Dr. Katalin Nagy

Clinical and experimental tests carried out with medicinal water and medicinal caves containing radon

University Doctoral Thesis

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List of papers and lectures related to the topic of the thesis

I.

Nagy Katalin, Bereczki János: Az egri gyógyidegenforgalom fejlődési lehetőségei. Balneológia, Gyógyfürdőügy, Gyógy-idegenforgalom.1998;19:119-120.

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Contents

I. Objectives

The objectives of the thesis is testing the physiological effects generated by the bath and cave with radon-content, and testing radon absorption and excretion, and filtering any hazardous effects.

My clinical and experimental tests carried out using radon-balneotherapy cover 3 topics.

1) The effects of radon bath on the endocrine parameters of rheumatic patients

2) The effects of caves containing radon on the endocrine parameters of patients suffering from respiratory illnesses

3) Inspection of radon absorption through the skin and from the air, and excretion of radon during taking the radon bath, and the occurrence of radon in urine

II. Literary Overview

Springs containing radon have been used for centuries to cure rheumatic patients in various parts of the world, for example Ischia has been known for 2500 years, Bad Gastein for 800 years, Misasa in Japan for 800 years, and Münster am Stein for 500 years. On the other hand, rather small number of studies deal with the physiological changes occurring due to the effect of these treatments, and with the exact mapping of relationships between these changes and radon concentration. There are three methods in radon therapy: water-drinking, bathing, breathing therapy (inhalatorium). During the therapies radon entering the human organism is able to reach every tissue of the body with the help of the circulatory system, therefore, in theory radon can be measured in the air exhaled and in excretion products [1,2].

At the same time, experts of radiation protection argue against both the healing power assigned to radon, and the absorption of radon solved in water through the skin.

Main physical and chemical characteristics of radon: radon is a colourless, odourless noble gas, its atomic number is 86, its boiling temperature is -62 °C, its melting point is -71 °C. Consequently, at room-temperature and under atmospheric pressure it is gaseous. It is soluble in water and in different organic solvents. In solid and liquid state it is phosphorescing due to radioactivity. Isotope 222 of radon was discovered by Friderich E. Dorn, German chemist in Halle (Germany) in 1900, which he called the decay product (radium emanation) of radium. Later (1908) Ramsay and Gray also isolated it, they called it niton. It has been called radon since 1923. Its isotope 220 was discovered by two English scientists, R. B. Owens and Ernest Rutherford in 1899. An isotope of radon noble gas can be found in each of the three radioactive decay chains occurring innature (Table 1) [3,4,5].

Table 1 Main characteristics of decay chains related to radon isotopes

Decay chain	**Uranium**	**Thorium**	**Actinium**
Mass number code	4n+2	4n	4n+3
Initial element and its decay half-time	^{238}U $4.5 \cdot 10^9$ years	^{232}Th $1.41 \cdot 10^{10}$ years	^{235}U $7.1 \cdot 10^8$ years
Radium parent element and its decay half-time	^{226}Ra 1622 years	^{224}Ra 3.64 days	^{223}Ra 11.7 days
Radon progeny and its decay half-time	^{222}Rn (radon) 3.82 days	^{220}Rn (thoron) 55.6 sec	^{219}Rn (actinon) 3.9 sec
Potential alpha-energy in the short-lived decay chain	19.2 MeV per atom	20.9 MeV per atom	20.8 MeV per atom
Stable end-core	^{206}Pb	^{208}Pb	^{207}Pb

Actinon and generally thoron do not result in significant radiation dose. In case of actinon the cause for this is that ^{235}U does not occur in a considerable concentration in our surroundings (0.71 % of natural uranium), and on the other hand, actinon is an isotope with such short decay half-time, that a large part of it disintegrates at the place of its formation, and only a minimal part enters the atmosphere. The causes are similar in case of thorium. Due to its short lifetime it causes significant radiation dose only if the soil, rock, or building material has a high ^{232}Th concentration. In case of ^{222}Rn the situtation is different, since due to its 3.82 day-long decay half-time, it may emanate from the crust from a depth of 1-2 m in case of loose soil, or in special cases even from a greater depth, and this way it may get in direct closeness to people [6]. Radon is an unstable element. It does not have stable isotopes. During its decay an alpha particle is released. Its progenies are created as the result of a series of decays, and they are also radioactive. Short-lived radioactive isotopes (decay products) are alpha-, beta-, gamma-emitters with different half-times [3]. Hereinafter, the term *"radon"* means the ^{222}Rn isotope in all cases. Radon originates directly from the radium located in the soil and rocks, therefore its quantity is primarily determined by the ^{226}Ra activity concentration of the material.

Radium atoms are incorporated in the solid material in the soil and in rocks, so radon originating from them is only able to get to the surface or to larger underground spaces, if it can emerge from the solid material between the pores of the crystal and soil particles.

During the decay of the parent element, radon generated in the crystal lattice can primarily enter the pore space due to recoiling (direct recoiling ratio). However, radon generally has a greater kinetic energy than necessary for entering the pore space; therefore it is rather probable that it hits the opposite particle and there it is slowed down. In case the pore space is partially or totally filled with water, it can absorb the energy of the moving radon atom, so it is more likely to stay in the pore water, where it can diffuse out to the parts of the interpore space filled with air. The quotient of the number of radon atoms emanated to the pore space and those generated in the crystals is the emanation coefficient (ε).

Factors influencing emanation:

- Density: depending on density, radon is able to emerge from a depth of 20-70 mm of the solid material to the pore space.
- Particle size: in case of particles larger in size more decay happens in depths greater than 20-70 nm, so this has a reducing effect on emanation.
- Moisture content: inter-pore water slows down emitted radon atoms, therefore particles also get into the inter-pore space, which would get into another particle without a slowing effect regarding their kinetic energy. Thus, moisture between pores increases the number of direct emissions. However, water being present dissolves a part of the radon gas, and

also hinders diffusion of radon, so the high radon-content already hinders the outflow of radon gas.

- Porosity: the more porous a material, the greater the surface on a unit of mass, and the greater the chance that radon generated during the alpha-decay of radium gets out of the particle.
- Radium distribution: emanation is also influenced by the homogeneity of the distribution of ^{226}Ra, and how much it accumulates locally [4].

The flux of radon flowing out into the air-space (exhalation) is the activity of radon flowing out on a unit surface in a unit period of time. The unit of exhalation is Bq/m^2s.

Factors directly and indirectly influencing exhalation are:

- Radon concentration of the inter-pore space,
- Gas permeability of the soil,
- Moisture-content of the soil,
- Granular structure of the soil,
- Emanation coefficient,
- Part of the day,
- Season,
- Weather conditions,
- Lift of tide.

Possessing these information it can be seen that the presence of radium in a given area does not definitely mean the increase of the radon concentration of the air-space, as it depends on emanation and exhalation, which are influenced by many other factors [4].

More than half (approx. 1.3 mSv/year) of the natural radiation dose of the population (2.4 mSv/year) originates from inhaling radon and its progenies. The health damaging effect has been proved by epidemiological inspections carried out on uranium and coal-miners, and by animal tests. According to the results of several surveys of this kind, in case of higher radon radiation dose the probability of the formation of lung cancer is proportional with the degree of the radiation dose. Most of the epidemiological and case-control studies carried out among the population showed that in case of higher radon concentration values this relationship is also valid among the population [7,8,9,10].

The radiation dose effecting the human body does not primarily originate from radon, but from its short-lived alpha-emitting progenies. The explanation for this is that while radon inhaled will probably be exhaled, and only a minimal part, approximately 3 % will be disintegrated in the lungs, the progenies bound to aerosol particles in the air, will stay in the lungs in a significant ratio after inhalation, deposited on the surface of the lungs, and the generated alpha-particles directly ionize the bronchial and alveolate epithelial cells covering the inner surface of the bronchia and the lungs. As the place of deposition of aerosols within the lungs strongly depends on their sizes, the absorbed doses are different at different parts of the lungs [11,12,13,14].

The range of activity of alpha-particles in living tissues is about 30 μm, therefore the dead epithelial cells covering the skin absorb a significant part of the alpha-particles emitted by radon and its progenies. Therefore, atmospheric radon means danger only to the lungs, the damage of other tissues, organs can be almost fully excluded. Ionizing radiation, and therefore alpha-radiation as well, take their effect in a direct or indirect way within biological systems. As a result of direct effect, directly the molecule in which energy-transfer happened, gets damaged. In the living cell, due to the direct effect, the macro-molecules forming the enzime systems of the cells and carrying heritable information, and the different membrane structures may become damaged. The basis for the indirect effect is the formation of free radicals with high reactivity generated in the water by the radioactive radiation, i.e. radiolysis. Free radicals coming into existence may transform the absorbed energy of ionizing radiation farther from their location of formation within the cells. Damages of the cells resulting from the above mentioned effects may lead to metabolic diseases, or in a worse case chromosome-aberrations, transformations inclined for proliferation may occur. The degree of biological reactions, effects formed in the living organism is in ratio with the quantity of energy absorbed by the cells, tissues, i.e. with the dose. In case of small doses (up to approximately 100 mSv) stochastic effects detectable only by statistical methods are mentioned. In case of changes formed as a result of radiation of higher dose and already detectable by cytogenetical methods, the effect is deterministic, and only occurs over a specific threshold dose. Considering the biological effect of radiation dosed originating from radon concentration observable in our surroundings, the formation of radiation disease clinically detectable and detectable by cytogenetic methods is not possible. If any biological effect is formed at all, then in this case usually cellular proliferation may appear after 15-20 years of incubation. Stochastic effect does not have a threshold value (below which the change is not observable), small dose has a small, greater dose has a greater probability to cause some change within the organism. According to our present knowledge, in case of stochastic effect the dose-effect curve is linear, that is the biological effect of a small dose radiation is also detectable in a long-term, however, changes occur so rarely, that their frequency can only be described statistically. Thus, due to receiving a specific radiation dose it cannot be stated that the given person will surely become ill, but if a whole population was treated with such a radiation dose, it could statistically be determined, in how many cases malignant or even lethal disease would occur among them.

The radioactivity of waters is influenced by the complex effect of geological, hydrogeological, physical, chemical processes. Radon occurs in waters within rather wide limit values ($6 \cdot 10^{-4}$ – 1000 Bq/dm^3). The radon-content of waters is in relation with the type of rock forming the watertight layer, but it also depends on for example its crackedness. Radon dissolves well in water, but being gas, its solubility significantly decreases as temperature increases, the value of the solubility factor has a 4.5 times difference between 0 °C and 75 °C (Table 2). Thus, the radon concentration of waters is influenced by the temperature of the water. As it has previously been mentioned, ^{222}Rn is the decay product of ^{226}Ra, so the quantity of radon is determined by the activity concentration of ^{226}Ra. Due to its characteristics ^{226}Ra alkali-earth metal is easily washed out of minerals containing its parent element, and it wanders to the aquifer layers after being dissolved in the water between the solid particles of the soil, and then it emerges to the surface through natural springs and drilled wells. The ^{226}Ra concentration of thermal and mineral waters alters within wide intervals. The ^{226}Ra-content of surface waters (rivers, lakes) is usually lower than that of underground waters, the cause of which is to be found in the fact that underground waters being in touch with the water-bearing rocks for rather long periods may dissolve great quantities of radionuclide from them [15,16]. Radium-content in case of seas, oceans is a few mBq/kg, and by ground-waters it is a few Bq/kg, but in some cases ground-waters with one hundred Bq/kg have also been found.

Balneotherapy, i.e. treatment with medicinal water has been a curing method used since ancient times [17,18]. Medicinal water is what such natural mineral water called, which has proven curing effect. During balneotherapy the mechanical, thermal, and chemical characteristics of the water jointly take their effect on the human organism. The strength of the triggered balneotherapeutic stimulus depends on the composition of the medicinal water and also on the concentration of the materials solved in it. Several theories were formed in history concerning the mechanism of action of the medicinal bath treatment. According to the so-called pharmacological approach the chemical components of the medicinal water absorbed through the skin are able to reach any target organ with the help of the blood-stream, and they exercise their curing effect there. A sceptical counter-advice contradicts the pharmacological approach, according to these skin is not an absorbing organ, the quantity entering the blood-stream is not enough to establish pharmacological effect, although absorption can be detected in a small quantity. However, a weak point of theis concept is that it disregards the effect of the mineral components deposited in the skin taken on the skin and through this on the organism [9].

The curing effect of thermal waters containing radon has been known in therapy for a long time, and it has also been applied wordwide, still radon bath is one of the most controversial curing operations within balneotherapy. There are different views concerning its effect. According to its objectors the exact mechanism of action of radon bath is not known, furthermore, its radio-biological mechanism and the consequences of its application are unknown, and since it is a radioactive material, problems of dosimetry also arise and lot of people are afraid of its application. Despite all these, others attribute positive biological effect to it, however, none of these has ever been expressly proved [2].

Balneological therapies are coming to the fore throughout the world, as natural therapy, when treating several illnesses. In most of the cases radon is always present in the water of resurgent springs in a smaller or greater quantity, regardless of their components. This affects the radon concentration in the bath and that generated in related air spaces. Depending on the radon-content of the water, and on the characteristics of the ventilation system of the bath, significant radon concentration should be expected in several cases. Radon concentration values about and exceeding 100 Bq/dm^3 have been measured in the “Rudas”, “Gellért”, “Rácz”, and in the Turkish Bath in Eger so far in Hungary (Table 2) [20,21,22].

