radon, sources and migration of radon. In this chapter was discussed the health effect of radon, the specific measurements units used and regulations related with the radon activity concentrations.

Chapter 3 presents the radon in different environmental factors, in soil, in water, in air (outdoor and indoor).

Chapter 4 deals with the details of methods of radon measurements by instantaneous and continuous measurement methods, based on different techniques. The chapter contains also the solid state nuclear track detectors methods.

Chapter 5 presents experimental methods for solid state nuclear track detectors. This chapter is divided into five sections. In the first section was presented the optimization of measurements with CR-39 track detectors. In the second section was measured and calculated the optimal development time for CR-39 track detectors. Determination of optimal placement for track detectors is found in the third section. The fourth section contains the presentation of dependence of track density for the developed track detectors  depending on storage time. The last, fifth section presents the intercomparison of radon meter measurements with national and international laboratory.

In the chapter 6 contains results about radon concentration in indoor air, dwellings, schools, kindergarten. Also in this chapter was presented the results about measurements of radon concentration in the mofettes, thermal spas and salt mines.

Chapter 7 is the chapter with conclusions.

# CHAPTER I.
# RADIOACTIVITY

This chapter includes the main disintegration modalities and characteristics of the radiations emitted (radiation alpha, beta and gamma). Also was presented the phenomena occurring of the interaction between these radiations and substances.

# CHAPTER II.
# THE RADON

In this chapter has been studied the properties-, sources- migration of the radon, the radon flux, the specific measurement units used in the detection of the radon and there daughters and the national and international regulations used for the radon activity concentration in different environments.

# CHAPTER III.
# RADON IN DIFFERENT ENVIRONMENTAL FACTORS

The main source of radium and radon is the soil. The radon quantity of soil depends on radium concentration, on the structure of the soil and rocks respectively on physicals and chemicals properties. On account of local specific geological structure the emanated radon concentration varied from place to place. [29].

Generally soils in terms of the concentration of radon can categorize as high-risk areas, medium-risk areas and low risk areas.

The high-risk area is where the concentration of radon in the soil exceeds 50 kBq /m$^3$. This includes those places where the soil is rich in uranium ( radium ), or has a high permeability .

Medium risk area is where soil radon concentration varies between 10-50 kBq/m$^3$ and has a medium permeability soil.

Low-risk area is categorized as soil where radon concentration does not exceed 10 kBq / m3 and the soil has low permeability.

The content of radon into the pores depends on the concentration of radium atoms fraction and from the soil surface soil particles such that radon atoms formed by the decay can escape into the pores .

Radon exhalation on pores to the air is influenced by the pore size of the particles of soil, soil moisture , temperature and pressure .

If the space between the pore is with water, the emanation of radon from the ground becomes more difficult, and is dependent on the ratio between the water/gas volume and temperature.

In general the mineral and geothermal waters have high concentration of radium and radon. These waters are used in spa treatments, producing an additional irradiation of the patient and medical staff. The water used in the household may be one of the factors that can contribute to the radon concentration of the room. It is therefore important to study the radon concentration of water .

For exterior air, the concentration of radon in the air is heavily influenced by local momentary value and the flow of radon from the soil and the movement of air masses in the atmosphere directly related to weather conditions.

An analytical treatment of the problem of radon in exterior air distribution must take into account all these parameters.

When the radon emanates from soil into the exterior air fast diluted and its concentration decreases with increasing height above the ground .

Indoor radon concentration mostly depends on the concentration of radium in the soil below the building, physical and chemical parameters of soil, building structure, methods and frequency of ventilation , meteorological factors (pressure , temperature, humidity ) .

The main source of indoor radon is the soil under the building . In general , the concentration of radon in the room has a source , approx. 60 % soil, approx. 20 % of building materials , about 18 % outside air. Water consumption contributes about 1.8% and gas consumption by less than 1%.

The second main source of indoor radon are the building materials. The classical building materials (clay, sand, stone, granite, etc. ) contains natural radioelements in different concentrations, depending on place of origin.

In the last years there have been experienced and have produced a series of new construction materials that tend to replace those classics.

The radon emanation in dwellings depends on the weather condition to.

# CHAPTER IV.
# RADON DETECTION

Chapter 4 deals with the details of methods of radon measurements by instantaneous and continuous measurement methods, based on different techniques.

The chapter contains also the solid state nuclear track detectors methods.

The radon measurements can be grouped:

- direct or indirect measurements (after detecting alpha particles from radon and progeny) ;
- active and passive methods after measuring techniques
- after sampling methods ( the sampling instant sample- continuous days or weeks or integrated measurements )
- by type of detector used ( ionization chamber, Lucas cells, track detectors, etc. ) .

In radon measurement the most frequently detectors are mostly used is: ionization chambers, scintillation cells, semiconductor detectors, detectors with carbon, electric detectors, solid state nuclear track detectors.

***Solid state nuclear track detectors***

The solid state nuclear track detectors (SSNTD) are represented by traces of plastics or polymers that are able to leave detectable traces the impact of alpha particles through their surface [ 67 ] . The materials most commonly used are cellulose nitrate represented by ( LR - 115 ) and plastics ( CR - 39 and Makrofol ).

This type of detector is used heavily in long-term passive measurements , the technique being used lately in this direction [ 60-62 ] .

To build a model to describe the occurrence of marks in solid track detectors, account should be taken of properties that have been observed experimentally [ 70 ] .

It is known that a heavy particle loaded, going through some material, most of its energy is lost through ionization and excitation of atoms in the material.

A very small percentage of energy loss due to elastic collisions with the atoms of the material. Energy ceded almost all the material is converted into heat, so the trajectory of particle material will suffer a mild heat shock .

Currently used theory is the ion explosion theory ( " ion explosion spike " ) [74] . After the pattern formation mechanism of the trace is shown in Figure 1 .

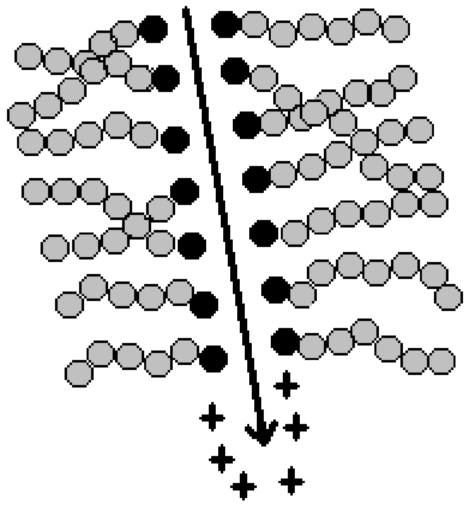

**Figure 1.:** Schematic diagram of the polymer chains breaking the penetration of heavy particles loaded

Throughout its trajectory charged particle heavy, solid material ionizes atoms. Rejecting electrostatic forces will deploy occurring ionizing atoms, thus creating a large number of vacancies and interstitial defects. This process will occur only then if the load space than the particle trajectory does not drop quickly (ex. by recombination of electrons) and if the forces are large enough to be able to dislodge atoms .

Primary tracks can be studied only complicated method (for example, transmission electron microscopy) structural changes which are obvious matter, located in the small domain . The chemical methods such marks can be made visible using optical microscopy [ 75 ] .

Each chemical treatment method is based on the fact that the rate of solubility of the material is larger than the damaged area of the radiation at the point where the radiation has been reached. After chemical treatment, primary tracks will appear instead of small cone-shaped holes that with advance chemical process will increase and become more flat. This process can be pursued in the next Figure 2.

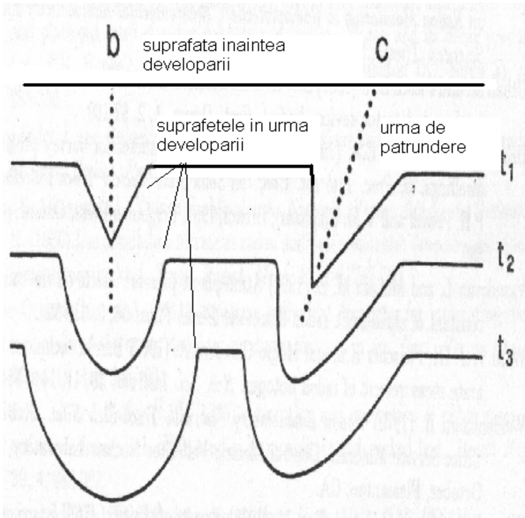


**Figure 2.:** Characteristic of development of SSNTD

The materials most often used to track detectors are polymers .

The CR-39 track detectors material is plastic, allyl diglycol, and it is sensitive to radiation α , between 0.2 to 8 MeV energies which [ 73.75 ] .

The technique used is: the detector is stuck in a small plastic box, called Radapot, or Radamon. The box is provided with apertures to permit the entry of radon in its interior. The box Radamon has a special paper inside coating that does not let in air radon progeny, instead radon enters by diffusion , in a proportion of 95%. The radon progeny decay stay inside the box , it will land on its walls crumbling before [ 74 ] CR -39 detector will detect both α particles emitted by radon and its progeny ones issued .

CR -39 detector will detect both α particles emitted by radon and its progeny those issued [ 70 ]. The following figure ( Figure 3 ) are visible traces of alpha radiation produced material trace detector CR -39 .

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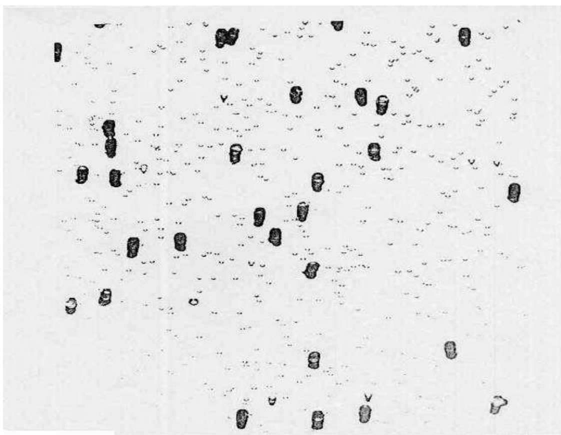

**Figure 3.:** Fission fragments and tracks in the detector α CR -39

The number of track in the material of detector that will appear will be proportional to the concentration of radon in the box and shutter speed. Of the tracks, based on a calibration can calculate the concentration.

A very important issue that arises in all these detectors or dosimetric equipment used in their calibration is to be used in actual measurements and to be able intercomparasion results of all measurements made in different regions of the world by different laboratories

# CHAPTER V.
# EXPERIMENTAL METHOD

Chapter 5 presents experimental methods for solid state nuclear track detectors. This chapter is divided into five sections. In the first section was presented the optimization of measurements with CR-39 track detectors. In the 2 section was measured and calculated the optimal development time for CR-39 track detectors. Determination of optimal placement for track detectors is found in 3-me section. The 4 section contains the presentation of dependence of track density for the developed track detectors in function of storage time. In the last 5 section was presented intercomparison of radon meter measurements with national and international laboratory.

