
One century of radon therapy

Klaus Becker

Vice-President, Radiation Science & Health,
Boothstr 27, D-12207 Berlin, Germany
E-mail: prof.dr.klaus.becker@t-online.de

Abstract: Supplementing a recent review 'Health effects of high radon environments in Central Europe: another test for the HLNT hypothesis [1]', this review of medical radon applications (in particular for the treatment of painful degenerative joint and spine diseases) covers mainly the first century of large-scale use and scientific studies on this subject since the discovery of radon. Most of the studies and experiences originated in Europe, in particular Germany, Austria, and the former USSR. They have in common that they are not well known in the anglophonic scientific literature, where radon therapy is still frequently considered a placebo-type 'traditional medicine', and not be compared with the drugs such as non-steroid antirheumatics. However, based on the substantial experiences as reflected in more than one thousand papers, mostly in peer-reviewed scientific journals, on this subject, radon therapy by inhalation or baths has been established as an evidence-based effective treatment not only by empirical experience in different times and cultures, but also in randomised clinical double-blind studies. It should be further explored as an effective alternative to the use of pharmaca. Unlike radon, drugs cause serious side effects, with more than ten thousand annual casualties. The benefits in the adequate use of low-dose radon exposures far exceed the hypothetical lung cancer risk attributed to the inhalation of low radon concentrations. Further research could provide better understanding of the mechanism of the stimulating radon effects on the body's defence systems.

Keywords: radon therapy; medical radiation benefits; history of radiation effects and applications; radon balneology.

Reference to this paper should be made as follows: Becker, K. (2004) 'One century of radon therapy', *Int. J. Low Radiation*, Vol. 1, No. 3, pp.333–357.

Biographical notes: Dr. Klaus Becker is MS in Chemistry at Berlin Free University, and PhD on radiation dosimetry at Munich Technical University. He was head of radiation research groups at Jülich Nuclear Research Center and Oak Ridge National Laboratory, and 1975–1998 Director of DIN German Nuclear Standards Committee, and of the Technical Committee 'Nuclear Energy' of ISO. He has also been consultant for IAEA, WHO, etc. in about 25 countries. He has to his credit more than 300 scientific publications, several books and patents, mostly on radiation measurements, radiation protection, and standards. He has been involved in many national and international advisory bodies, conferences, societies, and journals. Since 1993, Becker is also Vice President of 'Radiation, Science Health'.

1 Introduction

About a century ago, the therapeutic use of the newly discovered gaseous ‘emanations’ from the radioactive elements radium and thorium commenced in Central Europe on a rapidly expanding scale. However, relatively little is known in the English-language scientific and popular literature about the therapeutic use of Rn-222, the noble gas which is a decay product of Ra-226 (with a varying contribution of its further radioactive decay products known as radon daughter products, or progeny, in this review summarised as ‘radon’). Instead, reports about the potential health hazards of radon in mines and homes, claimed to cause large numbers of lung cancers, dominated the scientific and popular literature in recent decades (for reviews, see [1–4]). Neither a book on radon politics in the USA [5], nor the Radon Literature Survey Series of the US DOE (e.g. [6]), and various reports on radon effects by ICRP, NCRP, BEIR IV, BEIR VI, or UNSCEAR even mention biopositive radon effects; and in a recent letter exchange in a leading radiation protection journal [7] the term ‘radon spa’ has even been suggested to be an ‘oxymoron’.

It is the purpose of this review to provide a compilation for the interested readers who are not familiar with the substantial experiences and literature in Europe, where radon therapy, in particular for the treatment of painful inflammatory and degenerative joint and spine diseases, has long been valued, with an overview of the information and experience which has accumulated in more than one thousand scientific publications, mostly in peer-reviewed medical journals.

There have been several stages in the history of radon therapy, including the times when it was only indirectly known by its positive health effects millennia ago; the first decades of scientific exploration of its properties and concentration in various sources of mineral waters after its discovery, and uses in old or newly established therapeutic facilities. During this period, the terms ‘radium’ and ‘radon’ were used frequently as synonyms, resulting in names such as ‘Radiumbad’ in German-speaking countries. Soon the careful medical supervision of the treatment procedures and their results was initiated with many reports on the results, thus narrowing the sometimes very wide spectrum of applications essentially to the first known uses, namely painful rheumatic and arthritic joint and spine diseases. In particular in the former Soviet Union, radon therapy was studied and used, with numerous publications on this subject and over a million annual treatments. However, some other applications, such as the use of sealed capillaries filled with radon for local tumour treatment in the USA, or radium compresses for external treatment of various ailments, are not covered in this review.

Occasionally, doubts about the merits of radon therapy have been expressed and are still common in parts of the medical community, e.g. in comparing it with various types of ‘traditional’, ‘natural’, or ‘folk medicine’ such as acupuncture, etc. as used for many centuries in Eastern Asia and Africa, or homeopathy, mostly in Europe. Some of such cures have been demonstrated in serious animal and human studies as being effective, while most of them clearly belonged to the category of ‘alternative medicine’ based on the firm belief on the desired effect. Radon therapy should not be confused with this type of treatments, as well as with some other treatments. E.g.