Table 2 Radon concentration values of baths located in different countries

Bath name	**Average radon concentration of the spring-water [Bq/dm^3]**
“Rudas” bath, “Juventus” spring	135
„Rudas” bath, “Attila” spring	289
„Rudas” bath, “Hungária” spring	393
“Rácz” bath	123
„Gellért” bath, spring No. III.	49

„Gellért” bath, spring No. VI.	104
Turkish Bath in Eger Turkish pool spring	103
Taishan (China)	57
Nanshui (China)	280
Polichnitos spa (Greece)	210
Badgastein (Austria)	662
Bad Steben (Germany)	800
Bad Elster (Germany)	1300
Jachymov (Czech republic)	4250

Radon is present in radioactive medicinal waters partly in a form dissolved in water, on the other hand, in the form of gas not dissolved in water, which emerges in the form of bubbles. The quantity of this latter form exceeds the quantity of radon dissolved in water.

According to the supposed mechanism of action the radon absorbed in water can directly be absorbed through the skin from the bath water during the radon bath, while the emerging radon entering the air space over the pool takes its effect inhaled as a natural inhalatorium [23,24].

Most of the literature data agree with the pain-killing effect of radon bath [25,26].

Besides the pain-killing effect it is supposed that it promotes increased evolvement of capillaries, it intensifies uric acid excretion, activates adrenalin-production, decreases DNA-synthesis, strengthens DNA-repairing mechanisms, increases the activity of the protective system and the functions of the genitals. [27].

Radon does not react with any chemical component of the human body. It can enter the organism through the skin and the lungs, it is distributed by the blood-stream. Radon is fat-soluble, therefore it propagates in the tissues of the body rich in fat, e.g. in endocrine glands and nerve-fibres, which are surrounded by a mantle containing lipid. It stays within the organism for a short period of time, its biological half-time is short, 15-30 minutes. The greater part of radon quickly leaves the organism through the lungs. Only approximately 0.5 % of radon dissolves in the tissues, and its decay products accumulate in the adrenal gland, in the adipose tissue, and in the genitals.

Radon has a low penetration power, therefore it can only reach far parts of the organism with the help of vehicle material [2].

Its application is primarily recommended in case of rheumatic arthritis and painful neuritis (neuralgia) [28,29,30]. The duration of the bath is usually 15-20 minutes in 33-34 °C water. Bath treatment will have results if taken as a regular course (after 15-20 bath treatment). Therapeutic application of radon in the form of cave therapy, bath treatment or water-drinking has a history, for example in Bad Kreuznach and also in Bad Gastein, where it has been used with this purpose since 1940. Negative effects of radon during the therapy was not experienced here.

Bath culture in Eger

The history of bath culture in Eger goes back to elder days. Ponds formed by the water of thermal springs has been used by the population of the town for bathing and washing since the beginning. According to a document from the Middle-Ages originating from 1448 the first bath of Eger, “Balneum Chartusiensum”, i.e. Carthusian bath was located in the centre of today’s Eger, by the stream Eger. Thus, the bath has already been operating in Eger in the Middle-Ages. According to available data Tamás Bakócz, the bishop of Eger had the thermal water bath renovated in 1495. In the 15th century thermal water baths were also serving medicinal purposes besides having a wash. The most important period within the history of baths in Eger have been the years under Turkish oppression, as the 91 years after the town has got under Osmanli rule in 1596 was accompanied by the evolution of advanced Turkish bath culture. The Islam orders regular ritual bath-taking, washing, therefore the Turks highly appreciated medicinal waters, and they have built baths over the springs throughout the empire. The medicinal bath of pasha Arnaut was built some time between 1610 and 1617, the successor of which is today’s Turkish bath. The building of the turkish bath was followed by the establishment of two steam baths, one for men, and the other one for women. The latter was named after the mother of the emperor, and it had the name Valide Sultana. Therefore, in Eger such a favourable situtation was formed, that besides the steam bath it also had two hot-water baths as well. The bathing culture flourishing during the Turkish reign declined after expelling the Turks in the first half of the 18th century, the archbishop’s bath almost collapsed. Hot-water ponds surrounding the bath building were used by women for washing, and also tanners worked here. During the Rákóczi War of Independence the thermal bath became rather popular, even monarch Ferenc Rákóczi was among the visitors. In the middle of the 18th century archbishops Ferenc Barkóczy (1742), then count Károly Eszterházy (1791) ordered the expansion of the bath of Eger, and they also had the Turkis bath renovated. During the renovation works commenced in July 1742 the mirror bath was completed by the north-western corner of the Turkish pool, over the hottest, and at the same time, highest radon-content spring of the hot-water bathing-house. In 1764, Ferenc Markhot, the official physicist of Heves hundred and the town of Eger, an outstandingly well-learned doctor chemically analyzed hot-water springs in Eger. Owing to this, doctors of the age could use thermal water for medication knowing its chemical composition. Bathing culture of the town revived again in the second half of the 19th century, and in 1920 the unused, large, hot-water pond lying beside the thermal bath was built up to form a public bath. The first steam bath was established in the thermal bath in 1921, and the Turkish pool was also renovated in the building of the bath. In 1938 the building of the bath was modernized and reconstructed. The Rheumatology Department of the Heves County Hospital connected with the so-called “neck part” to the building of the old medicinal bath was built up in 1965. The medicinal bath of the Rheumatology of the Heves County Hospital in Eger was opened after another reconstruction in 1979, under the name Turkish Bath [31].

Medical caves

Cave therapy has been a therapeutical procedure used for a long time in the Middle and Eastern European countries for curing respiratory illnesses. Anglo-Saxon countries consider this type of therapy as a part of alternative medicine, as scientific evidence is hardly available [32].

Presumed mechanism of activity includes constant temperature and humidity, climate with low stimulus, bacterial sterility, negative ionization, high calcium-content of the powder condensation (antiallergic effect). Increased CO_2-content helps breathing. Besides caves with high salt-content (salt mines), several European countries have caves containing radon as well (one of the best known is Bad Gastein).

Records on medicinal caves were made even by people from the Middle Ages, but scientific inspections started only in the fifties in Germany. During the period of World War II. the inhabitants of a small town, Ennepetal seeked shelter against the bombing of the Ruhr-region in the Klutert cave. Refugees included some people suffering from bronchitis, whose condition got significantly better under the safeguard of the cave. After the war research work and measurements started, which provided basis for the scientific background of cave therapy.

In Hungary, healing effect was detected first during the exploration of the Béke Cave in Aggtelek. As a result, a few years after the discovery of the cave, the first medicinal cave of the country was established, and then therapy was started in more and more caves. Today, five medicinal caves are in operation in Hungary [33,34,35]: Béke Cave (Aggtelek karst), István Cave (Bükk mountains), Hospital cave in Tapolca (Tapolca basin), Szemlőhegy cave (Mountains of Buda), Abaliget Cave (Mecsek mountains).

Tapolca is located on the Western end of the Balaton Highlands, in the centre of the basin named after the town. The natural curiosity of Tapolca, the pool cave originating from the Mesozoic era was discovered in 1902 during well-digging, and ten years later it was opened for the visitors as well. The lower rooms and a part of the upper passages of the cave system formed by karstic water are covered by water of 19 degrees Celsius. Visitors can take a trip in a boat around this 300 metre-long section. Passages leading down to lower rooms can be seen well in the clear water with different depths. [36] The healing effect of the special climate of the cave has been known for a long time. The relatively constant temperature of 14-16 degrees Celsius, the almost 100 % relative humidity and the extremely clear air provide help for allergic, asthmatic, and other respiratory illnesses. Another section, the Hospital cave discovered in 1925 is used for this purpose.

Children suffering from whooping-cough were already cured without any medical control in the pool cave even by the beginning of the 20^{th} century, and by the beginning of the 60s therapeutical inspections have been carried out, which provided reassuring results, but due to lack of space the cave under the hospital also got into the foreground, where measurements proved more favourable capacities.

Experimental treatments started in 1972, and from 1982 it has been officially operating as a medical cave. It is the only hospital cave in the country, which has the hospital and medical care located next to it. Thanks to the elevator, the therapy is possible even for those suffering from motion organ illnesses, as they can go down to the cave with little physical exertion.

III. Patients and methods

Test 1:

During our examination carried out in the water with 80 Bq/dm^3 radon-content in the Turkish Bath in Eger the effect of the bath treatment on the hormone levels of rheumatological patients was examined. As a control, the hormone level determination of patients receiving thermal water treatment in the pool of Hotel Flóra in Eger was carried out under similar conditions, but by negligible radon-content (6 Bq/dm^3).

Inclusion Criteria: at both locations in this test rheumatological patients suffering from degenerative spinal and articular deformations took part (diagnosis: arthrosis genu et coxae, spondylosis et spondylarthrosis lumbalis). 27 patients, 19 women and 8 men were treated in the Turkish Bath. Their average age was 49.8 years (24-70).
25 patients, 19 women and 6 men were treated in Hotel Flóra. Their average age was 58.16 (44-76).
At the commencement of the inspection the patients were informed in detail about the course of the test, and the patients filled in an assenting declaration.

Exclusion Criteria: acute febrility, illnesses with fainting, psychosis, large-scale inflammation of the skin, infective illnesses, coronaria illness with idle stenocardia, unstable pecoral angina, malignant hyprtension, severe cardial decompensation, respiratory disorder, incontinentia urine et alvi, acute stages of motion organ illnesses (e.g. acute radiculitis, arthritis).

At both locations the bath took 15 times 30 minutes, the water temperature was 31 ºC in the Turkish Bath, and 32 ºC in the Flóra bath. Patients were ambulant patients and did not receive other treatment. In both cases, before the bath treatment was examined: the thyreoiedea stimulating hormone (TSH), related to the thyroid functioning and controlling, prolactine carrying out the controlling lactation, cortisol and adrenocorticortop hormone (ACTH) related to the functioning and controlling of the corticoid, and Dehydroepiandoszteron (DHEAS) in the serum.

Test 2:

The objective of the test carried out in the cave containing radon in Tapolca is to find out whether staying in the cave with radon-content influences the operation of the endocrine system of patients being treated there suffering from respiratory illnesses, depending on the concentration.

Inclusion Criteria: chronic respiratory illness, except for acute exacerbation of the illness
Exlusion Criteria: acute exacerbation of chronic illness, if the patient is not self-supplier, immotile, or comes upon oxygen.

A total of 81 patients took part in the test. The patients were informed in details about the course of the examination, and they filled in an assenting declaration. During the summer period (measurements were carried out in June, July, August), when radon concentration was high, 46 patients were tested, 26 women and 20 men. Their average age was 58.02 years, the youngest patient was 17, the oldest one was 79 years old. During the winter period (December, January, February) 35 patients were tested, 16 women and 19 men, their average age 62.5, the youngest patient was 33, the oldest one was 80 years old. During the treatment the patients spent 4 hours a day in the cave beside continuous medical observation for three weeks (except for Saturdays and Sundays). Except for radon concentration, other parameters of the cave were unchanged: constant temperature (13.9 °C) and relative humidity around 100 %, high CO_2 concentration, exemption from pollen and germs.

Distribution of diagnosis (summer):

46 patients: asthma bronchiale 31, Bronchitis chronica 9, Rhinitis allergica 3, Silicosis 2, Fibrosis pulmonum 1;

Distribution of diagnosis (winter):

35 patients: asthma bronchiale 18, bronchitis chronica 12, rhinitis allergica 1, silicosis 3, spontaneous PTX 1.

Tested endocrine parameters: The levels of the following hormones were measured during the survey: thyroid-stimulating hormone (TSH), free triiodthyronine (fT3), free thyroxine (fT4), prolactin, dehydro-epi-androsterone sulphate (DHEAS), corticotropin (ACTH), beta-endorphin (BE), and cortisol.

Test 3

In this study the objective set out was studying the absorption of radon through the skin, by inspecting the radon concentration of the air exhaled, and inspecting the excretion by urine of radon having entered the organism.

Measurement of radon in the exhaled air

Our experiments were carried out in the bubbling pool of the Turkish Bath in Eger, beside the continuous radon inspection of the air space and the therapeutical water. 17 volunteers, 8 men and 9 women took part in the experiment, their age ranged from 13 to 74 (45.9). The experiment consisted of two parts.

In the first case the volunteers before entering the therapeutic section and the pool gave a sample of air, and then they spent 60 minutes in the therapeutic pool, while they were breathing in the air of the therapeutic section. Before leaving the therapeutic section, they gave another sample of air.

In the second case the volunteeres gave a sample of air before entering the therapeutic section and the pool, and then they spent 60 minutes in the therapeutic pool, while breathing from an diving cylinder. Before leaving the therapeutic pool they gave another sample of air, without having the air of the therapeutical area inhaled. After collecting the samples the radon concentration of the air sample was determined. A total of 68 samples have been analyzed.

Diving cylinder were filled in an open area with continuous air-movement 11 days before the commencement of the experiments. The radon concentration of the air samples taken from the bottle was below the detection level (1.9 Bq/m^3). During the experiment, the hourly average radon concentration of the therapeutical area was continuously measured, and also the radon concentration level of the water of the therapeutic pool was also determined each day.

Urine sample determination

During our survey carried out in the Turkish Bath in Eger, the primary objective of our work was studying the absorption of radon through the skin by analyzing urine samples. Is radon actually absorbed through the skin, if yes, in what degree, and by what excretion procedures? Our experiment was carried out in the bubbling pool of the Turkish Bath, where the radon-content of the urine of participants was checked before and after taking the radon bath, and besides, continuously inspecting the radon-content of the air space and the therapeutical water.

Besides, within the framework of a 24-hour measurement, the radon-content of the Turkish pool was checked by hourly sampling. The radon-content of gases emerging in the therapeutic pools and the radon concentration forming in therapeutical areas were inspected.