Solid state nuclear track detectors (SSNTDs) have been used for a long time for radon measurements. Every detectable α-particle produces in a SSNTD a single trail of damage, which, after chemical enlargement turns into narrow channel and is made visible under microscope. SSNTDs exhibit different sensitivities; some of them are sensitive to alpha particles in the energy range of the particle emitted by radon and his progeny. Mostly, these SSNTDs are cellulose esters (nitrate and acetate) and polycarbonates like bis-phenol-a polycarbonate and CR-39.

RadoSys2000 device has a comprehensive set of tools designed to work radon concentration measurement integrated over time. (Figure 4) .


**Figure 4.:** Device RadoSys 2000 (right), the box Radapot for detector CR-39 (top left corner) device for detectors development (bottom left corner)

The latent tracks can be etched with help of a suitable etching solution of NaOH, under controlled conditions (temperature, time and etching concentration). (Figure 6).

In this study was used CR-39 track detectors etched at reading by a Radosys system in our laboratory. Etching conditions that is used in this device are: NaOH of 6.25 molar, temperature $90^0$C

The radon concentration was calculated after a simple equation:

$$c_{Rn} = \frac{\rho \cdot F_c}{t}$$ (

(1)

where:

**$C_{Rn}$**- radon concentration calculated, [Bq/m$^3$]

**ρ-** track density, [track/mm$^2$]

**$F_c$**- calibration factor, [kBqh/m$^3$/(tracks/mm$^2$)]

**t**- exposure time, [h]

In use of track detectors, as with other measuring devices, calibration method is very important.

To correct measurement of radon concentration using track detectors need to know if the method we use is correctly applied. If track detectors must verify the following :

A. development time

B. correct positioning of the detectors on site enclosure where we want to measure the concentration of radon

C. Track density dependence and track detectors developed depending on storage time

## Calculating the optimal development time

The experiments (three experiments methods) were made at the Interdisciplinary Research Institute of the Babes - Bolyai University, Faculty of Environmental Sciences, Cluj-Napoca.

In the experience was track detectors and the measuring device, Radim 3A. This was placed in radon chamber with a radon source.. (Figure 5.)

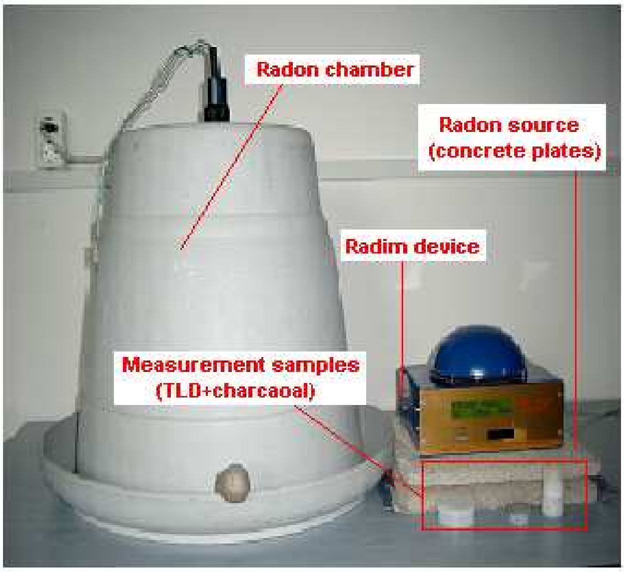


**Figure 5.:** Radon chamber used for experience

To check the radon concentration using track detectors should be checked if the concentration found is what exists (measured by other methods ).

Because radon concentration measured with track detectors is based on measured track density (Formula 1 ) in the device , we need to know whether the number of tracks is correct.

For this, the first thing is to know whether the detector is developed in an appropriate time. The precision of measurements of track detectors it was check in several ways.

**A).** The track detectors were introducing in the radon chamber with Radim device and with source of radon. Time of exposure was 8 days. At development of detectors we start at concentration of NaOH solution (c=6.25mol, t=90$^0$C). Were studied detectors at different times of development, at 3,5h, 4h, 4,5h, and 5,5h. In table 1 is presented the results. Every detector was measured at 5x.

**Tabel 1.:** Average, Geomean and the median of radon concentration in function of development time

| $t_{development}$ (h) | **3,5** | **4** | **4,5** | **5,5** |
|---|---|---|---|---|
| **$\langle C_{Rn} \rangle$ ($Bq/m^3$)** | 2964±424 | 3275±174 | 3734,625±303 | 3383,875±295 |
| **GEOMEAN** | 2934 | 3271 | 3724 | 3372 |
| **MEDIAN** | 3168 | 3334 | 3740 | 3338 |

The optimal development was at **4,5*h*.** (Figure 6).

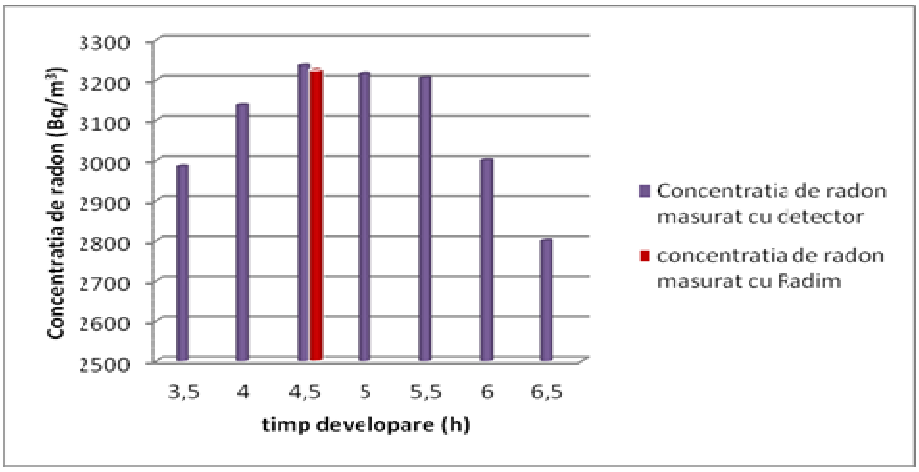


**Figure 6.:** Radon concentration distribution in function of development time

In figure 7 is the saturated curve for development time.

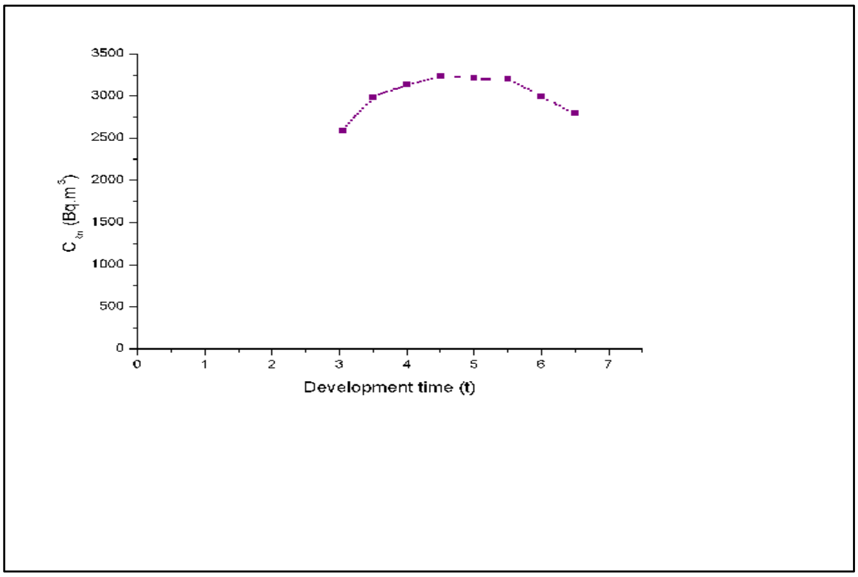


**Figure 7. :** Saturation curve in function with development time

In the three experiments and methods to the named conditions experienced during optimal development time, at 4.5h.

## Determination of the ideal location positioning track detector

**A).** Under radon chamber was fitted with the device Radim, as control device, eight detectors. The radon source was a special concrete with radium and cesium. The exposure time was seven days. They were placed under radon chamber for concretize the optimal positioning and closing for the detector chambers. Thus two detectors were placed in a vertical position with tight lid, 2 in a vertical position with not tight cap. The others for detectors were positioned conversely. The results are in the table 3.

**Tabel 3.:** Radon concentration measured with detectors in the differents position

| Detector | Detector position | Track density (track/mm$^2$) | $C_{Rn}$ (Bq/m$^3$) |
|---|---|---|---|
| B71061 | **Normal, tight** | **9,227** | **2557** |
| B71020 | **Normal, tight** | **10,662** | **2955** |
| B71082 | Normal, not tight | 11,303 | 3132 |
| B71083 | Normal, not tight | 13,739 | 3807 |
| B71075 | **Overturned, tight** | **10,581** | **2932** |
| B71071 | **Overturned, tight** | **11,289** | **3128** |
| B70998 | Overturned not tight | 14,180 | 3807 |
| B71019 | Overturned, not tight | 13,554 | 3756 |

As can be seen from the results, it was difference in the cases. In the case when the detector chamber was tight the radon concentration it is less then 1,26 times. In the case when the chambers were overturned, the difference between concentrations measured with detectors tight and not tight was lower then 0,8 times.

Depending on the positioning of the detectors chambers, never came to measured concentrations, a significant difference. In the tight chambers cases, the difference between normal/overturned position was 0,91, respectively for the not tight cases, the difference between normal/overturned was 0,92.

The radon concentration measured with Radim was $C_{Rn}$=3471Bq/m$^3$.

**B)**. The CR-39 detectors can put in differences detectors chambers: radamon, radapot etc.. One of the experiments is that under radon chamber we put with Radim aparat, detectors in differences chamber types. (figure 8), 5 detector for each.



RSE RSF-long RSF-small

**Figure 8.:** Detectors chamber used at experiment

The average concentrations were: for the RSE type $<C_{Rn}>=521(Bq/m^3)$, for RSF-long type $<C_{Rn}>=619(Bq/m^3)$ and for RSF-small $<C_{Rn}>=520(Bq/m^3)$.

The radon concentration measured with detectors in the RSF-long chambers show the same results as the Radim device.

**Track density dependence and track detectors developed depending on storage time**

The reuse of chambers for the exposure of detectors has been experimented. In this study we have used detectors introduced in new chambers, respectively in chambers already exposed.

After developing and reading track detectors CR-39, the radon concentration is presented in figure 9.

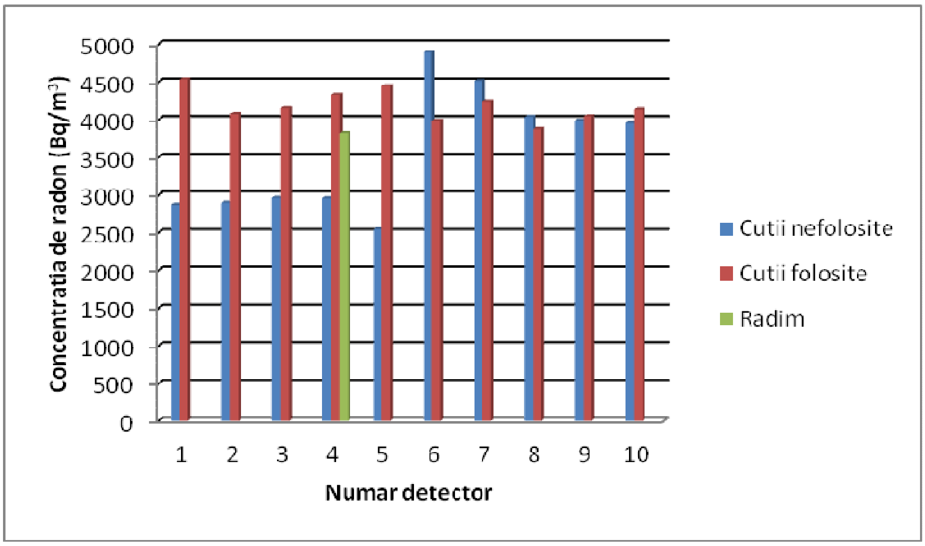


**Figure 9.:** Radon concentration measured with different detectors chambers

The results show a difference between the concentrations measured with detectors placed in new chambers and those measured with detectors placed in already used chambers.

In the case of the new chambers the average value of radon has been **3562Bq/m$^3$**, and in case of the used chambers the average concentration was **4181Bq/m$^3$.**

The detectors in the already used chambers have shown a larger concentration than in the cases of detectors placed in new chambers. The explanation is that the previous measurements left some radon descendants on the chamber walls, which still radiate. One can also observe that 10 detectors have shown more similar concentrations, with a standard deviation of ±206 (~5%).

In case of the detectors exposed in the new chambers, the concentrations are smaller, but more spread (standard deviation of ±810 and the percentual standard deviation of 9%).

As it can be seen on the chart, the radon concentration registered by the detectors in different chambers does not defer much from that measured with the Radim device. Nevertheless, there are differences and if we excluded the aging phenomenon, the measurements would bring to our attention the importance of reusing the old chambers (for exposure), due to their contamination especially in the case of first exposure to large concentrations and then the reuse for smaller concentrations.

## TRACK DENSITY DEPENDENCE OF THE DEVELOPED DETECTORS DEPENDING ON STORAGE TIME

As track detectors are generally used to measure radon in dwellings, for the same exposure conditions a large number of detectors are used. Exposure is followed by developing, storage and reading of detectors. If the detectors are not well washed and dried with distilled water, on their surface there can remain NaOH solution. This fact can lead to the deepening of tracks. On this account there is a risk that the results obtained might not be real.

To check the reaction in time of the developed detectors, the detectors exposed in closed spaces have been analyzed. These have been read immediately after developing, respectively after 5 months.

71,42% of the detectors, if read later, have shown larger concentrations, 42,86% had a deviation larger than 10%.

These results show the fact that there is a connection between the developing period and storage time of the detectors. Unfortunately this is not favorable for the late reading of the already developed detectors.

## INTERCOMPARISON OF THE RADON MEASURING DEVICES

Through several intercomparison experiments of the method of track detectors type CR-39 with other measurement methods used for the measuring of radon indoors, the efficiency of the reading device of the research laboratory has been checked.

In order to establish the measurement performance of indoor radon, the measurements have been carried out using several specialized devices belonging to the laboratory (Alphaguard, Radim, Luk 3A, Ramon, Charcoal, track detectors CR-39).

The standard deviation was in the range between 6-12%.

During several interlaboratory tests (IFIN-HH, Bucharest, Romania; Pannon University, Veszprem, Hungary; Institute of Radiological Sciences of Chiba, Japan) the aim was the perfectioning of the method of track detectors CR-39, with the target of reducing measurement errors.

Through all experiment methods the use of solid state track detectors has been perfectioned.

# CHAPTER VI.
# INDOOR RADON

## THE ACCUMULATION OF RADON IN INDOOR AIR

While the average radon concentration in the free atmosphere is of 8 $Bq/m^3$, in buildings the concentration levels are higher (12-300$Bq/m^3$) and they can reach very high levels, a few thousands $Bq/m^3$ [80].

The accumulation of radon in closed spaces depends on the main radon source, which is the soil beneath the building. Next to this, it also depends on the physical and chemical parameters of the soil, the structure of the building, the method and frequency of ventilation, the heating of the building, weather factors (atmospheric pressure, temperature, and relative humidity). One has to take into consideration an increase of the radon concentration due to the fact that the inhabitants save energy by insulating the buildings. The changing of regular windows with thermopane windows, the good insulation of the walls lead to the accumulation of radon concentration, the natural ventilation being much reduced.

If the materials used for the foundations become old, cracks can appear, through which radon can find its way easily. A solid foundation insulates very well and can reduce the diffusion of radon from the soil.

The indoor radon concentration also depends on the household activities and first of all on the ventilation (natural ventilation) of these spaces. If we ventilate with windows and doors open, the radon concentration will be reduced in 15-20 minutes to the concentration level of the outdoor air. (figure 10) [81].

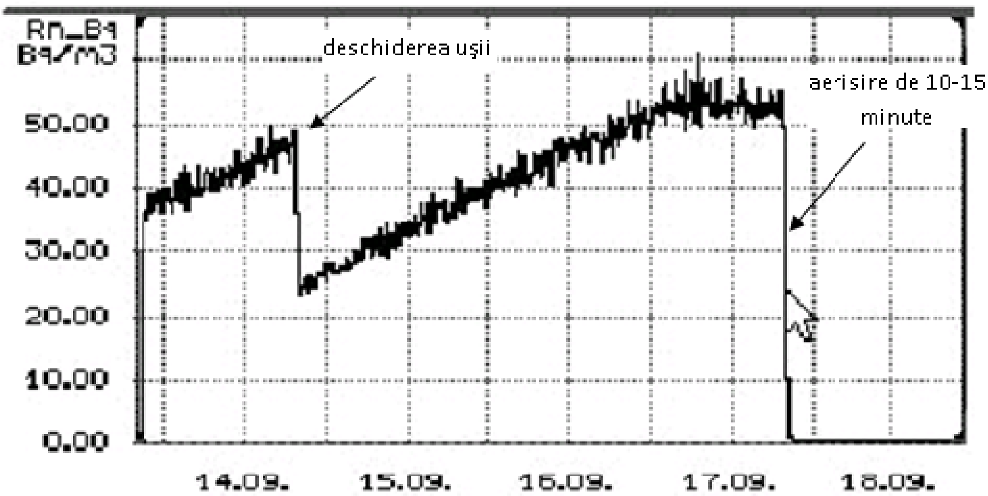


**Figure 10.:** The radon concentration and the ventilation results

Due to the multitude of factors that influence the radon concentration in dwellings, it is very difficult to determine the representative value of radon concentration. That is why the radon concentration is evaluated through the annual average of the concentration, eliminating the daily and seasonal fluctuations. For the calculation of the annual radon concentration in closed spaces calculation formulae are used [82].

$$C_{Rn\ annual}=0{,}75\cdot C_{Rn\ winter} \qquad (2)$$

where:

$C_{Rn\ annual}$- anual radon concentration (Bq/m$^3$)

$C_{Rn\ winter}$- radon concentration measured in winter season (Bq/m$^3$)

$$C_{Rn\ annual}=1{,}5 \cdot C_{Rn\ summer} \qquad (3)$$

where:

$C_{Rn\ annual}$- anual radon concentration ($Bq/m^3$)

$C_{Rn\ summer}$- radon concentration in summer season ($Bq/m^3$)

In closed spaces, residential or public, it is advisable to use solid state track detectors for the measurement of radon concentration.

The selection of locations for the radon measuring will take into account the geographical and geological factors.

In the study of radon in dwellings and public institutions, the areas of interests have been chosen so that the study covers both plain (Satu Mare, Galați, Bucharest), and hilly areas (Alba, Cluj, Bistrița, Mureș, Sibiu), respectively areas with mountains (Bihor, Gorj, Prahova, Covasna, Harghita).

Figure 12 presents the map of Romania with the studied areas.

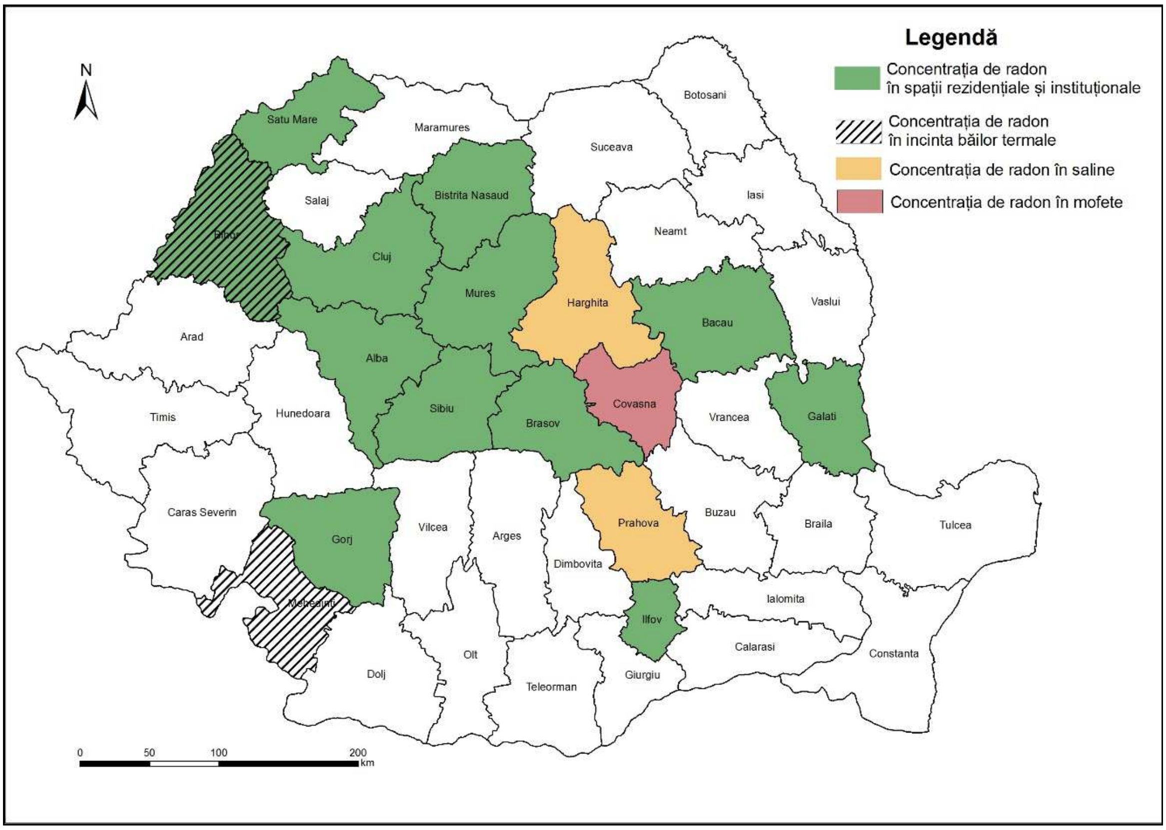


**Figure 11.:** The map of Romania with the studied areas

In this study we have measured the radon concentration in 15 counties of Romania, in dwellings, schools, mofettes, thermal spas, salt mines (**Alba county**-houses, **Bacău county**-schools, **Bihor county**-houses and thermal spas, **Bistrița Năsăud county**-houses, **Brașov county**-houses, **Bucharest**-houses, **Cluj county**-houses and schools, **Covasna county**-mofettes, **Galați county**-houses, **Gorj county**-houses, **Mehedinți** county **–** thermal spas and mines, **Mureș county**-mine, **Satu-Mare county**-schools, **Sibiu county**-houses and schools, **Prahova county**-mine).