48 urine samples of 12 persons (5 women, 7 men, average age 38.5 (13-54)) were processed. Before starting the survey, the test subjects drank checked radon-free mineral water or beer, minimum half a litre. On the first day they spent approximately one hour in the bubbling pool, while they were breathing from checked radon-free diving cylinder. The same happened on the second day, but this time inhaling the air of the air space. In both cases urine samples were taken before and after taking the bath.

Radon measurement method [37,38,39]

Radon easily leaves water due to shocks, therefore it is practical to carry out measurements directly at the location of sampling. Sampling was carried out using radon-closing vessels, taking care that no air-bubble stays over the water sample after closing the vessel, as it would provide an opportunity for radon to outdiffuse. The measurement can be divided into two sections. The first section is driving out the radon dissolved in water into a Lucas-cell, and the second section is the measurement of the activity of the radon collected in the cell. Driving off was carried out using gasifier type PYLON WQ 1001. This is a system equipped with a needle valve, vacuum-meter, quick connector, dryer, and sampler, and ceramic sphere, expressly elaborated for field radon measurements. The 180 mL water sample necessary for the measurement should be taken from water running in a little spout, dribbled carefully down the wall of the sampling measuring-tube, it should promptly be plugged and connected to the gasifier system. Lucas-cell type PYLON 300 (coated with ZnS inside) was used as measuring cell, which was also connected to the system. The measuring cell was vacuumed using a hand-pump, and air was flown through the water by opening the needle valve in a way that the driving-off lasts for approximately 5 minutes. Fine distribution of the air was provided for by a porous ceramic sphere. Removal of steam traces was ensured by a $CaCl_2$ dryer tube connected in front of the Lucas-cell. 5 minutes later the remaining air was flown into the cell by opening a bypass valve, then the cell was disconnected from the system and connected to a radon-meter PYLON AB-5. For the secular equilibrium between radon and its progenies to be formed, after 3 hours of a waiting period 3 parallel measurements were carried out with 10-minute measuring periods. The background of the cell before the driving-off was also defined by a 3 x 10 minute measurement period. Being aware of the measured intensity levels, the radon activity concentration of water can be calculated with the help of the following relationship:

$$A_{Rn-222} = \frac{(B-H)}{F \cdot D \cdot S \cdot V \cdot 3} \qquad (1)$$

where:

A_{Rn-222} is the radon activity concentration of the water sample, [$Bq \cdot L^{-1}$]

B is the gross counting pulse number, [cps]

H is the measured background, [cps]

F is the counter efficiency

D is the drive-through efficiency

S is the correction factor (decay correction factor of radon is $e^{-\lambda t}$)

V is the volume of the sample, [L] (usually 0.180 L)

Therapeutic conditions

Therapeutical area:

Alphaguard Pro200 (ionization chamber), detection limit: 2 Bq/m^3

Diffusion operation mode, hourly average

Therapeutic pool water:

Radim 3-WR (félvezető detektor), detection limit: 2 Bq/dm^3

Sampling operation mode

Emerging gases:

LUK-3, (0.1 dm^3 Lucas-cell (ZnS(Ag)), detection limit: 20 Bq/m^3

Urine samples:

1 dm^3 Lucas-cell (ZnS(Ag)), NP420 P single-channel analyzer, detection limit: 1.9 Bq/m^3

Hormon-level measurement

TSH(µmol/l), Prolactin, (µmol/l) DHEAS (µmol/l) were determined using immuno-radiometric assay (IRMA). For this two such antibodies are necessary, which recognize two different epithopes of the molecule. One of the antibodies is marked with radioiode ("signal" antibody), the other one is unmarked (so-called "capture" antibody). Measurement of ACTH, fT3(pmol/l), fT4(pmol/l), cortisol (nmol/l) was done by radio-immunoassay (RIA) method, the working principle of which is based on the principle of the competitive radio-immunoassay. Using test material indicated with 125I, the beta-endorphine (BE) (fmol/l) was also determined using RIA.

Mineral composition and radon-content of the Turkish spring supplying the Turkish Bath: Radon-content: 90 Bq/dm^3 (75-100) by the spring, Ca: 98.8 mg/l, Mg: 16.7 mg/l, HCO3: 342 mg/l. Radon-content in the medicinal pool 80 Bq/dm^3.

Mineral composition and radon-content of the spring “József” supplying the pool of Hotel Flóra:

Radon-content: 67± 5 Bq/dm^3 Ca: 90.4 mg/l, Mg: 19.24 mg/l, HCO3, 341.65mg/l, Radon-content in the medicinal pool 7.5 Bq/dm^3 (6-9).

Statistical methods

1) Statistical calculations were carried out using single and double sample Student’s distribution on a significance level of 5 %. Previously, Kolmogoroff-Smirnoff test was used to check, whether none of the variables significantly differed from the normal distribution.

2) During the analysis the data were subject to Student’s test (paired samples test). The data were statistically analyzed using SPSS 15 software.

IV. RESULTS

Test 1 results

Significant differences were not found between the values measured before and after the treatment neither in the Turkish Bath, nor in the Flóra bath, and not even comparing the values measured at the two bath locations. (table 3)

Table 3 Difference between the variables before and after taking the bath, in the Turkish Bath and in the Flóra bath

Hormones	Place	N	Mean	Std. Deviation	Std. Error Mean	**Sig. (2-tailed)**
TSH_before and after taking the bath	Turkish	28	0.086	0.554	0.105	
	Flóra	21	-0.240	0.708	0.154	N.S p=0.089
Prol_ before and after taking the bath	Turkish	25	-8.240	113.984	22.797	
	Flóra	23	11.435	94.617	19.729	N.S p= 0.517
Kort_ before and after taking the bath	Turkish	28	-21.036	221.252	41.813	
	Flóra	23	3.174	200.139	41.732	N.S p= 0.684
Dheas before and after taking the bath	Turkish	28	-0.232	1.336	0.252	
	Flóra	24	-0.042	1.052	0.215	N.S p= 0.568
ACTH_ before and after taking the bath	Turkish	27	-0.009	3.123	0.601	
	Flóra	24	-0.290	4.385	0.895	N.S p= 0.796

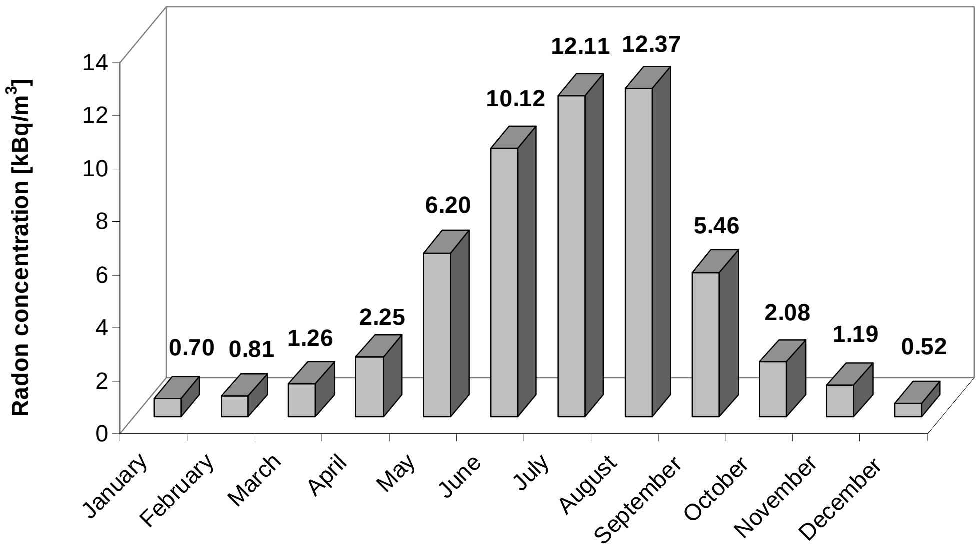
		Paired Differences		Paired Samples Test		
Place	Hormone levels before (b) and after (a) the treatment	Mean	Std. Deviation	t	Df	Sig. (2-tailed)
Turkish	TSH_b - TSH_a	0.086	0.554	0.825	27	N.S p=0.416
	Prol_b - Prol_a	-8.240	113.984	-0.361	24	N.S p=0.721
	Kort_b - Kort_a	-21.036	221.252	-0.503	27	N.S p=0.619
	Dheas_b - Dheas_a	-0.232	1.336	-0.920	27	N.S p=0.366
	ACTH_b - ACTH_a	-0.009	3.123	-0.015	26	N.S p=0.988
Flóra	TSH_b - TSH_a	-0.240	0.708	-1.551	20	N.S p=0.137
	Prol_b - Prol_a	11.435	94.617	0.580	22	N.S p=0.568
	Kort_b - Kort_a	3.174	200.139	0.076	22	N.S p=0.940
	Dheas_b - Dheas_a	-0.042	1.052	-0.194	23	N.S p=0.848
	ACTH_b - ACTH_a	-0.290	4.385	-0.324	23	N.S p=0.749

Table 4 Changes of the hormone values before and after the treatment

Test 2 results

The first figure shows that radon concentration is relatively low in the winter period, while it is higher in the summer months, the average radon concentration level exceeds even 12 thousand Bq. This seasonal fluctuation is typical in case of Piedmont-type caves (figure 1). The high ratio of change in the seasonal concentration is caused by the difference in outdoor temperature during the winter and the summer. The entrance of caves of this type is located nearly on the same level as the cave passages. Two kinds of air-circulation may be generated depending on the temperature of the surface air. In the winter the colder outdoor air enters the cavities of the cave, and warming up there it flows upwards along the crackings. This time lower radon activity can be measured in the air space of the cave, radon is kept back in the crackings, and it does not flow from the crackings towards the air space of the cave, but in the opposite direction. Therefore, in the winter higher concentration values can be measured in the crackings hidden in the rocks above the cave. In the summer the direction of the air-circulation turns, the air flows outwards from the cave, the outdoor air flows into the air space of the cave filtered through the system of crackings, carrying along radon gas accumulated in the crackings. Therefore, higher radon activity concentration will be typical in the air space of the cave in the summer.

Figure 1 **Changes of radon concentration in the cave in Tapolca in the winter and in the summer**



TSH and ACTH levels neither in the winter nor in the summer changed. Free thyroxine (FT4) significantly decreased during the winter period. FT3 was identical in winter and in summer (although, significant changes could be observed by several patients), DHEAS decreased, but not signicantly during the winter period, and prolactine also increased during the winter period, but not significantly. BE increased in the winter and in the summer as well, but this change was not significant. Cortisol significantly decreased during the winter (figures 2-9).

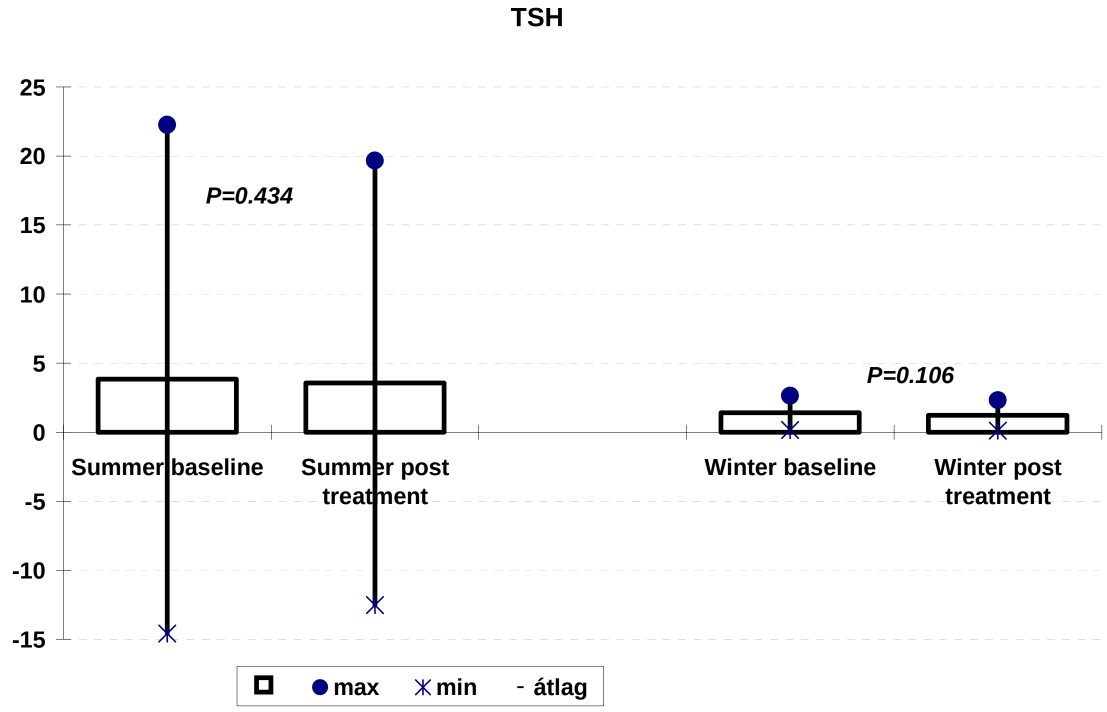


Figure 2

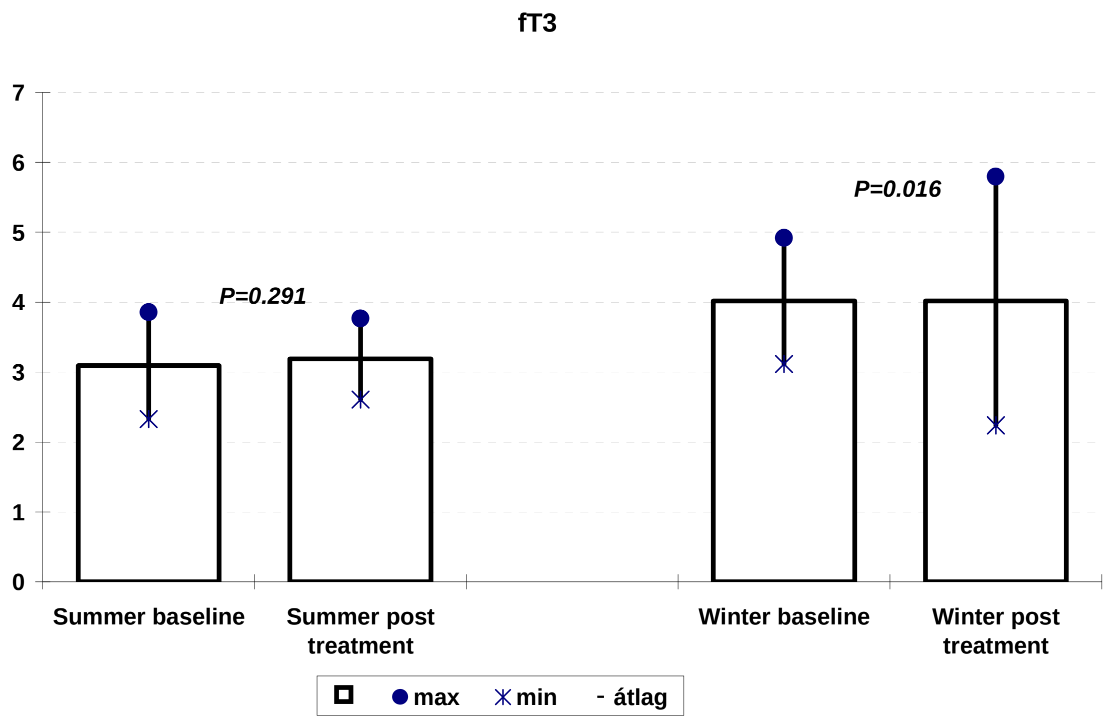


Figure 3

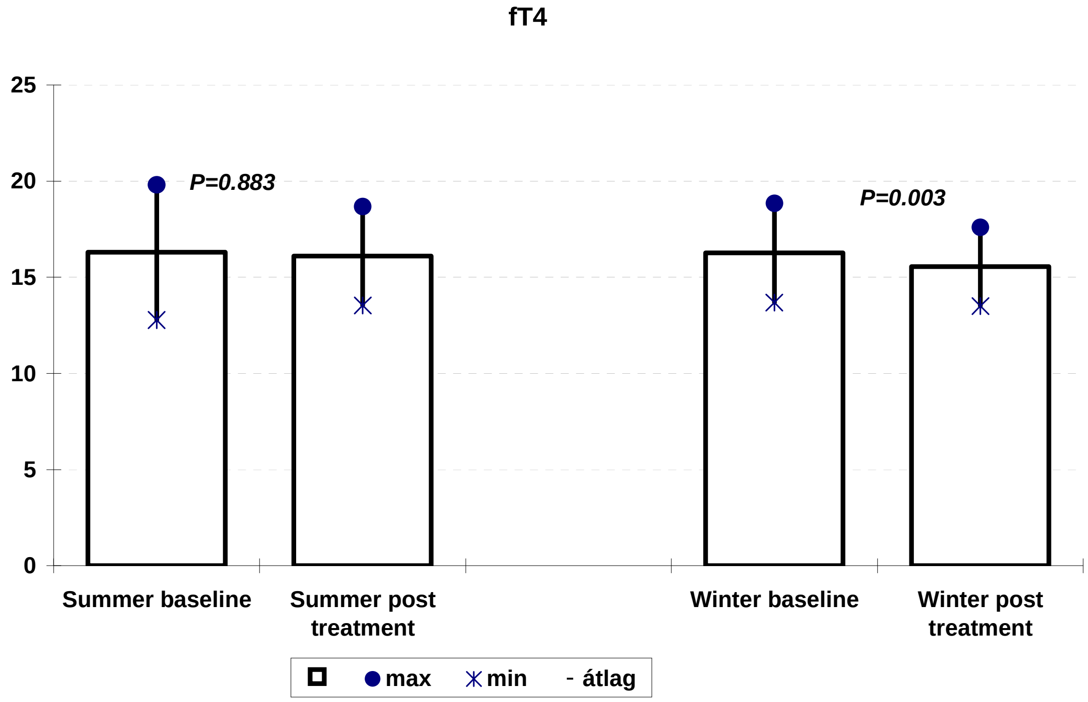


Figure4

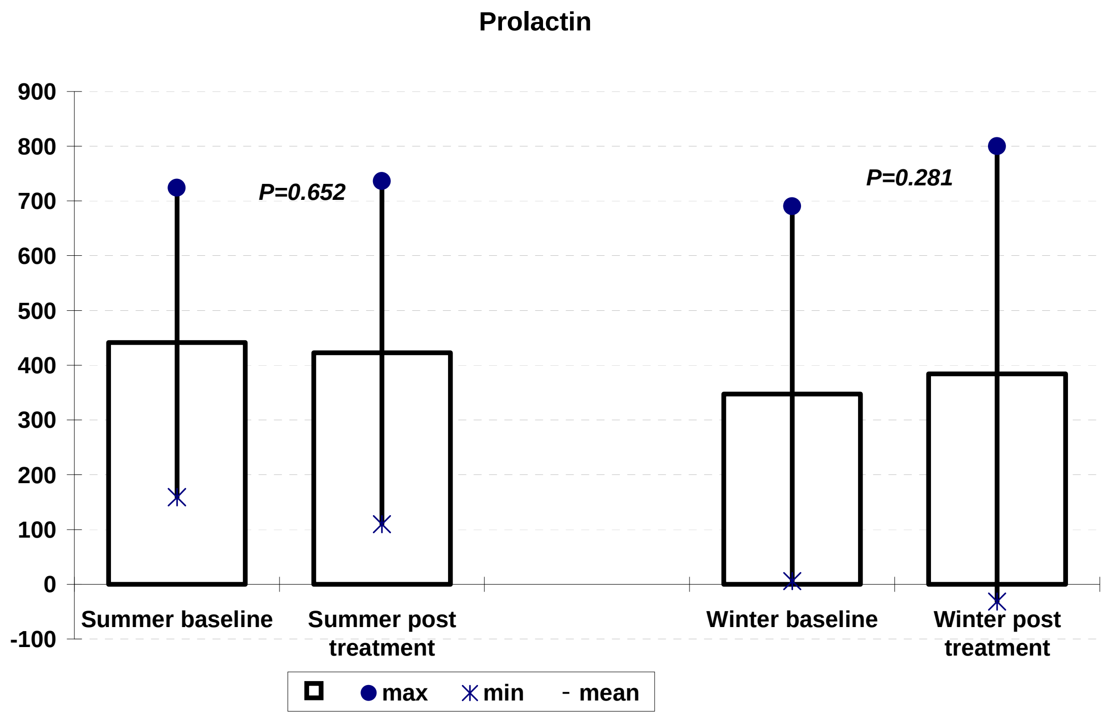


Figure 5

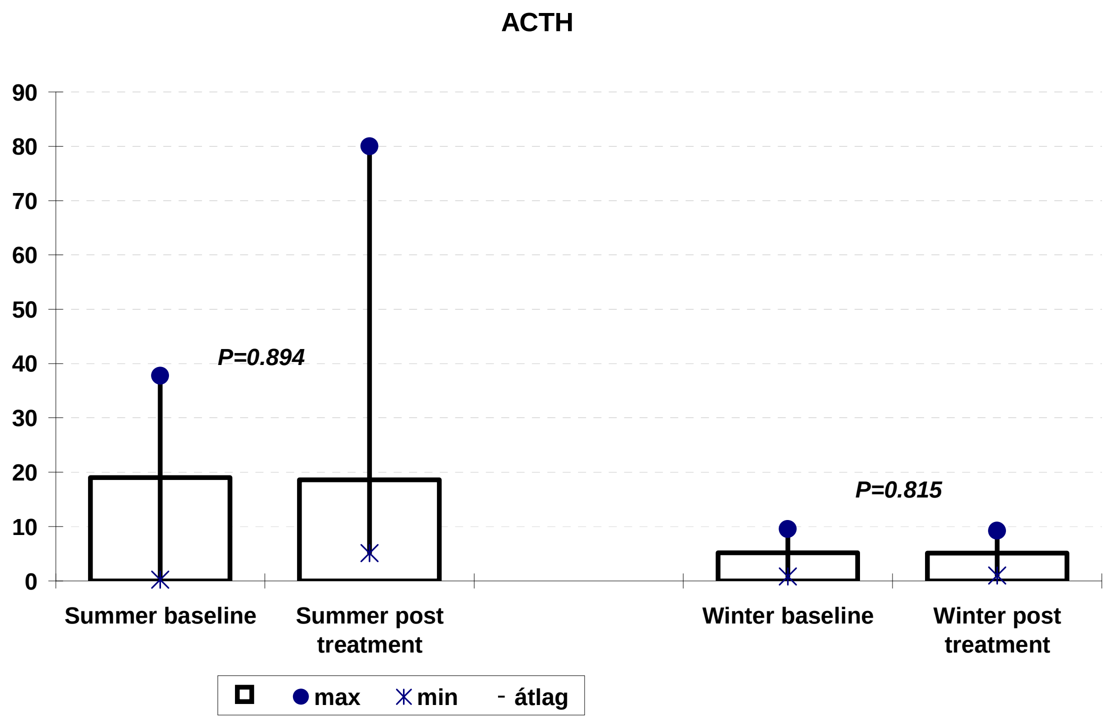


Figure 6

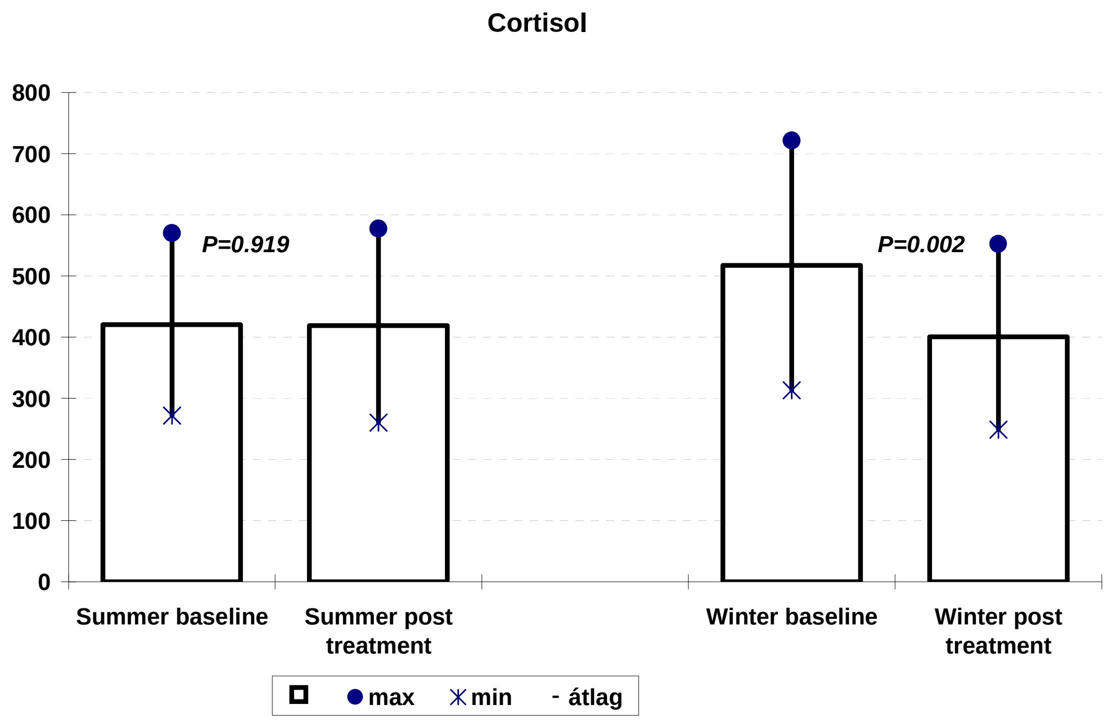


Figure 7

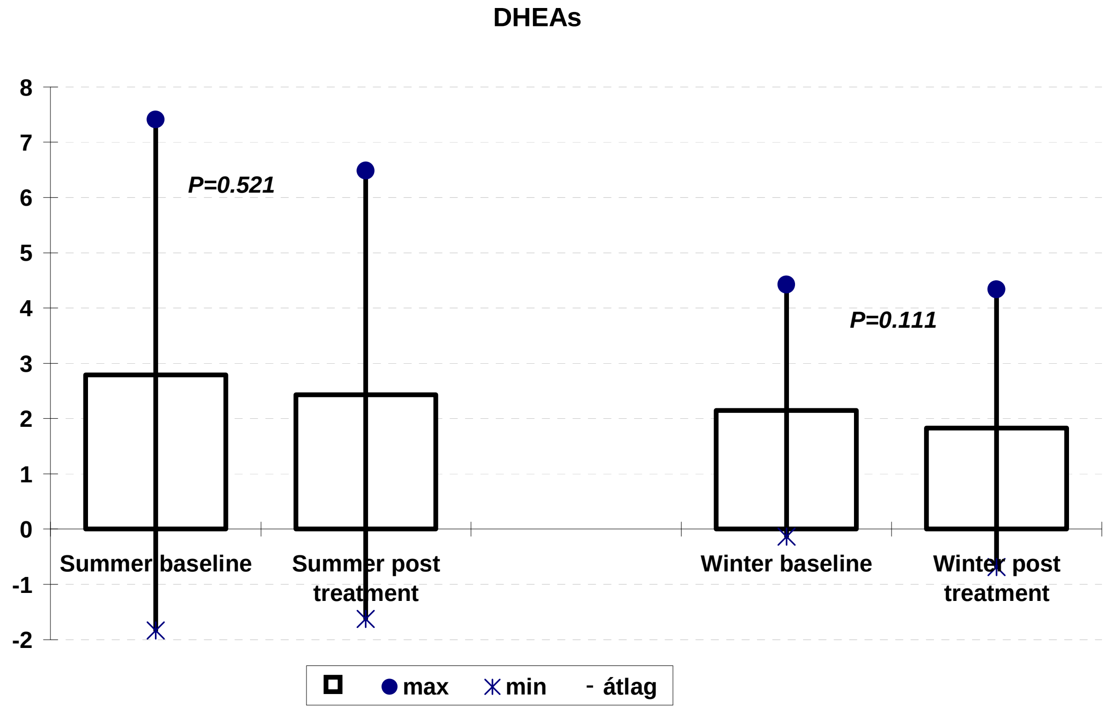


Figure 8

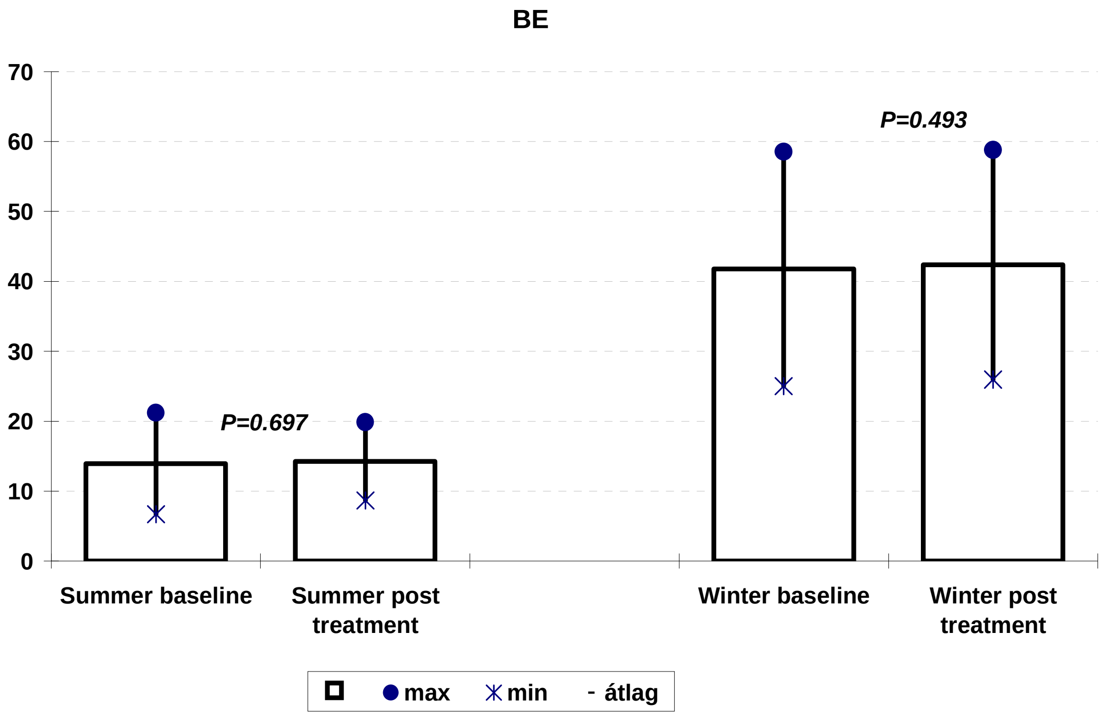


Figure 9

Test 3 results

Results of the air sample inspections

Air sample inspection results when inhaling the air of the therapeutical area

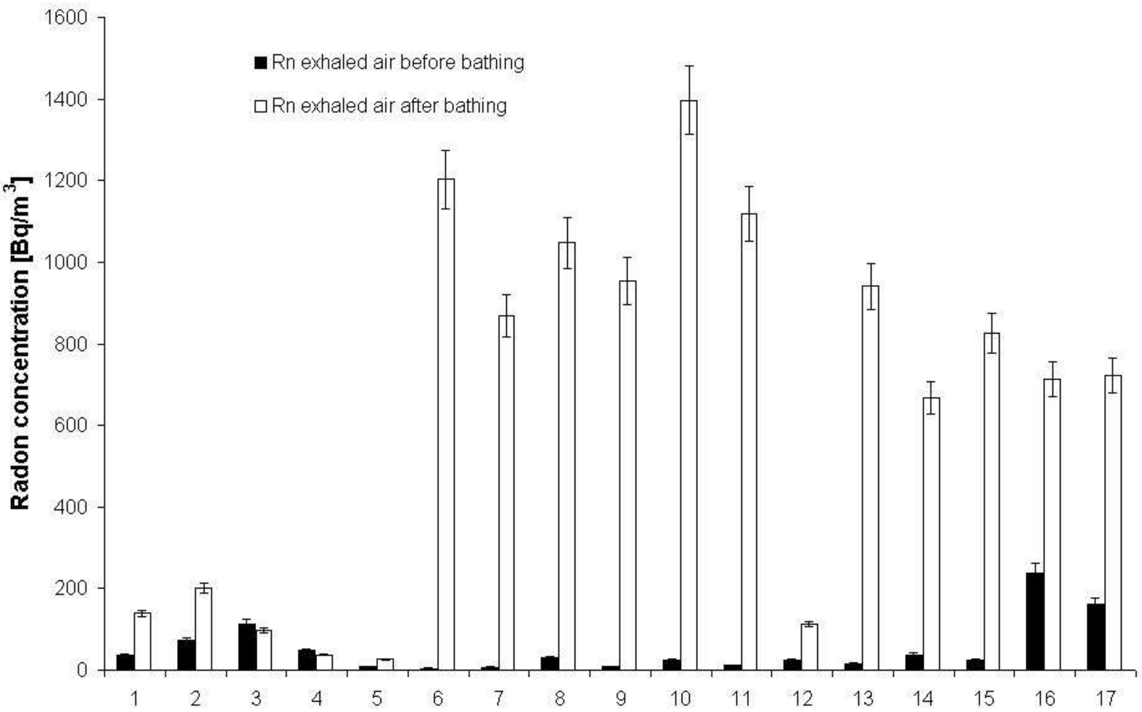


Figure 10 Changes of radon concentration of air samples before and after staying in the therapeutical water, when inhaling the air of the therapeutical area

Figure 10 shows the radon concentration of the air exhaled by the volunteers before entering the therapeutical area, and then after staying there for 60 minutes, while inhaling the air of the therapeutical area. In case of the 17 volunteers inspected, the average radon concentration of the air exhaled before entering was 50.8 Bq/m^3, the highest level was 239.2 Bq/m^3, the lowest level was 4.2 Bq/m^3. These great differences cannot be explained yet.

After staying in for 60 minutes, the average radon concentration of the air exhaled was 651.2 Bq/m^3, its highest value was 1397 Bq/m^3, and the lowest value was 27 Bq/m^3. These great differences cannot be explained yet. Values changed in the highest degree, 41.2 percent between 500 and 999 Bq/m^3.

Table 5 Distribution of radon concentration values of the air samples after inhaling the air of the therapeutical area

Distribution interval [Bq/m^3]	**Distribution percent [%]**
>1500	0
1000-1500	23.5
500-999	41.2
200-499	5.9
<199	29.4

Comparing the radon concentration values before and after staying in the cave, except for the results of volunteers No. 3 and 4, an increase exceeding the error limit can be seen everywhere. Allowing for these results, the average increase related to 15 cases was 56.5 times, in the highest case it was 286.4 times, and in the lowest case it was 2.7 times.