For the measuring of indoor radon we have used solid state track detectors CR-39, exposed for periods of 2-3 months. The method of track detectors represents a convenient solution which allows the supervision of radon for a long period in residential and institutional areas.

This method has been validated by the National Radiological Protection Board (NRPB) and by the American agency EPA [83, 84].

According to the NRPB measurement protocol, the detectors have been placed in the populated areas of the houses, such as bedrooms and living rooms, on a height of 1-1.5 m from the ground, in order to detect the indoor radon concentration. The investigated houses have only one stored.

The developing in the laboratory and the automatic reading of the registered tracks has been carried out with the equipment RadoSys-2000 (Elektronika, Budapest, Hungary), under optimal conditions.

The exposure data resulted directly from the measurements have been corrected by applying the seasonal corrections, thus obtaining the annual average values of the activity concentrations of radon. [82]

In order to check the behavior of the solid state track detectors, they have been placed in other locations as well, different from the dwellings, in thermal spas, salt mines, respectively mofettes.

The results obtained in this study are presented in the subchapters below.

## Measuring the radon concentration in dwellings

After analyzing the results obtained following the studies carried out, it can be specified the fact that the use of track detectors is relatively easy for the measuring of radon concentration in closed spaces, both in dwellings and in educational institutions. Their advantage is that they can be used for simultaneous measurements.

From the results obtained it was possible to specify the most frequent concentration in the studied areas, taking into account the fact that areas having different geological and geographical forms have been chosen, with a variety of houses constructed.

In order to determine the radon concentrations in dwellings and public institutions 906 detectors of type CR-39 have been placed.

In table 8 and figure 12 the values of radon concentrations are presented, measured with track detectors CR-39 in indoor spaces in Romania.

**Tabel 4.:** Radon concentration in the studies area

| **Frecvency** | **Alba** | **Bacău** | **Bihor** | **Bistrița** | **Brașov** | **București** | **Cluj** | **Galați** | **Gorj** | **Satu Mare** | **Sibiu** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-40 | 1 | 1 | 52 | 28 | 5 | 3 | 44 | 0 | 9 | 0 | 11 |
| 41-80 | 2 | 5 | 66 | 44 | 33 | 8 | 68 | 4 | 6 | 0 | 19 |
| 81-120 | 3 | 3 | 47 | 24 | 34 | 4 | 34 | 2 | 2 | 5 | 6 |
| 121-160 | 4 | 2 | 30 | 9 | 27 | 1 | 16 | 4 | 2 | 9 | 2 |
| 161-200 | 2 | 2 | 12 | 8 | 21 | 0 | 9 | 0 | 2 | 1 | 3 |
| 201-240 | 1 | 2 | 12 | 5 | 16 | 1 | 10 | 1 | 0 | | 4 |
| 241-280 | 2 | | 6 | 0 | 14 | 2 | 3 | | 1 | | |
| 281-300 | 1 | | 7 | 1 | 6 | 1 | 9 | | 1 | | |
| >300 | 1 | | 18 | 2 | 30 | | 9 | | 1 | | |

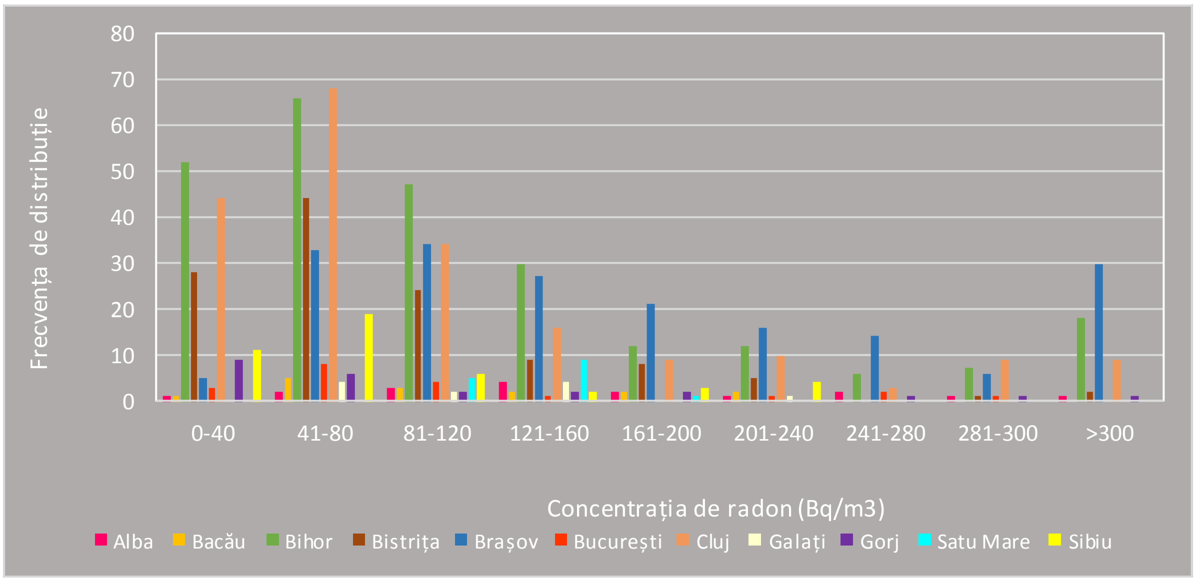


**Figure 12.:** Radon concentration distribution in the studied area

In the 906 measurements in the areas studied in 17% the radon concentrations were <40Bq/m$^3$, 28% fell into the range 41-80Bq/m$^3$, 18% were between 81-120Bq/m$^3$. The maximal annual values have been registered in Bihor County, the locality of Ștei (1604Bq/m$^3$) and in the county of Cluj, the locality of (1127Bq/m$^3$).

The European Commission recommends the value 300Bq/m$^3$ [28] as the maximum allowed activity for residential radon. According to the results obtained in only 86 cases of all, approximately 9,5% of the examined dwellings have concentrations higher than these values, being required the application of some reparation techniques.

It has been proved that the vibrations resulting from the intense traffic have emphasized the accumulation of approximately 50% more radon compared to the radon concentration measured in an area with less traffic. In order to be able to demonstrate this, we have placed detectors in dwellings situated exactly next to roads with intense traffic (the international road E81) or with less traffic (the locality of Unirea, the county of Alba).

If a road is very busy, it is obvious that the vibrations will contribute both to the acceleration of diffusion through the pores, and to the transport through cracks and holes. This fact can lead to the more emphasized accumulation of radon in dwellings situated exactly next to the road. Figure 13 presents the measuring points.

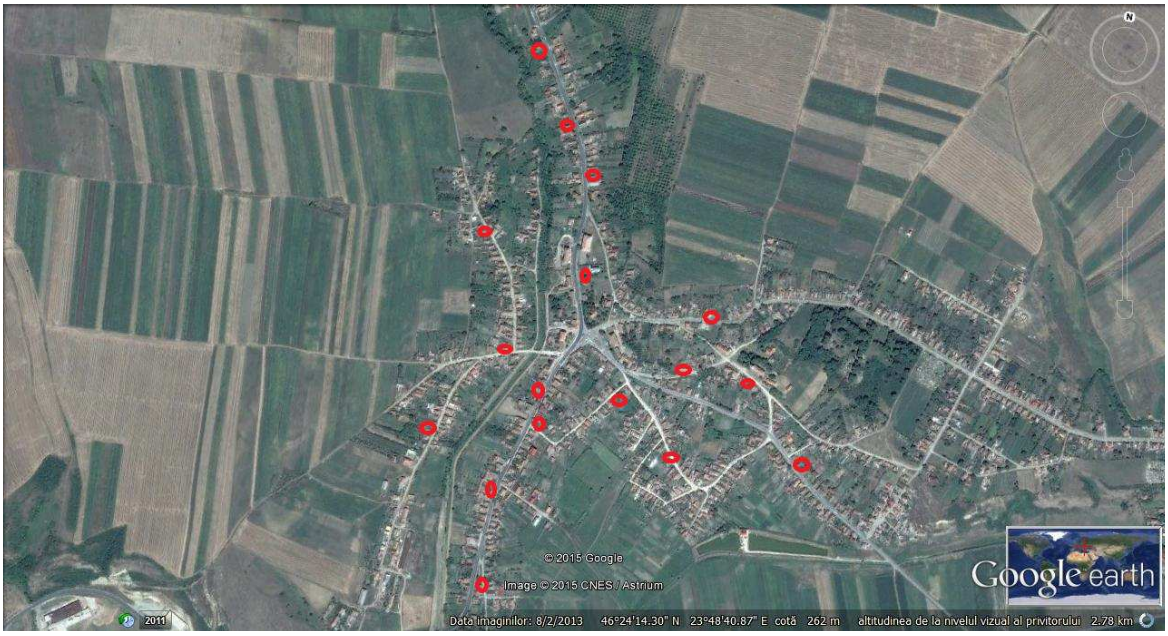


**Figura 13.:** Map with the measured points in Unirea, county of Alba

The values obtained in dwellings in the period May-June and October-December in the locality of Unirea, county of Alba are presented in table 5, respectively figure 14.

**Tabel. 4.:** The radon concentration measured in homes, Unirea, County of Alba

| **Nr.** | **Detector cod** | **ρ [track/mm$^2$]** | **$C_{Rn}$ [Bq/m$^3$]** | **$C_{anual}$ [Bq/m$^3$]** | **Studies areas** |
|---|---|---|---|---|---|
| 1 | D38504 | 5.62915 | 178 | **267** | **intense traffic** |
| 2 | D38530 | 5.54368 | 182 | **273** | |
| 3 | D38528 | 6.37701 | 202 | **303** | |
| 4 | 218679 | 15.2054 | 297 | **223** | |
| 5 | 218519 | 8.22173 | 148 | **111** | |
| 6 | 216614 | 19.5194 | 385 | **289** | |
| 7 | 218632 | 12.0328 | 229 | **172** | |
| 8 | 218769 | 11.4524 | 217 | **163** | |
| 9 | D38532 | 0.77872 | 25 | **38** | **less traffic** |
| 10 | D38506 | 1.35565 | 43 | **65** | |
| 11 | D38531 | 2.93684 | 93 | **140** | |
| 12 | 218205 | 7.31251 | 125 | **94** | |
| 13 | 218641 | 9.07293 | 169 | **127** | |
| 14 | D38527 | 2.93684 | 93 | **140** | |
| 15 | D38510 | 2.6377 | 84 | **126** | |
| 16 | D38507 | 2.10351 | 67 | **101** | |

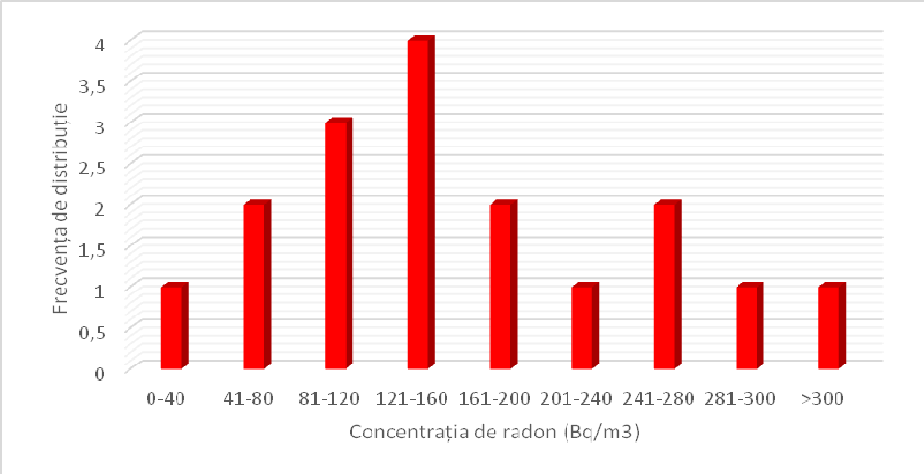


**Figure 14.:** Radon concentration distribution in Unirea, County of Alba

From the data obtained it results that $C_{Rnmin}$=38Bq/m$^3$, $C_{Rnmax}$=303Bq/m$^3$, <$C_{Rn\ anual}$>=165Bq/m$^3$, the geometric average being 144Bq/m$^3$ and the median 140.

The most frequent concentration is situated in the range between 121-160Bq/m$^3$ in 23,52% of the cases. Then follows a percent of 18,75% in the range between 81-120Bq/m$^3$. The ranges 41-80 Bq/m$^3$, 161-200 Bq/m$^3$ and 241-280 Bq/m$^3$ appear in 12,5% of the cases. Values above the maximum concentration allowed by the EU, that of 300Bq/m$^3$ [28], have been found in 6,25% of the cases. The annual average of radon concentration in the area of very busy streets has been of 225Bq/m$^3$, and that for isolated areas of 104Bq/m$^3$. It has been proved that the vibrations resulting from intense traffic emphasized the accumulation of radon with approximately 50% more compared to the radon concentration measured in isolated areas.

The measurements carried out in the area of Ștei, the county of Bihor, respectively Cluj-Napoca, the county of Cluj have demonstrated the contribution of construction materials in the accumulation of indoor radon concentration. The results are presented as follows:

**Measuring radon in the houses of Ștei, the county of Bihor**

The locality of Ștei and the studied area is situated in the county of Bihor, on the banks of Crișul Băița. Figure 15 presents the map of the respective area with the localities where the radon concentration has been measured. In the valley of Crișul Negru, at approximately 25 km from the town of Ștei, a large uranium deposit was discovered in 1949, in Băița, the county of Bihor. It was considered the largest uranium deposit of the country. In this place uranium was exploited in the period between 1950-2000.

The uranium mine is situated uphill the village Băița, this being the nearest populated area. In some villages like Băița Plai, Nucet, respectively the town of Ștei there are dumps resulted from the mine. Some dumps contain uranium waste.

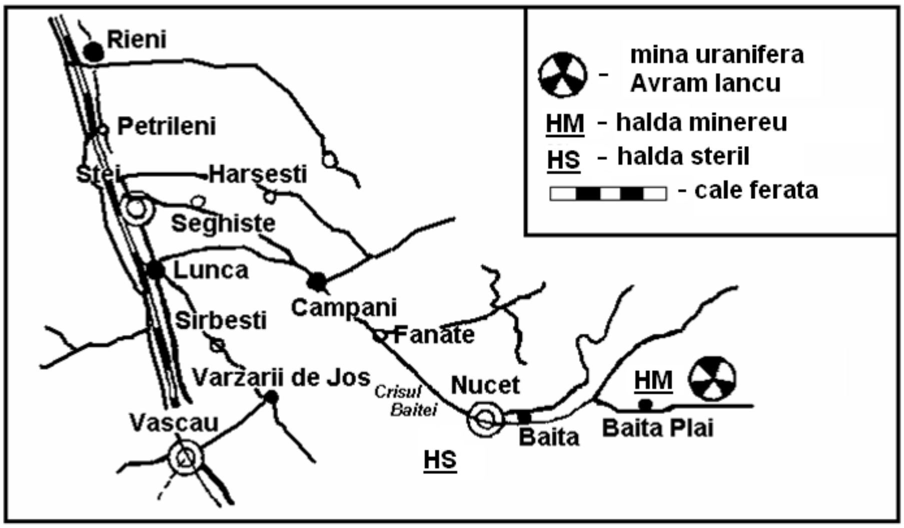


**Figure 15.:** Map of Stei area, County of Bihor

Along with the development of this area new houses appeared, built also from materials from the waste dumps containing uranium. An auxiliary factor is represented by the use of construction materials coming from the riverbed of Crișul Băița: foundation stone, gravel, sand. In these dwellings not only the soil beneath the house influences the radon concentration, but in a great measure also the construction materials used.

The measurements started in 2003-2004. In winter time, during 4 months, in the first phase 24 detectors were placed in 8 localities in the area Ștei-Băița.

In the campaign 2003-2004 dwellings were chosen, of which it was known from previous measurings that they had large radon concentrations. [86]. Some of the studied buildings had been constructed with waste from the Băița mine.

In the campaign 2006-2007 the studied area was extended. The measurements were carried out not only in the dwellings constructed with waste from the Băița mine, but also in those made of brick. The minimum radon concentration was 11Bq/m$^3$, and the maximum 1604Bq/m$^3$.

**Tabel 5.:** Indoor radon concentration measured in Ștei-Băița area, county of Bihor

| Periode | $C_{Rnmin\cdot}$ (Bq/m$^3$) | $C_{Rnmax\cdot}$ (Bq/m$^3$) | $<C>_{anual}$ (Bq/m$^3$) | GEOMEAN (Bq/m$^3$) | MEDIAN |
|---|---|---|---|---|---|
| 2003-2004 (24 measurements) | 92 | 1988 | 410 | 277 | 228 |
| 2006-2007 (255 measurements) | 11 | 1604 | 150 | 93 | 89 |
| **Total (279 measurements)** | **11** | **1988** | **172** | **135** | **95** |

The difference between $C_{Rn\ anual}$=410Bq/m$^3$, respectively the geometric average of 277Bq/m$^3$ (campaign 2003-2004) and that of $C_{Rn\ anual}$ 150Bq/m$^3$, respectively the geometric average of 93Bq/m$^3$ (campaign 2006-2007) is due to the fact that in the first campaign there had been selected only houses built with waste from the Băița mine, and in the second campaign there were chosen also houses made only of brick.

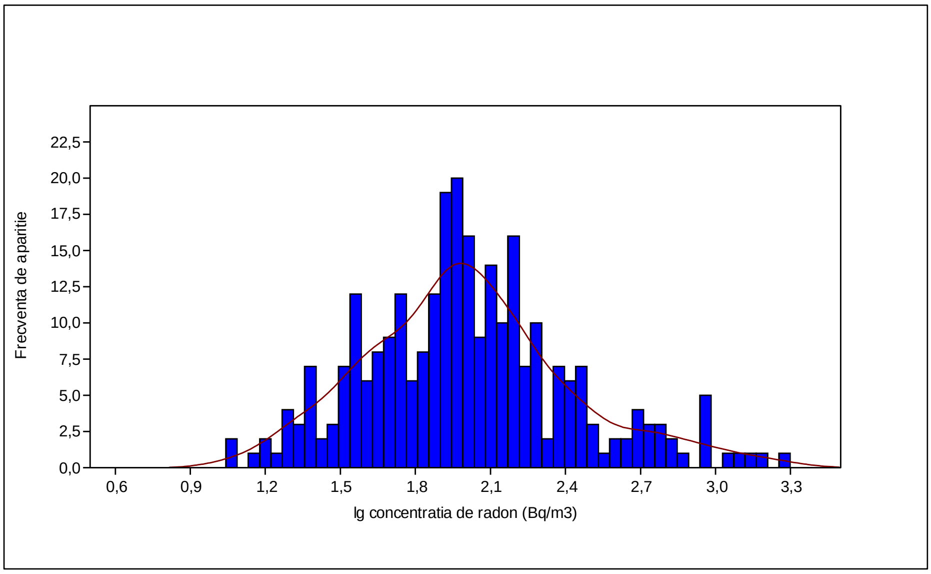


**Figure 18.:** Lognormal distribution for indoor radon concentration in Ștei-Băița area, county of Bihor

For the area Ștei-Băița, from the data held, it results a double lognormal distribution, with two maximums. The first maximum is characteristic for the brick houses, the second maximum for the dwellings built from materials with a large content of radioactive mineral.

## Radon measurements in Cluj-Napoca, the county of Cluj

In order to determine the radon concentration in the air of closed spaces, track detectors CR-39 were placed in dwellings in Cluj-Napoca, 86 houses, respectively 34 blocks of flats. The studied area was divided into neighbourhoods (figure 19). In this study the detectors were exposed during 200-210 days in the months June 2007 – January 2008.

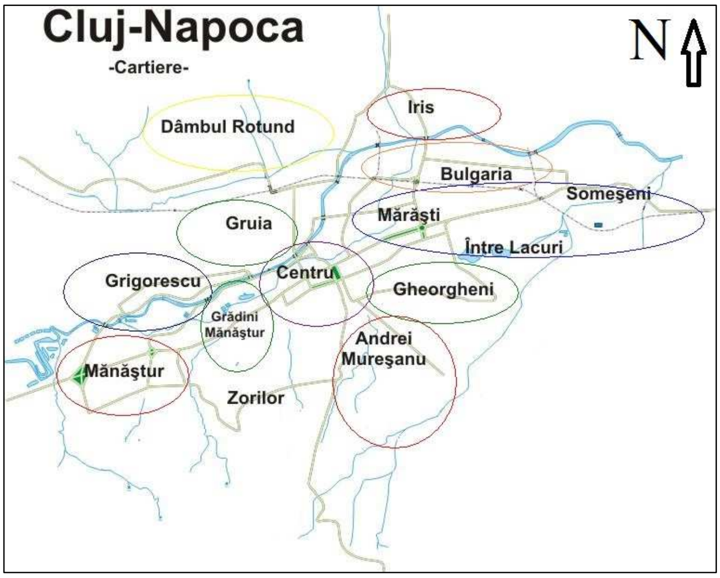


**Figure 19.** The studied areas in Cluj-Napoca, county of Cluj

When choosing the dwellings, the materials used during construction were taken into account. The materials used for the construction of the houses and of the blocks are presented in figure 20.