The radon concentration of the air exhaled after staying in the bath and the hourly average radon concentration value of the therapeutical area for the given period is shown in figure 11. Volunteers No. 3 and 4 were not in the bubbling bath during this survey, but in the Turkish pool, in the therapeutic air space of which the radon concentration (433 Bq/m^3) measured using the temporary sampling method was lower than that measured in the therapeutical area of the bubbling pool (average 1303 Bq/m^3). Here, the highest radon concentration during our surveys was 1616 Bq/m^3, and the lowest was 829 Bq/m^3. It may come up that increase could not be found in cases No. 3 and 4, as they spent that 60 minutes in a place with a lower radon concentration, but in case of such little number of samples it cannot be definitely expressed.

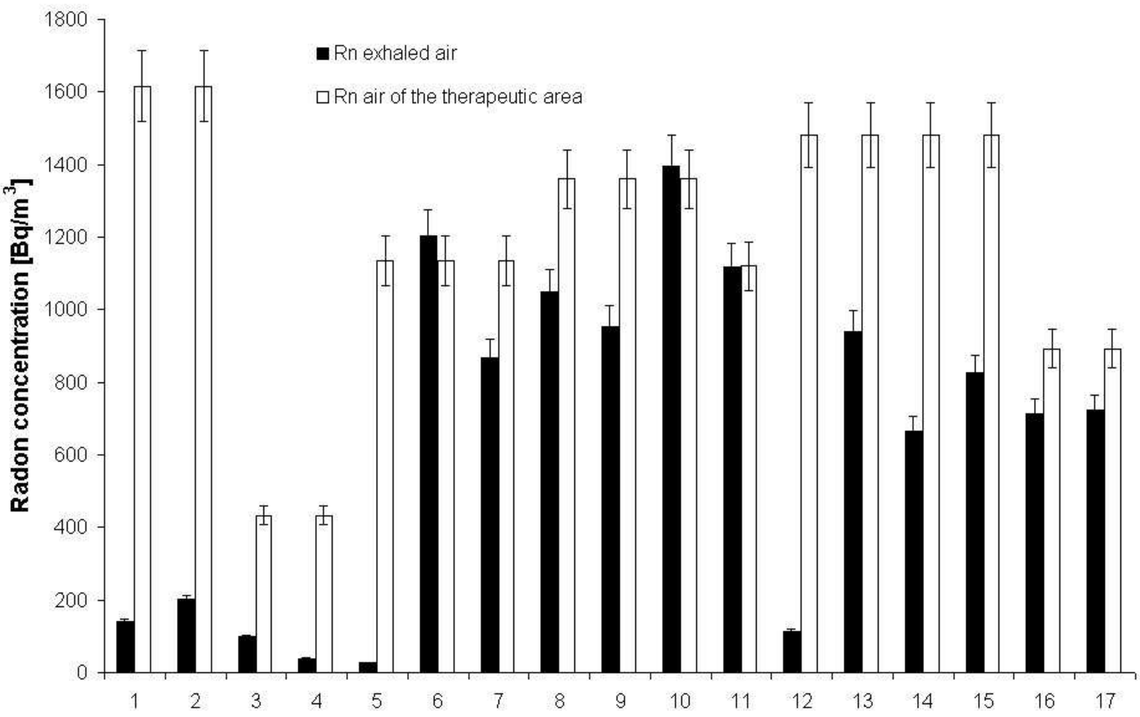


figure 11 Radon concentration values of air samples after staying in the therapeutical water, and the radon concentration of the air of the therapeutical area

It should be given attention that, except for cases No. 6, 10, and 11, where the difference between the radon concentration of the air exhaled and the radon concentration of the air of the therapeutical area is within the error limits, the radon concentration of the air exhaled stays well below the radon concentration of the air of the therapeutical area. This time the average difference was 7.3 times, the highest one was 42.1 times, and the lowest one was 1.2 times. Knowing that the greatest ratio of inhaled radon is to be exhaled, the 7.3 times average difference seems rather considerable, the exact cause for it is not known yet.

The comparison of the radon concentration of the air exhaled by the volunteers during the survey and that of the therapeutical water is shown on figure 12. The changes of the radon concentration of water between 65.4 and 85.9 Bq/dm^3 were not influencing the radon concentration of the air exhaled in any of the cases.

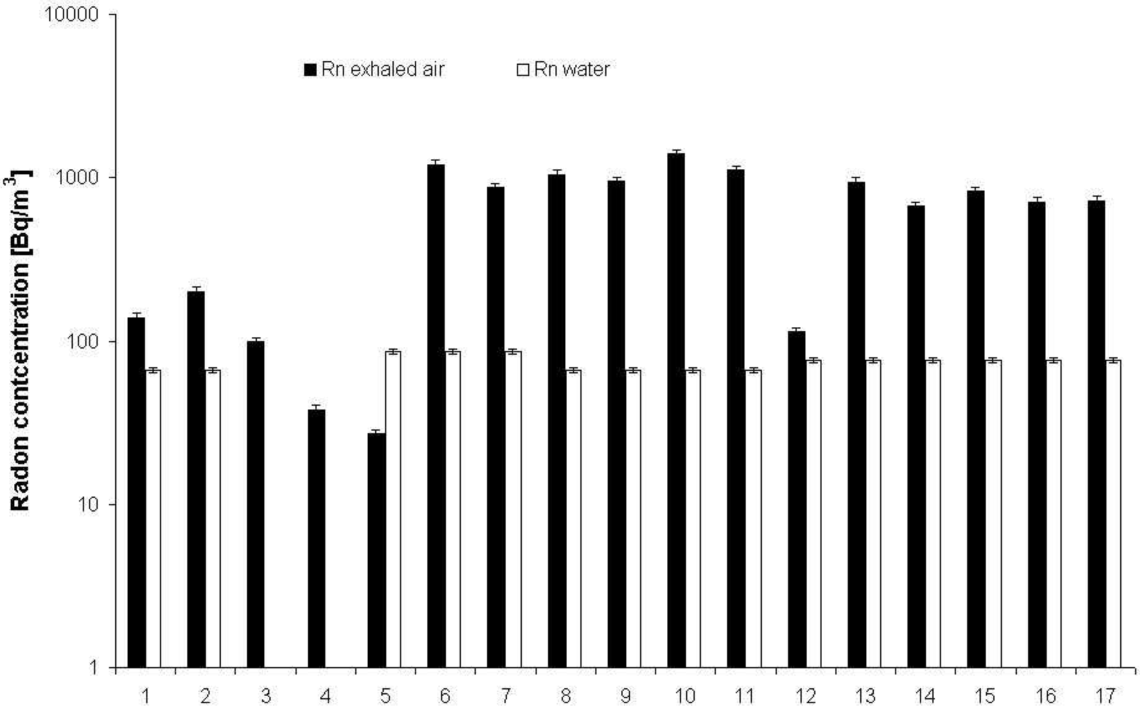


Figure 12 Radon concentration of the air exhaled and of the therapeutical water when inhaling the air of the therapeutical area

In case of inhaling the air of the therapeutical area, by the highest radon concentration of the therapeutical water (85.9 Bq/dm^3) the growth ratio altered between 3.4 and 286.4. No relationship can be discovered between the growth ratio of the radon concentration in the air exhaled and the radon concentration of the therapeutical water.

Air sample survey results when breathing from diving cylinder

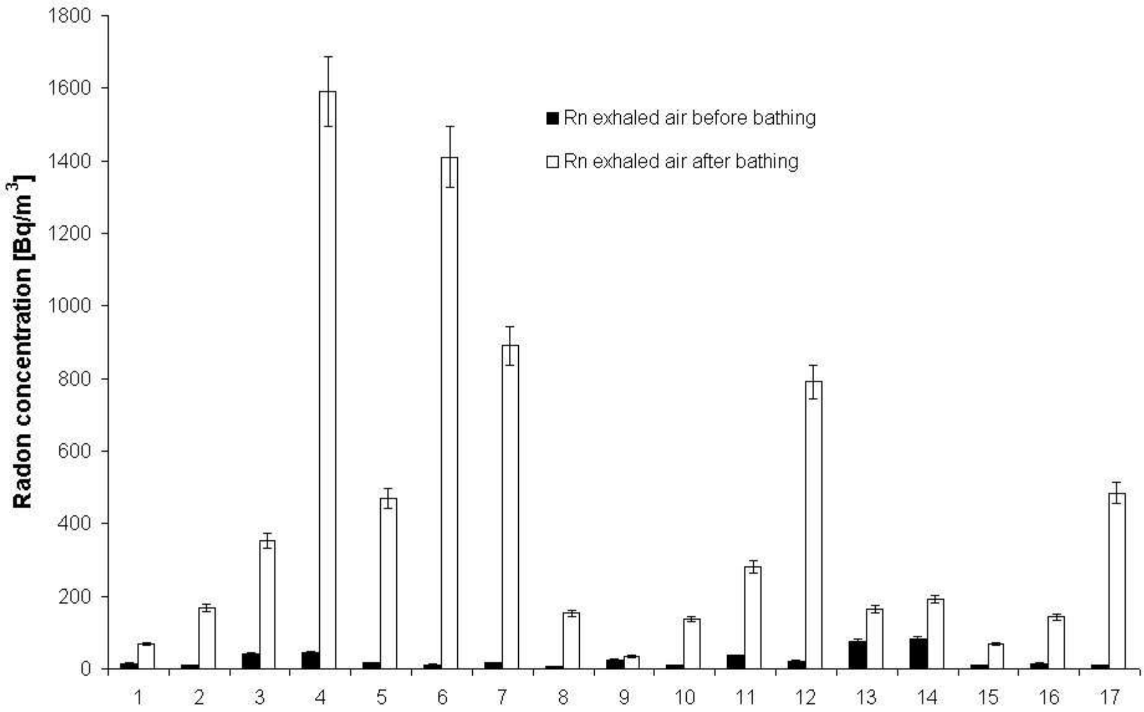


Figure 13 Changes of the radon concentration of air samples before and after staying in the therapeutical water, when breathing from a diving cylinder

Figure 13 shows the radon concentration of the air exhaled by the volunteers before entering the therapeutical area, and after staying there for 60 minutes, while breathing from a diving cylinder, without inhaling the air of the therapeutical area. In case of the 17 volunteers the average radon concentration of the air exhaled before entering the bath was 26.4 Bq/m^3, its highest value was 83.2 Bq/m^3, and the lowest value was 5.9 Bq/m^3. Just as in the case of breathing without a diving cylinder, the differences cannot be explained yet. Table 6 shows the radon concentration distribution values of the 34 air samples inspected before entering the bath. The values changed in the highest degree, 55.9 percent below 25 Bq/m^3.

After spending 60 minutes in the bath and breathing from an oxygen bottle the average radon concentration of the air exhaled was 435.3 Bq/m^3, its highest value was 1590.8 Bq/m^3, and the lowest value was 34.6 Bq/m^3. These great differences cannot be explained yet either. The distribution values of the results obtained are shown in table 7. In the highest degree, 52.9 percent, the values changed below 199 Bq/m^3.

Table 6 Distribution values of the radon concentration of air samples before entering the bath

Distribution interval [Bq/m^3]	**Distribution percent [%]**
>200	2.9
100-200	5.8
50-99	8.9
25-49	26.5
<25	55.9

Table 7 Distribution values of the radon concentration of air samples when breathing from a diving cylinder

Distribution interval [Bq/m^3]	**Distribution percent [%]**
>1500	5.9
1000-1500	5.9
500-999	11.8
200-499	23.5
<199	52.9

Comparing radon concentration values before and after staying in the bath, an increase beyond the error limit can be observed everywhere without exception. The average growth concerning 17 cases was 24.7 times, the highest growth was 119.5 times, and the lowest growth was 1.4 times. After spending 60 minutes in the therapeutical water and breathing from a diving cylinder, a higher radon concentration could be measured related to the initial values, which expressly proves that radon enters the human organism through the skin, and then it leaves the body with the air exhaled.

The comparison of these ratios with the data obtained when inhaling the air of the therapeutical area is shown in table 8. It can be observed, that when staying in the therapeutical water the air of the therapeutical area is inhaled, the ratios grow reaching almost twice the value. At the same time, this summary is deceptive, as in 6 cases from 15 the ratio was greater when the patients were breathing from a diving cylinder. Therefore, taking the test parameters into consideration, it cannot be stated that if radon absorption also happens through the respiratory organs, not only through the skin, then it increases the radon-content of the air exhaled, related to the radon absorption through the skin.

Table 8 Comparing test parameters

Parameters	**Inhaling the air of the therapeutical area**	**Breathing from an oxygen bottle**
Number of volunteers	15	17
Ratio of the growth of radon concentration during the test		
Average value	56.5	24.7
Highest value	286.4	119.5
Lowest value	2.7	1.4

The comparison of the radon concentration of the air exhaled by the volunteers and that of the therapeutical water during the test is shown in figure 14. The changes of the radon concentration of the water between 65.4 and 85.9 Bq/dm^3 was not effecting the radon concentration of the air exhaled in any of the cases. When breathing from a diving cylinder, in case of the highest therapeutical water radon concentration (85.9 Bq/dm^3) the growth ratio changed between 2.1 and 37.5. No relationship can be found between the growth ratio of the radon concentration of the air exhaled and the radon concentration of the therapeutical water.

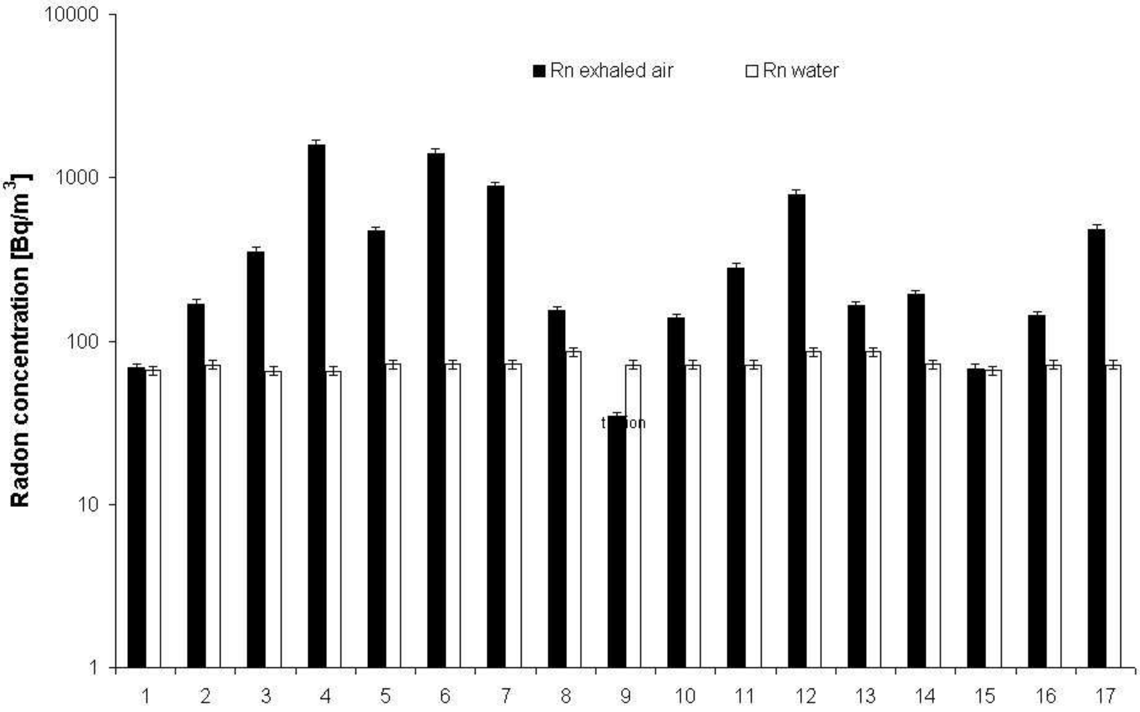


Figure 14 Radon concentration of the air exhaled and that of the therapeutical water when breathing from a diving cylinder

Urine sample test results

Radon absorption through the skin was tested by 12 persons (5 women, 7 men) by determining the radon-content of urine. Before the commencement of the experiment the test subjects drank tested radon-free mineral water or beer, at least half a litre. During the first day they spent approximately one hour in the bubbling pool, while they were breathing in tested radon-free air from diving cylinders. On the second day the same happened, but they were breathing in the air of the air space. Urine sampling was collect before starting and after taking the bath. Figure 15 shows the radon concentration values of urine measured when breathing from a diving cylinder. In seven cases there was no change beyond the error limits, and in five cases a decrease in the radon concentration of the urine samples was be observed. Figure 16 shows the radon concentration values of urine measured when breathing without a diving cylinder. In seven cases there was no change beyond the error limit, decrease could be observed in five cases, while increase in two cases, but one person from the latter spent 137 minutes in the bath. Eight persons exhaled 500 Bq/m^3 radon, and five persons exhaled 1600 Bq/m^3. The two increased values could be observed in the case of 500 Bq/m^3.

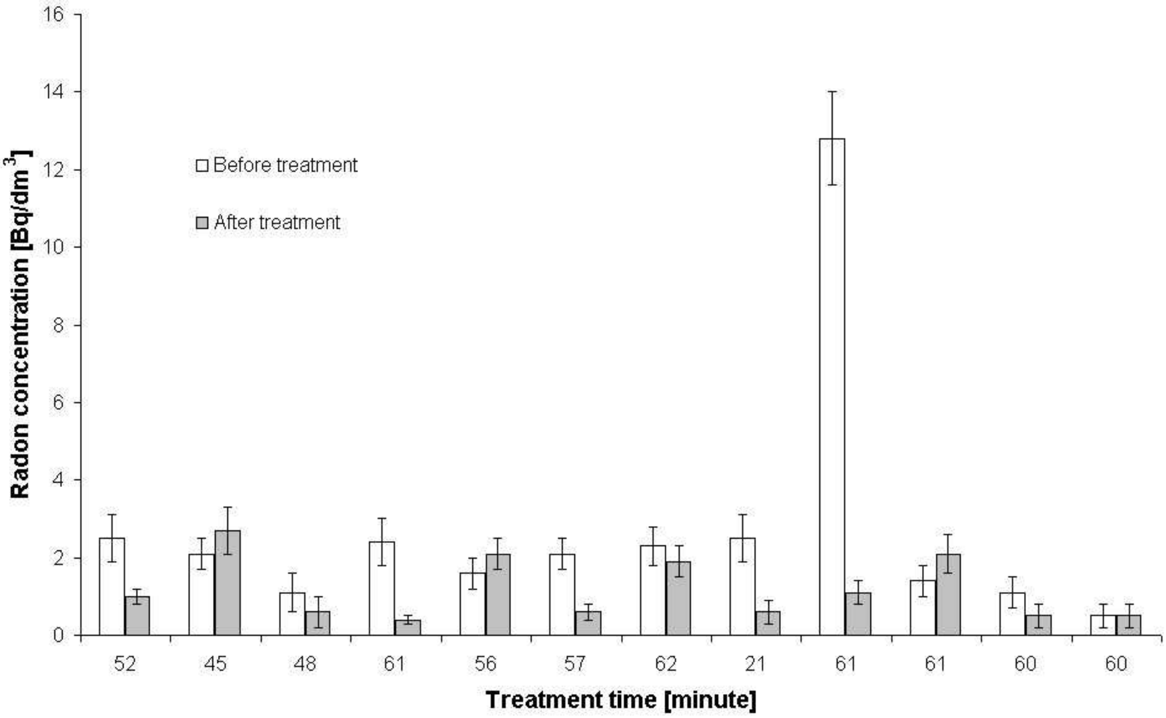


Figure 15 Changes of radon concentration values in urine samples before and after the treatment, when breathing from a diving cylinder