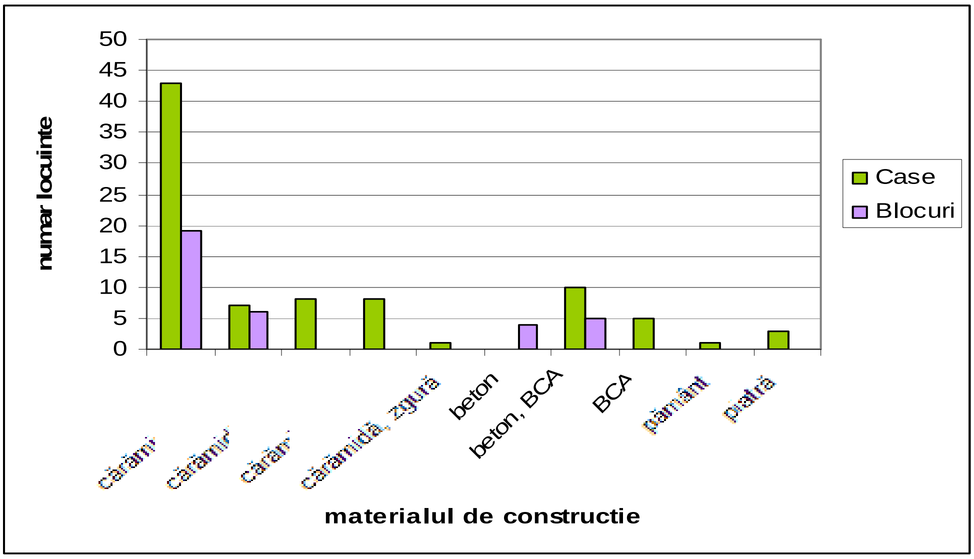


**Figure 20.:** The materials used for the construction of the houses and of the blocks

The most frequent material used both for houses, and for blocks of flats was brick, followed by the combination concrete-BCA. The combinations brick-stone, brick-BCA, respectively BCA and stone were used only for the houses. The blocks of flats were constructed only of brick, concrete or their combination.

From the 86 houses studied, 50% (43 houses) were made of brick, 1.16% (1 house) of dirt, 3.5% (3 houses) of stone, 9.3% (8 houses) of the combination brick+BCA, 8.14% (7 houses) brick-concrete. The combination brick+stone was used in 10.5% (9 houses) of the cases and 17.44% (15 houses) were made of concrete+BCA.

The radon concentrations separated for construction materials are presented in the table below:

**Tabel 6.:** Radon concentration in function of construction material

| **Construction material** | **Nr. houses** | $C_{Rnmin\ anual}$ **[Bq/m$^3$]** | $C_{Rnmax\ anual}$ **[Bq/m$^3$]** | $\langle C_{Rn\ anual} \rangle$ **[Bq/m$^3$]** |
|---|---|---|---|---|
| brick | 43 | 17 | 1119 | 181 |
| dirt | 1 | 345 | 345 | 345 |
| stone | 3 | 47 | 423 | 203 |
| brick+stone | 9 | 41 | 1127 | 345 |
| brick+concrete | 7 | 15 | 144 | 100 |
| brick+BCA | 8 | 72 | 227 | 124 |
| concrete+BCA | 15 | 35 | 497 | 125 |

The highest concentrations have been measured in the houses made of brick (1119Bq/m$^3$) and the combination brick+stone (11127Bq/m$^3$). The lowest values have been measured in houses made of brick (17Bq/m3), respectively the combination brick+concrete (15Bq/m$^3$). The two highest concentrations have been measured in houses from neighbourhoods situated next to each other (Bulgaria and Mărăşti).

The most frequently seen radon concentration falls into the range 41-80Bq/m$^3$, that is in 26.8% of the cases, 12.8% between 0-40Bq/m$^3$, 20% above 81-120Bq/m$^3$. In a percent of 9.3% there were concentrations between 121-160Bq/m$^3$, 4.6% for 161-200Bq/m$^3$, respectively for the range 201-240Bq/m$^3$. Only 17.4% of the cases exceeded the concentration higher than 300Bq/m$^3$, the maximum allowed by the EU [28].

Knowing that the most important source of indoor radon is the soil, the study has analyzed the way in which the concentration of this gas varies with the increase of the level. In this sense track detectors CR-39 have been placed in 34 blocks of flats in several neighbourhoods of Cluj-Napoca. In each construction the following exposure procedure has been used: in each block of flats, in the same entrance, on the same column, one detector has been placed, one meter above the ground level, on three different levels (on the ground floor, $1^{st}$ floor and $3^{rd}$ floor).

In figure 21 one can observe the fluctuation of radon upright. In all the 34 blocks of flats the radon concentration decreases with altitude, confirming the theory from the specialized literature.

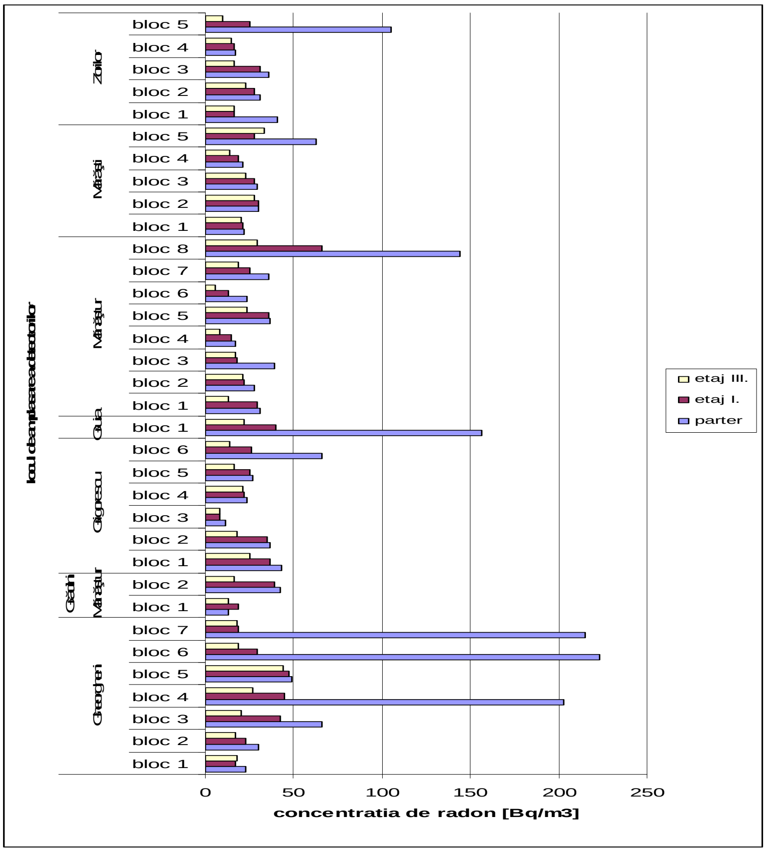


**Figura 21.:** the radon concentration decreases with altitude

Table 7 presents the average radon concentration on levels, depending on the construction material used.

**Tabel 7.:** Radon concentration measured on levels in function of construction material used

| **Level** | **$\langle C_{Rnanual} \rangle$ brick [Bq/m$^3$]** | **$\langle C_{Rnanual} \rangle$ concrete [Bq/m$^3$]** | **$\langle C_{Rn} \rangle$brick/$\langle C_{Rn} \rangle$concrete** |
|---|---|---|---|
| parter | 82 | 105 | 0,8 |
| etaj I. | 40 | 48 | 0,8 |
| etaj III. | 28 | 31 | 0,9 |

One can notice a liniar decrease, depending on the level, both in the case of blocks of flats made of brick, and of those made of concrete. The radon concentration decreases approximately 50% on a level. There is no significant difference in radon concentration regarding the construction material (table 7).

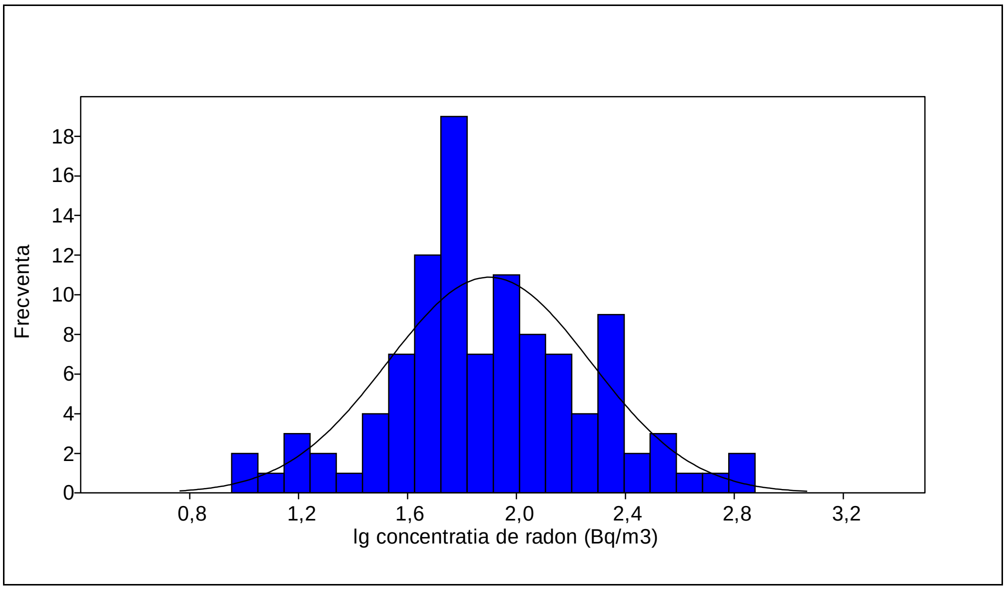


**Figure 22.:** Logaritmic distribution in county of Cluj

Figure 22 demonstrates that the radon concentration shows a lognormal distribution. The most frequent concentrations fell into the range between 41-80Bq/m$^3$. These values correspond to those measured in Transylvania [82], [87-90].

## The measuring of radon concentration in schools and kindergardens

In the last years, the problem of environment quality regarding closed spaces (offices, dwellings, schools) has become extremely important, as it can harm our health. Children, teenagers are the most affected by these pollution factors [7], [9].

Knowing this, the aim of the study was the measuring of radon concentration in schools in four counties: Bacău (the town of Onești), Cluj (the city of Cluj-Napoca), Satu Mare (the city of Satu Mare) and Sibiu (the town of Agnita).

The measuring points, in all the cases, have been selected so that schools be in different areas (for example in the centre and in the outskirts of the city). It has been taken into account the distance from busy areas. During the measurings the researchers took into account: location and ventilation of the classrooms, etc.

**Onești, the county of Bacău**

The radon concentration was measured in 15 schools and kindergardens in the town. The duration of measurements was one month in the spring.

As an average of these concentration, the value of ***84 Bq/m$^3$*** was obtained, and for the annual one ***119Bq/m$^3$***. $C_{Rnmin}$=29Bq/m$^3$, $C_{Rnmax}$=237Bq/m$^3$, the geometric average was 103Bq/m$^3$ and the median 116.