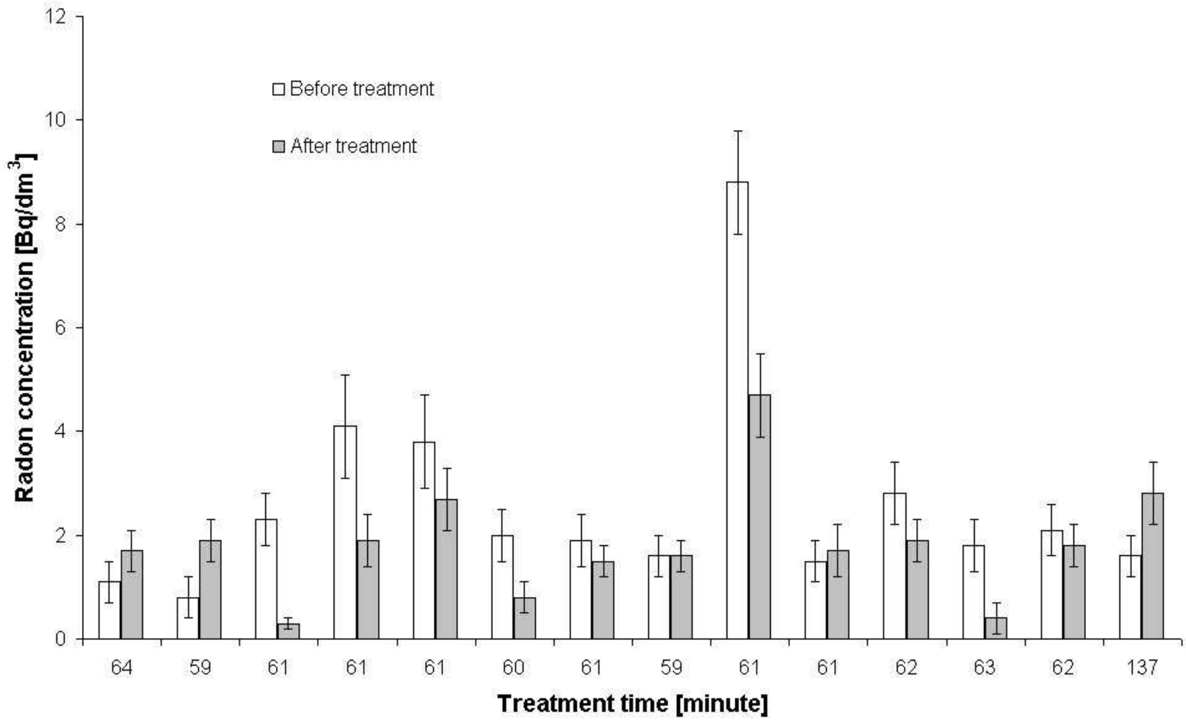


Figure 16 Changes of radon concentration values before and after the treatment, when breathing the air of the therapeutic area

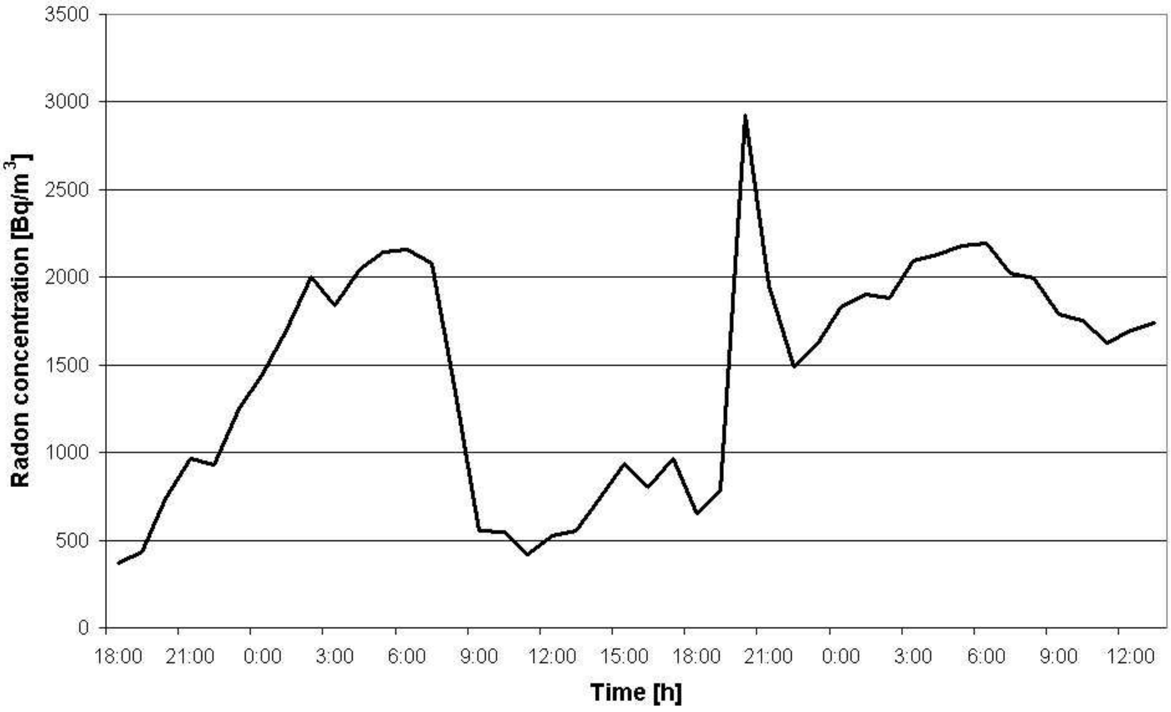


Figure 17 Changes of radon concentration in the air space of the bubbling pool during the inspection of urine samples

V. Test assessment, discussion, conclusion

Test No. 1

Statistical data did not show significant difference in the hormone levels examined. However, after analyzing the examined values in detail, individual changes were found.

Concerning TSH, hormone results before the treatment in the Turkish bath were in the normal range, except for one. Remarcable changes were found by 3 patients. One patient of the three was in the state of latent hyperthyreosis without any clinical symptoms by the beginning of the treatment. After the treatment, thyroid overfunctioning already showing itself in the form of manifested clinical symptoms occurred, which required medicinal treatment. Before the bath treatment one of the two euthyreoid patients with normal thyroid functions had latent overfunctioning, hyperthyreosis due to the bath treatment, the TSH value of the other patient decreased to the lower limit value of the normal value. The TSH value of the majority of patients decreased by the end of the treatment, which referred to the enhancement of the thyroid operation, although, it still remained within the normal range. In Hotel Flóra, before and after the bath treatment, the TSH values were within the normal range by the majority of the patients, and increased in a small degree by the end of the treatment.

Concerning prolactin, hyperprolactinemia, that is increased serum prolactin level was detected by 5 patients before the treatment in the Turkish bath, and this was significant in the case of 2 patients. After the bath treatment the serum prolactin level of two patients increased further, however, the high prolactin level before the treatment of the others decreased, and even the prolactin level of one of them entered the normal range. From the patients with normal prolactin level before the treatment, the prolactin level of 4 patients after the treatment exceeded the upper limit of the normal treatment, although only a little. In case of those treated in Hotel Flóra, one of the patients had expressly higher prolactin level before the treatment, which decreased by the end of the treatment, other important changes were not detected. Opposed to those experienced in the radon bath, no abnormal increase in the prolactin level was detected. By determining cortisol and ACTH in the Turkish bath before starting the treatment, a decrease was detected by patients with higher serum cortisol level, and by patients with lower cortisol level, distribution within the normal value range was found. Regarding ACTH levels, no important changes were found. By the comparison of ACTH and cortisol levels the classical feed-back mechanism was not detected, so a significant decrease in the cortisol level did not cause an increase in the ACTH level. Among patients taking the bath in Hotel Flóra, the cortisol and ACTH levels changed within the normal range. Regarding DHEAS, no changes were detected by individual cases.

Bath treatment with radon-content is more and more popular among patients. According to some data, the risk factor of radioactivity does not influence patients when taking the bath [42]. At the same time, data on taking the radon bath and the frequency of the appearance of lung cancer are contradictory [43]. Radon bath is used for illnesses of the motion organs, mainly for spondylarthritis ankylopoetica and rheumatoid arthritis [44], but, for example, the beneficial effect on the system of free radicals has also been proved [45]. During our work, it was found concerning corticoids, that radon bath increased lower cortisol level, and decreased higher cortisol level, taking a modulating effect. Japanese authors found increased ACTH and endorphine level after the radon bath, proving its pain-killing effect [46].

Conclusion:

Radon treatment may have an effect on hormones, it has a high probability of enhancing the operation of the thyroid, it has an effect on the hormone-production of the adrenal gland, and it can have provocative effect in case of latent or manifest hyperprolactinaemia. Radon treatment of those suffering from endochrinological illnesses, especially patients with thyroid illnesses requires enhanced precaution.

Test No. 2

Cave therapy is one of the most popular forms of treatment for chronic respiratory illnesses [47,48]. The cave in Tapolca has been used for medication purposes in Hungary for decades, and radon is continuously being measured in the cave [49,50, 51]. Radon concentration in the Hospital cave in Tapolca is different in the winter and in the summer, it is lower in the winter, and higher in the summer. It was supposed that in the summer, in case of higher radon concentration more significant changes would be found in the hormone levels of the patients.

However, in opposition to our expectations it seems that the climate with lower radon-content in winter caused more significant individual changes than the air with a higher radon-content in the summer. The main cause for this is not known yet.

Thyroid:

Summer values

Inspecting separately some cases falling out of the normal range in the group treated during the summer months, only slight changes could be detected in the operation of the thyroid gland. At the beginning of the treatment the values of 3 patients were not within the normal range. The condition of the two patients suffering from latent hyperthyreosis did not deteriorate during the treatment. By the end of the treatment the fT4 and fT3 values of both patients remained within the normal range. The rather high TSH value of a patient suffering from severe hypothyreosis slightly moderated, and the fT4 value slightly increased due to the cave therapy.

Winter values

Highlighting the individual cases falling out of the normal range, the number of patients with abnormal thyroid gland functioning was originally higher, and the effects of the treatment on the thyroid gland functioning were more expressed than by patients in the summer period. At the beginning of the treatment one of the patients had manifest T3 hyperthyreosis. The treatment did not deteriorate initial parameters. At the same time, in case of one of the four patients suffering from latent hyperthyreosis at the beginning of the treatment, the treatment provoked also T3 hyperthyreosis, however, latent hyperthyreosis of the other 3 patients did not worsen due to the treatment. Cave treatment in the winter did not significantly influence the values of the three latent hypothyreotic patients. The hormone levels of 2 male patients from those being in euthyreoid condition at the beginning of the treatment became abnormal after the treatment. By one of them manifest T3 hyperthyreosis, in case of another one latent hyperthyreosis with FT4 level close to the limit value formed.

Adrenal glands

During the treatment significant effect on the DHEAS level neither in the winter, nor in the summer could be detected. At the same time, the initial serum cortisol level was significantly higher in the winter than in the summer, and as a result of the treatment in the winter significant ($p<0.01$) decrease was found. The cause of this could not be found yet, but it is supposed that the winter treatment caused a more enhanced stress situation for the patients, and then the stress-relieving effect predominated.

If during the analyzis of the data the gender is also taken into consideration, then a significant decrease is found by women in the cortisol concentration ($p<0.01$) of the blood samples before and after the treatment.

Hypophysis cerebri

Significant change could not be detected during the therapy by the hormones produced by the hypophysis either. However, in hyperprolactinaemic cases the prolactin level remarkably increased both during the winter and summer months. During the winter months (by lower radon concentration) a more significant increase could be observed, however, the statistical analysis could not be evaluated due to the small number of cases.

Conclusion

Based on the above, it can be stated that the treatment carried out in the cave with radon-content has an effect on endocrine organs. These influences did not show to be irreversible, but during the establishment of the radon therapy indication, anamnesis-related data should be given sufficient attention. Patients suffering from proven endocrinological illnesses requires special care.

Test No. 3

Treatments in the Turkish bath in the majority of the cases are carried out by inhaling 500 Bq/m^3, and in therapeutical water with an average of 80 Bq/dm^3, resulting in proven healing effect. This is important as related literature do not mention application of such low activities in radon therapy. However, healing indices show that the treatments are efficient. Regarding the future, from radiation protection aspect it would be important to determine the minimum, but yet efficient therapeutical radon concentration values.

Radon was measurable in the initial sample of each tested person, which provides evidence, that when people get into touch with this gas during their everyday activites, it enters the human body and leaves it with urine. Therefore, if a greater quantity of radon enters the human body, then it will expectably appear in urine after some time. How much this “greater quantity” of radon is, it still needs to be clarified. The radon concentration values of tested initial samples changed between 0.5 and 12.8 Bq/dm^3. In case of the latter high value it seems to be practical to carry out a radon survey in the dwelling area and drinking water of the test subject, as radon concentration of about 10 Bq/dm^3 could be observed during two consecutive days in the given urine.