The distribution of values is presented in figure 27.

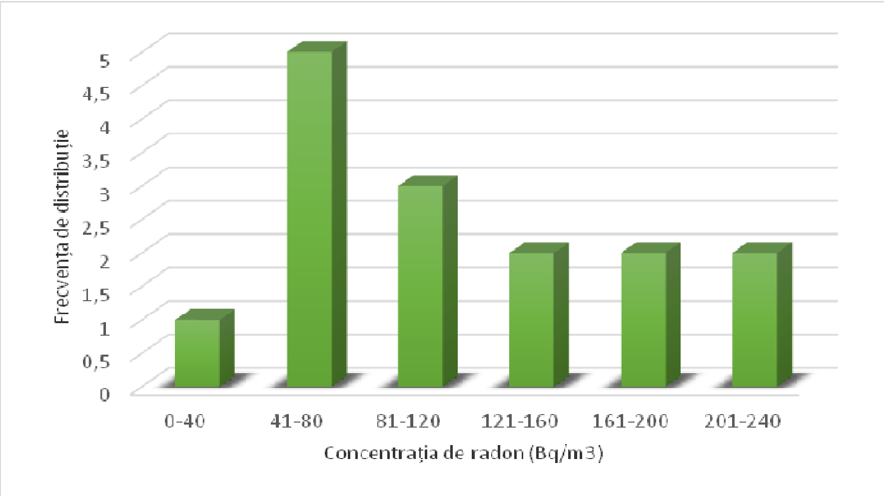


**Figure 23.:** Radon concentration distribution measured in schools of Onești, county of Bacău

The data obtained show that mostly, in 33.33% of the cases, the radon concentration falls into the range 41-80Bq/m$^3$, 20% falls into the range 81-120Bq/m$^3$. In a percent of 13.33% each, the concentration has been between 121-160Bq/m$^3$, 161-200Bq/m$^3$ and 201-240Bq/m$^3$.

Following the processing of data, there were no values higher than the maximum concentration allowed by the EU [28].

For 26.66% of the cases, where the values have been in the range 161-240Bq/m$^3$, it has been proposed to the management of the institution the as frequent as possible ventilation of the classrooms as a method for reducing radon.

**Cluj-Napoca, the county of Cluj**

According to the location choosing protocol, in the city of Cluj-Napoca from the 100 functional schools, a number of 62 have been subjected to the radon measuring campaign. The exposure time has been 35 days during spring.

As an average of these concentrations, for the annual value the average radon concentration of ***133Bq/m³*** has been obtained. $C_{Rnmin}$=23Bq/m$^3$, $C_{Rnmax}$=690Bq/m$^3$, the geometric average has been 95Bq/m$^3$ and the median 83.

From the data obtained it resulted that in 16.13% of the cases the radon concentration was lower than 40Bq/m$^3$, 33.9% corresponded to the range 41-80Bq/m$^3$, 12.9% to the range 81-120Bq/m$^3$, 9.67% for the concentrations between 121-160Bq/m$^3$, 8% for those between 161-200Bq/m$^3$, 4.8% for 201-240Bq/m$^3$, 3.2% for 241-280Bq/m$^3$. In only 11.3% the concentration in the classrooms exceeded the value allowed by the EU, that of 300Bq/m$^3$ [28].

In 22 schools of the 62 examined the natural ventilation has been very intense, because the windows and doors could not be closed properly. The fact that the classrooms in the schools built between the years 1970-1990 have a wall with windows on 80% of it, constituted a problem when analyzing radon. This has been demonstrated following the results obtained. In these schools the radon concentration fell into the range 30-75Bq/m$^3$.

The concentrations higher than those admitted by the law were measured in the institutions situated in the same areas as the dwellings analyzed in Cluj-Napoca.

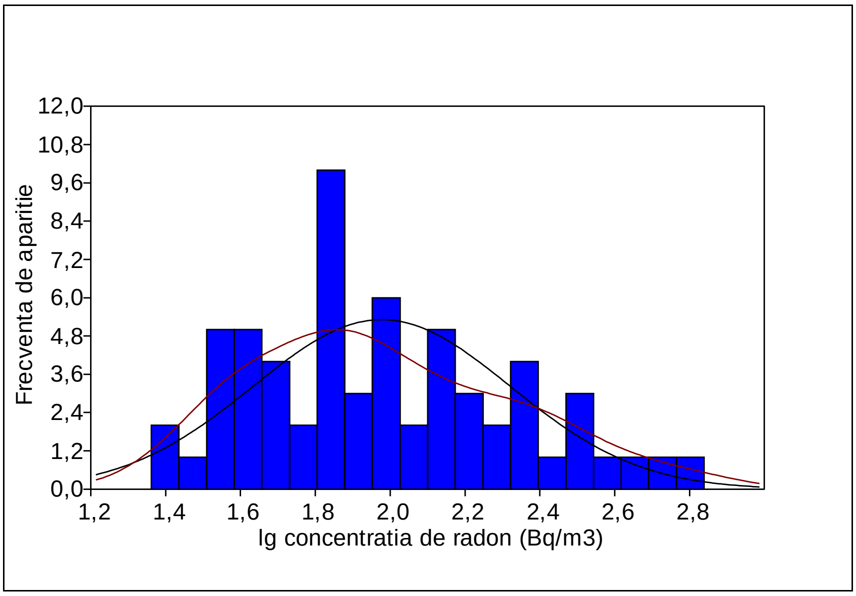


**Figure 28.:** the logarithmic distribution of the radon concentration measured in schools of Cluj-Napoca, the county of Cluj.

Figure 28 presents the logarithmic distribution of the radon concentration measured in schools of Cluj-Napoca, the county of Cluj. The results have a lognormal distribution.

The radon concentrations in schools fall into the concentration ranges measured in the dwellings in Cluj-Napoca. The values come under taking into account the area of the location as well (neighbourhood, street).

**Radon measurements in schools of Satu Mare**

In the campaign of measures of radon concentration in schools the town Satu Mare also participate. In the 15 schools from town they put detectors of traces CR-39 in classrooms located at the ground floor of buildings. The campaign was carried out in the spring 2009.

The annual minimal concentration was $C_{Rnmin}$=85Bq/$m^3$, $C_{Rnmax}$=167Bq/$m^3$. $\langle C_{Rn\ anual} \rangle$=126Bq/$m^3$, the geometrical mean was 125Bq/$m^3$, and the median was 125.

The most frequently appeared radon concentration was 121-160Bq/$m^3$ in 53,33% of cases followed by the interval 81-120Bq/$m^3$ in proportion of 33,33%. Radon concentration did not exceed the maximum value allowed by the law.. [28]. in any of the schools.

In all the cases the school walls did not have cracks, the windows and doors of studied classrooms were adequate. They could be the cause of low natural ventilation.

Radon concentration measured in 15 institutions did not have high deviation, as it results from the median value 125.

**Agnita, Sibiu county**

In the town of Agnita, Sibiu county there were two campaigns for measurement of radon in closed spaces (houses, schools and kindergartens). In case of houses we had 20 measurements, in case of schools we had 25. The results were presented in table 47 (for houses), respectively table 54 (for schools and kindergartens).

From the results obtained we calculated the situation regarding the distribution of radon concentration in the studied area. (figure 29).

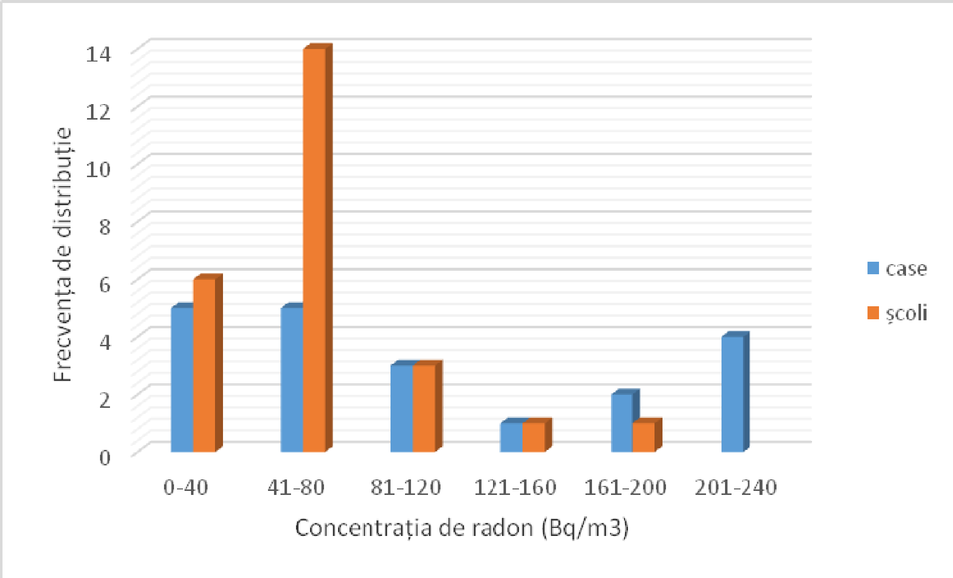


**Figure 29.:** the distribution of radon concentration in Agnita, county of Sibiu

Radon concentration in both cases in the largest percentage was in interval 41-80Bq/m$^3$. It was not a significant difference for intervals 0-40Bq/m$^3$, 81-120Bq/m$^3$ and 121-160Bq/m$^3$. The high concentration in interval 201-240Bq/m$^3$ appeared only for houses.

The lower values measured in schools and kindergartens, compared to the houses, are due to natural ventilation. In the campaign period some institutions had cracks on the wall, the windows and doors were old, did not close well. They were responsible for the natural ventilation of classrooms.

In case of houses no such problems appeared, the natural ventilation was not able to hept decrease the radon concentration inside.

In the study of radon concentration measurement indoors with trace detectors CR-39 balneary resorts were included.

Many specialized studies proved that radon could have also therapeutic effect, if it is maintained in certain limits. [92-94].

### *Radon measurements in mofettes*

Volcanic areas are rich in gas emanations largely composed of $CO_2$. Depending on these gases through what layers they cross to the surface dry emanations may appear, the mofettes. The gas across the ascending path may “collect” different isotopes of radon ($^{222}$Rn, $^{220}$Rn). Thus, the gases from mofettes can contain substantial quantities of radon. [95-96].

Mofettes were and are still used empirically in the treatment of various diseases. Nowadays they are used as dry $CO_2$ baths in the treatment of several diseases such as: dysfunctions of cardiovascular system, hypertension, rickets, and gynaecological problems.

In order to study radon concentration in mofettes, we chose the most frequently used by patients as follows: Bene mofette of Covasna, Banu mofette of Covasna, the mofette from the precincts of Cardiological Hospital Covasna, Băile Tușnad mofette and the mofette from the precincts of Hotel Balvanyos.