On the basis of the results it can be stated that during spending about 1 hour in the therapeutical water (80 Bq/dm^3) the absorption of radon through the skin cannot be detected by the analyzis of urine samples.

The 34 exhaled air samples of the volunteers before entering the therapeutical area of the Turkish Bath in Eger already contained detectable quantity of radon, the activity concentration of which changed between 4.2 and 239.2 Bq/m^3. At the same time, from the aspect of distribution, by 55.9 percent of the samples radon concentration was below 25 Bq/m^3. What it depends on, cannot be exactly stated, it is not known yet, but it is surely influenced by the radon concentration of the air inhaled and physical characteristics not yet identified of the person. After spending 60 minutes in the therapeutical water and breathing in the air of the therapeutical area, an increase beyond the error limit could be observed in the air exhaled, related to the initial values, except for two cases. It changed between 27 and 1397 Bq/m^3, and most frequently (41.2 %) between 500 and 999 Bq/m^3. During the inspection the maximum radon concentration value of the air of the therapeutical area was 1616 Bq/m^3. This was not exceeded by the radon concentration values measured in the air exhaled. By the two exceptional cases the volunteers stayed in the therapeutical area with lower radon concentration (433 Bq/m^3) for 60 minutes, which was not enough for an increase in radon concentration exceeding the error limit. Since it is only two cases, no drastic consequences should be drawn from them.

After spending 60 minutes in the therapeutical water and breathing the radon-free air from the oxygen bottle, an increase of the radon concentration beyond the error limit could be observed in each case in the air exhaled, related to the initial values. This value changed between 34.5 and 1590.8 Bq/m^3, and most frequently (52.9 %) it was below 199 Bq/m^3.

Conclusion

Taking the test conditions into consideration it can be stated that radon is capable of entering the human organism through the skin during the bath therapy, and then leaving it in a measurable quantity with the air exhaled. During the survey the radon concentration of the therapeutical water changed between 65.4 and 85.9 Bq/dm^3, which did not have any influence on the radon concentration increase of the air exhaled. The tests were carried out in relatively identical situations, still, the radon concentration in the air exhaled by the volunteers varied on a rather wide scale. Based on this it can be stated that the human body may take up and excrete radon in different ways, depending on yet unknown physical parameters.

VI. Summary

The objectives of the thesis is testing the physiological effects generated by the radon bath and radon cave, proving beneficial effects on patients, or filtering any hazardous effects.

Radon is a colourless, odourless noble gas, its atomic number is 86, its boiling temperature is -62 °C, its melting point is -71 °C, at room-temperature and under atmospheric pressure it is gaseous. It is soluble in water and in different organic solvents. Radon is present in radioactive medicinal waters partly in a form dissolved in water, on the other hand, in the form of gas not dissolved in water, which emerges in the form of bubbles. According to the supposed mechanism of activity, during taking a radon bath, radon absorbed in water can directly be absorbed through the skin, while radon emerging and entering the air space over the pool takes its effect when inhaled as a natural inhalatorium. The healing effect of thermal waters containing radon has been known in medicine for a long time, and has been used throughout the world. Most of the literature data agree with the pain-killing effect of the radon bath. Besides the pain-killing effect it is supposed that it promotes increased evolvement of capillaries, it intensifies uric acid excretion, activates adrenalin-production, decreases DNA-synthesis, strengthens DNA-repairing mechanisms, increases the activity of the protective system and the functioning of the genitals. Its application is primarily recommended in case of rheumatic arthritis and painful neuritis (neuralgia), and degenerative spinal and articular deformations. The duration of the bath is usually 15-20 minutes, and the temperature of the water is 33-34 °C. The bath treatment is effective if it is taken frequently as a course (after 15-20 bath treatments). There are three methods in radon therapy: water-drinking, bathing, breathing therapy (inhalatorium). Inspecting the efficiency of these methods, even literature provides different data. During the therapies radon entering the human organism is able to reach every tissue of the body with the help of the circulatory system, and then it leaves the body through the lungs, and with the help of the organs of elimination, therefore, in theory radon can be measured in the air exhaled and in excretion products.

My clinical and experimental tests carried out using radon-balneotherapy cover 3 topics.

1) The effects of radon bath on the endocrine paramters of rheumatic patients

2) The effects of caves containing radon on the endocrine parameters of patients suffering from respiratory illnesses

3) Inspection of radon absorption through the skin, and the occurrence of radon in the air exhaled and in urine

1179 samples (blood, urine, air) of 157 patients were analyzed during the survey.

1) Radon bath is a balneotherapeutical treatment, which has been used in treating degenerative musculosceletal illnesses for a long time. There are hardly any literature data on its effects on endocrine functions. In our study we were looking for the answer for the question, whether a bath with a relatively low radon-content (80Bq/l) influences the operation of the endocrine system.

During the inspection 27 patients suffering from degenerative musculosceletal illnesses received 32 ºC radon bath treatment (80 Bq/dm^3) for 15 days, 30 minutes a day.

As a control group 25 patients suffering from degenerative musculosceletal illnesses of similar conditions received thermal water treatment with a negligible radon-content (6 Bq/dm^3). Analyzing the obtained values usin Student's test significant differences were gained neither in values before and after the treatment, nor in comparing the changes of the two groups. Although, due to the great spread the result did not prove to be statistically significant, reviewing the cases it can be stated that radon can influence the functioning of the thyroid gland. Radon treatment of patients suffering from proven endocrinological illnesses requires special care, especially in case of patients suffering from thyroid illnesses.

2) Cave therapy is a kind of complementary treatment when treating patients suffering from chronic respiratory illnesses. The radon concentration of the cave with radon-content in Tapolca is different in the winter and in the summer, due to the different weather conditions. The objective of our survey is to find out, whether staying in the cave with radon-content influences the functioning of the endocrine system depending on the concentration. 81 patients took part in the survey. The following were inspected by 46 patients during the summer period, by a higher radon-content, before and after the treatment: thyreoiedea stimulating hormone, free triiodthyronine, free thyroxine, prolactin, cortisol, dehydro-epi-androsterone sulphate, corticotropin, beta-endorphin. The same tests were carried out by 35 patients during the winter period. Patients spent 4 hours a day in the cave for 3 weeks. FT4 and cortisol values significantly decreased in the winter after the treatment, but the values remained within the normal range. Changes were also detected in other hormones, but these were not significant, at the same time, significant hormone fluctutation could be clinically detected by several patients suffering from illnesses of the thyroid gland. Radon cure has an effect on endocrine organs, however, it did not prove to be irreversible. Radon treatment of

patients suffering from proven endocrinological illnesses requires special care, especially in case of patients suffering from thyroid illnesses.

3) In case of each person tested radon could be measured in the initial urine sample, which proves that when people get into touch with this gas during their everyday activites, it enters the human body and leaves it with urine. Therefore, if a greater quantity of radon enters the human body, then it will expectably appear in urine after some time. How much this “greater quantity” of radon is, it still needs to be clarified.
The radon concentration values of tested initial samples changed between 0.5 and 12.8 Bq/dm^3. On the basis of the results it can be stated that during spending about 1 hour in the therapeutical water (80 Bq/dm^3) the absorption of radon through the skin cannot be detected by the analyzis of urine samples.

The 34 exhaled air samples of the volunteers before entering the therapeutical area of the Turkish Bath in Eger already contained detectable quantity of radon, the activity concentration of which changed between 4.2 and 239.2 Bq/m^3. At the same time, from the aspect of distribution, by 55.9 percent of the samples radon concentration was below 25 Bq/m^3. It is not known yet what influences the radon concentration of the air exhaled, but besides the radon-content of the air inhaled, certain physical characteristics of the persons tested also play an important role. After spending 60 minutes in the therapeutical water and breathing in the air of the therapeutical area, an increase beyond the error limit could be observed in the air exhaled, related to the initial values, except for two cases. It changed between 27 and 1397 Bq/m^3, and most frequently (41.2 %) between 500 and 999 Bq/m^3. Radon concentration values measured in the air exhaled did not exceed the radon concentration of the air of the therapeutical area in any of the cases. By the two exceptional cases the volunteers stayed in the therapeutical area with lower radon concentration (433 Bq/m^3) for 60 minutes, which was not enough for an increase in radon concentration exceeding the error limit. Since it is only two cases, no drastic consequences should be drawn from them. After spending 60 minutes in the therapeutical water and breathing the radon-free air from the oxygen bottle, an increase of the radon concentration beyond the error limit could be observed in each case in the air exhaled, related to the initial values. The radon-content of the air exhaled changed between 34.5 and 1590.8 Bq/m^3, and by half of the cases it was below 199 Bq/m^3. Taking the test conditions into consideration it can be stated that radon is capable of entering the human organism through the skin during the bath therapy, and then leaving it in a measurable quantity with the air exhaled. During the survey the radon concentration of the therapeutical water changed between 65.4 and 85.9 Bq/dm^3, which did not have any influence on the radon concentration increase of the air exhaled. In spite of the fact that the tests were carried out in relatively identical situations, the radon concentration in the air exhaled by the volunteers varied on a rather wide scale. Based on this it can be stated that the human body may take up and excrete radon in different ways, depending on yet unknown physical parameters.

VII. New results of the thesis

1) During treatments carried out in baths with a relatively low radon concentration it was found that the bath with radon-content does not significantly influence the endocrine system, but during the detailed individual analysis of the results the conclusion was drawn that the radon bath treatment may have an influence on hormones, it probably increases the functioning of the thyroid, it influences the hormone production of the adrenal gland, and may have a provocative effect in case of latent or manifested hyperprolactinaemia. Radon treatment of those suffering from endocrinological illnesses, especially thyroid patients requires special precaution.

2) The cave therapy with radon-content effects endocrine organs. These influences did not show to be irreversible, but during the establishment of the radon therapy indication, anamnesis-related data should be given sufficient attention. Radon cave treatment of patients suffering from proven endocrinological illnesses requires special care, especially in case of patients suffering from thyroid illnesses.

3) Based on our results it can be stated that during approximately 1 hour spent in therapeutic water (80 Bq/dm^3) the absorption of radon through the skin cannot be detected with the analysis of urine samples.
Taking the test conditions into consideration, inspecting the radon-content of the air exhaled it was managed to be proved that during the bath therapy radon is able to enter the human body through the skin, and then to leave it through the lungs with the air exhaled, in a measured quantity. During the inspection the radon concentration of the therapeutic water varied between 65.4 and 85.9 Bq/dm^3, which did not cause any influencing effect on the radon concentration increase in the air exhaled. During the tests carried out in relatively identical conditions, the radon concentration in the air exhaled by the volunteers still varied on a large scale. Based on these, it can be stated that the human body may take up and excrete radon depending on physical parameters unknown for us at the moment.

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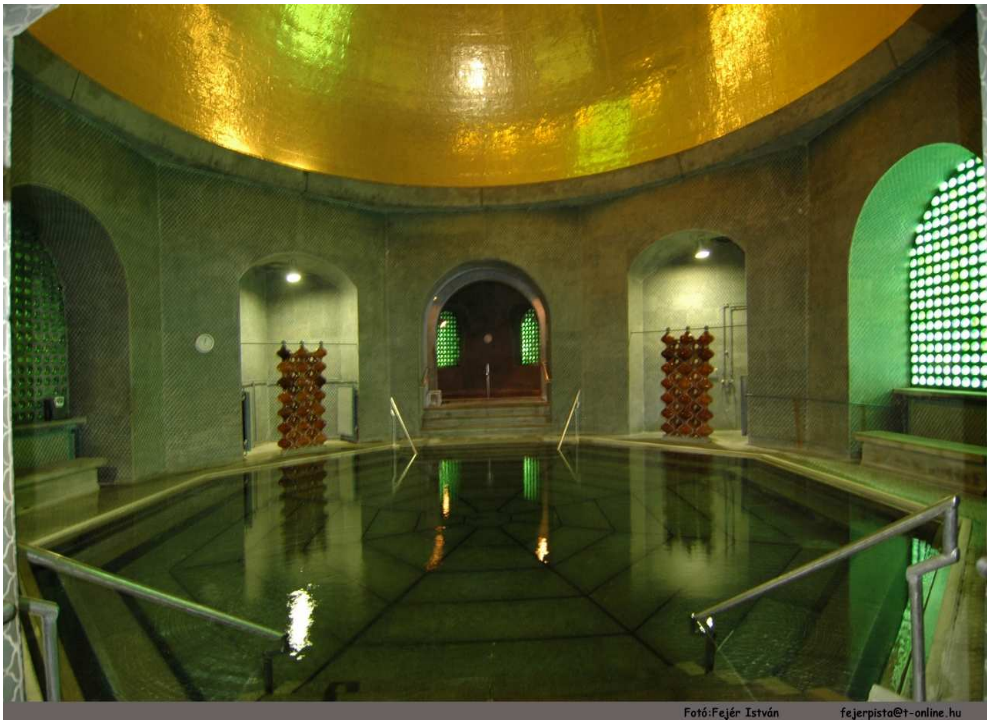
X. Appendix

The therapeutic cave of Tapolca

The Turkish Bath of Eger



Laboratory No 1. with facilities and accessories

Laboratory No. 1. with diving cylinders, Lucas cells on the floor, vacuum pump by the window

Lucas cell and single-canal analyser in lab No 2. (dark chamber)

Continuous radon measurement system in the therapeutic area

Volunteers are bathing in the therapeutic water whilst breathing in the air of therapeutic area

Volunteers in the therapeutic water are breathing in from Volunteers in the therapeutic water are breathing in from diving cylinder