**Tabel 8.:** Radon concentration in mofettes, in countys Harghita and Covasna

| **Detector** | **$C_{Rn}$ [Bq/m$^3$]** | **Locul de măsurare** |
|---|---|---|
| B71011 | 2181 | Mofeta ***Bene,*** Covasna, |
| B71084 | 4574 | Mofeta ***Bene***, Covasna, |
| B71036 | 982 | Mofeta ***Baile Tusnad*** |
| B71030 | 61 | Mofeta ***Banu***, Covasna, |
| B71038 | 592 | **Hospital Covasna**, *mofeta* |
| B71040 | 90 | Mofeta ***Hotel-Balvanyos*** |

Based on radon concentrations measured in mofettes we calculated the effective dose received by patients across a treatment, 5h.

The effective radiation dose received by inhalation of radon and its descendants was calculated by the formula:

$$\mathbf{E_{Rn}=C_{Rn}\cdot K\cdot F\cdot t} \quad (39)$$

where:

$E_{Rn}$-effective dose (Sv)

$C_{Rn}$- measured radon concentration (Bq/m3)

K-conversion factor (9nSv considered by ICRP; 12nSv considered by UNSCEAR)

F-equilibrum factor (0,4)

t- treatment time

The results obtained are presented in table 9.

**Tabel 9.:** Effective dose received by pacients in the mofettes

| Place | $t_{expunere}$ [h] | $C_{Rn}$ [Bq/m$^3$] | $E_{Rn}$ [Sv] |
|---|---|---|---|
| Mofeta ***Bene*** | 5 | 2181 | 0,0392 (ICRP) |
| | | | 0,0523 (UNSCEAR) |
| Mofeta ***Baile Tusnad*** | 5 | 982 | 0,0177(ICRP) |
| | | | 0,0236 (UNSCEAR) |
| Mofeta ***Banu***, | 5 | 61 | 0,0011 (ICRP) |
| | | | 0,0015 (UNSCEAR) |
| **Hospital Covasna,** mofetă | 5 | 592 | 0,011 (ICRP) |
| | | | 0,014 (UNSCEAR) |
| Mofeta ***Hotel-Balvanyos*** | 5 | 90 | 0,0016 (ICRP) |
| | | | 0,0022 (UNSCEAR) |

High concentrations obtained in mofettes used as treatment base do not have harmful effect on patients because the treatment session does not exceed 10-15minutes/day.
These results are in agreement with the already published results.[95].

**Measurement of radon in thermal baths**

If the gases coming from the basement in their path meet the phreatic water mineral waters or thermal waters appear. Thus radon reaches the air of treatment rooms.

For this study we chose Băile Herculane from Mehedinți county respectively Băile Felix and Băile 1 Mai from Bihor county.

In both cases we used detectors of traces CR-39, which were exposed to 1-1,5m of soil in treatment bases.

**Băile Herculane**

**Tabel 10.:** Radon concentration in Băile Herculane, county of Mehedinți

| Detector | $\rho_{urme}$ [urme/mm$^2$] | $C_{Rn}$ [Bq/m$^3$] | $C_{Rn\ anual}$ [Bq/m$^3$] | Locul expunerii |
|---|---|---|---|---|
| H40885 | 11,5633 | 262 | 393 | Bază tratament 1 |
| H40886 | 14,8433 | 336 | 504 | piscină |
| H40874 | 5,6659 | 98 | 147 | Bază tratament 2 |
| H40881 | 2,6424 | 46 | 69 | Bază tratament bazin sulf |

Radon concentrations vary between 69Bq/m$^3$ and 504Bq/m$^3$. These values are high both for patients and for employees who stay for 8h/day in that room. By studying the distribution frequency, in 50% of cases the concentrations exceed the maximum value allowed by the law, 300Bq/m$^3$. [28]

**Băile Felix-1 Mai**

**Tabel 11.:** Radon concentration in Băile Felix, county of Bihor

| Detector | $\rho_{urme}$ [urme/mm$^2$] | $C_{Rn}$ [Bq/m$^3$] | $C_{Rn\ anual}$ [Bq/m$^3$] | Locul expunerii |
|---|---|---|---|---|
| H40871 | 1,1834 | 26 | 39 | Felix, sala tratament 1. |
| H40873 | 1,7415 | 39 | 59 | Felix, Sala duș subacvatic |
| H40880 | 1,3995 | 31 | 47 | Felix, birou |
| H40883 | 1,1941 | 27 | 41 | Felix, chiosc alimentar |

**Tabel 12.:** Radon concentration in Băile 1 Mai, county of Bihor

| Detector | $\rho_{urme}$ [urme/mm$^2$] | $C_{Rn}$ [Bq/m$^3$] | $C_{Rn\ anual}$ [Bq/m$^3$] | Locul expunerii |
|---|---|---|---|---|
| H40875 | 1,0363 | 23 | 35 | 1 Mai, sala bazin mare 1 |
| H40877 | 7,1831 | 159 | 239 | 1 Mai, sala bazin mare 2 |
| H40882 | 3,5078 | 78 | 117 | 1 Mai, sala bazin mic |

In thermal baths from Bihor county, Felix and 1 Mai, the results obtained do not exceed the maximum concentration allowed for workplaces. [28].

**Radon in salt mine**

In this study we chose two salt pits frequently used by population, the salt pit of Slănic Prahova from Prahova county, respectively the salt pit Praid, Harghita county.

**Tabel 13.:** Radon concentration in Unirea mine, Slănic Prahova, county of Prahova

| Nr | Detector | $\langle\rho_{cor}\rangle$ [urme/mm$^2$] | $C_{Rn}$ [Bq/m$^3$] | $C_{Rn\ anual}$ [Bq/m$^3$] |
|---|---|---|---|---|
| 1 | K61619 | 0.5605 | 7 | 11 |
| 2 | K61622 | 0.4125 | 5 | 8 |
| 3 | K61624 | 0.363 | 5 | 8 |

Because the salt is not radioactive and the thick layer insulates well the inside from the contribution of neighbouring rocks, the radon concentration measured was very low, almost as was the bottom of detector.

In Praid mine, radon concentration showed very stable values close to the concentration of air from outside, this salt pit was in direct connection with the outside $\langle C_{Rn}\rangle_{salina}$=16Bq/m$^3$.

The values are much below the values found in caves and other mines. Because the measured concentrations are very low, it results that in the salt block there are no cracks where radon could enter from the surrounding rocks of salt ore.

# CHAPTER VII.
# CONCLUSIONS

The presence of radium in earth's surface determines the release of radon in atmosphere. Inside the buildings radon concentration is higher compared to radon concentration in atmosphere because of its accumulation in closed spaces. The accumulations of radon in inhabitable spaces depend directly on the soil structure on which that space is located and the composition of construction materials.

In the work we applied the method of trace detectors CR-39 respectively studied the efficiency of radon measurements in houses and public institutions by using the method mentioned above.

For detection of radon in closed spaces we used the method of detectors of solid body traces type CR-39. This method represents a convenient solution which allows the long-term supervision of radon inside the buildings.

The detector method CR-39 is a cheap method compared to the other radon measurement methods, and has more advantages among which we mention: the detector can be easily mounted in the box, because it has small sizes and it is a simple localization in the studied place. The greatest advantage is that simultaneously we can measure radon concentrations in several measurement points. This is favourable if we make measurements in a town or in an area of interest.

One of the objectives of the work was the application and improvement of trace detectors method CR-39 for radon measurements.

We determined experimentally the optimal time necessary for the chemical treatment of trace detectors CR-39. The optimal time for development was demonstrated 4.5h. to know the exact development time is very important, because it is involved in the calibration constant given by the manufacturer. It was proven that if the development time is higher than 4.5h, the existing traces increase, which decreases the resolution of detector. This is essential if we develop detectors with vary large densities of traces.

We experimentally demonstrated the good positioning of trace detectors during exposure. It was proven that the difference appears when the detector box is or is not properly closed. If the box is tight, radon concentration was lower by 1.26 times. The difference is because the box is not well closed, radon descendants may penetrate. Depending on the positioning of the box in which the detectors were stuck, no significant difference of radon concentration appeared. In case of tight boxes, the difference between normal/capsized was 0.91.

We checked by experiment the possibility of reusing the detector boxes already exposed. The detectors from the used boxes showed a higher concentration above 1,17 than the cases when they were placed in unused boxes.

We checked the dependence of trace density of developed detectors depending on the storage time, which is the time elapsed between the development time and the reading time. It was proven that there is a connection between the development time and the storage time of detectors. By many experiments of comparison of trace detector method CR-39 with other measurement methods used in the measurement of indoor radon, we checked the correct functioning of the reading machine from the research laboratory. The measurements were made with several special devices from the laboratory equipment (Alphaguard, Radim, Luk 3A, Ramon, Charcoal). The standard deviation was between the interval 6-12%, accepted for radon measurements in international comparison exercises.

In many intercomparison experiments with several laboratories (IFIN-HH, Bucharest, Romania; Pannon University, Veszprem, Hungary; Institute of Radiological Sciences din Chiba, Japan) we aimed at perfection of trace detector method CR-39, for the purpose of reducing the measurement errors.

The conclusions resulted from the effective measurements in the thesis (houses, schools, kindergartens, balneary resorts) in 15 counties of the country, total 906 measurements are as follows:

The values of radon concentration varied from 9 Bq/m$^3$ for a house located in Huedin, Cluj county to 1604 Bq/m$^3$ for a house located in the town Ștei, Bihor county.

The arithmetic mean of radon concentration measured is 138 Bq/m$^3$, by 1, 68 times higher than the average radon concentration previously reported in Romania. [82], [87], [88].

The concentrations measured in the town Ștei are higher than the values measured in the other towns.

Out of 906 measurements in the studied areas in 17% of cases, radon concentrations were < 40Bq/m$^3$, 28% were ranged in the interval 41-80 Bq/m$^3$, in 81-120 Bq/m$^3$ were 18%. A proportion of 9,5% of the measured houses exceeds the action level recommended by European Commission, the value of 300 Bq/m$^3$[28].

The measured values of radon concentrations in houses present a log-normal distribution in the following locations: the area Ștei-Băița, Bihor county, Bistrița-Năsăud county, Brașov county and Cluj county. In the other locations there was not enough data for a sufficient statistics.

For the area Ștei-Băița, the data results in a double-lognormal distribution, with two maxima. The first maximum is characteristic for houses with classical construction materials and the second maximum appears because of houses which were built with construction materials that contain wastes from the uranium mine with radioactive ore content.

From the analysis of total data obtained, we can see that there are significant differences between radon concentrations in houses located in the same town, as a result of using different construction materials on one hand, and the local permeability characteristics such as constructive characteristics of the building, on the other hand.

It was proven that the vibrations from heavy traffic heightened the accumulation of radon by about 100% more than the radon concentration measured in non-traffic area.

In case of blocks of flats, it was proven that radon concentration decreases with altitude, which confirms the theory from specialized literature. A linear decrease was noticed according to the level, both in blocks built with brick and in those built with concrete.

It was proven that trace detectors can be used both in residential areas and in special conditions such as high concentration of $CO_2$ (mofettes), high relative humidity (thermal baths) and in air full of salt particles (salt mines).

With improvement of trace detectors method CR-39 this method became more accurate and more easily used.  The measurements of radon concentration offer a database of information which can be used for subsequent studies.

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