- in many cultures, traditional use of hot springs for increasing the general feeling of well-being and relieving various old-age problems (in Northern Japan, even monkeys enjoy hot springs in winter)
- the ‘speleotherapy’ of bronchial asthma in the allergen-free atmosphere of NaCl or KCl salt mines, with a long tradition in Central and Southeastern Europe (e.g. the Wielizka mine near Krakov)
- the old habit of adding herbs, spices, salts, etc. to bathing or drinking water assumed to improve their beneficial effects.

As it turned out, radon did not belong into this category, and in fact helped to prevent serious side effects of the pharmaceutical treatment of painful rheumatic and arthritic diseases: While it is estimated that, for example, approx. 12,000 persons annually die from side effects of non-steroid antirheumatic drugs such as ASS and diclophenac (mostly due to stomach problems and internal bleeding) in the USA, and more than 1,000 in Germany [8], no lethal complications have ever been observed from radon treatments. In addition, it also enjoys an advantage of being inexpensively available in poorer parts of the world without affordable access to commercial pharmaceuticals for a large part of the population. Incidentally, the term ‘radon spa’ may be somewhat confusing, because in some countries a ‘spa’ is more associated with entertainment, ‘wellness’, weight reduction, drug abuse correction, etc. In a modern European radon spa, patients, with the treatment mostly paid for by the governmental health insurance, usually stay for about three weeks in clinics and receive the radon treatment under careful medical supervision as a prescription with careful control of the results. Nevertheless, the different and normally more healthy and relaxed environment, stimulation by a different climate, new social contacts, and other factors certainly contribute to a feeling of improved well-being. However, new randomised double-blind studies demonstrated distinctive long lasting additional positive radon health effects.

2 Therapeutic experiences before the discovery of radon

Palaeolithic offerings found near The Gastein sources in Austria suggest that already in prehistoric times therapeutic radon effects may have been appreciated there. As far as known, the Italian island of Ischia in the volcanic area around Naples, discovered by Greeks from Euböa about 2500 years ago, has been the first place in which warm radon sources have been used on a larger scale, and continue to be used for therapeutic reasons [9]. Antique artificial grottoes and bathing tubs cut out of the rocks cannot be exactly dated, but have in common a high radon concentration of the water.

The first written documents on health effects observed in Ischia are by Gulio Jasolino in 1559 on ‘the natural therapy on the island Ischia’, followed in 1835 by a book by Chevalley de Rivaz. In 1917, Curie discovered high radioactivity in Lacco Ameno and identified it as radon. The treatment is usually by inhalation or bathing, and also with sand which is also heated by emerging volcanic steam. The main indications for treatment are arthropathies [10]. It is likely that the use of the famous old spas in the alpine regions of northern Italy such as Merano (2,000 Bq/L in spring water) and Lurisia (40,000 Bq/L) [11] also date back more than two thousand years to ancient Roman times. Another example is Steben/Germany, with records of ‘strange properties’ of a radon

source from 1473, and the medical properties of this source described in 1690 [12]. In other cultures such as Japan, the radon effect (e.g. in Misasa) has also been a matter of empirical experience for many centuries.

There are numerous other locations now known as radon therapy facilities which have already been used as spas long before knowledge of ionising radiation and radon. It was generally known since the Middle Ages that the miners in the silver mines of Saxony/Germany and nearby St. Joachimsthal in Bohemia (now Czech Republic), although working under very difficult and generally unhealthy conditions and frequently suffering (and dying early) from lung diseases [1], had less problems with arthritic and similar diseases than the rest of the population. Therefore, the miners had sometimes uranium containing ore residues sewn into their clothes. They drank water which originated in the mines, and the local population used pitchblende (U ore) packages for the external treatment of inflammatory diseases [12]. Bruschius already wrote in 1548 in a description of the high radon Fichtelgebirge/Germany: "Here people get very old, have few diseases, and recover quickly if they have any."

Known for many important medical discoveries such as the fundamental truth, "It is the dose which makes a poison", the famous mediaeval physician Paracelsus devoted in 1525–1527 a chapter of a book on health sources to 'bat Castein' (Bad Gastein/Austria – Windischbauer [13]), and in 1780 the 'Thermis Gasteinensibus' (Gastein thermal baths) were the subject of a dissertation. In 1553 and 1571, encyclopaedias about health spas were published [14], and 1828 it was noticed that the electrical properties of the waters in Gastein were different from those of ordinary water. Half a century before the discovery of radioactivity, the famous German chemist Justus Liebig was advised by his physician to visit Gastein for treatment, but at first he refused to go there because his chemical analysis of the local water showed no analytical evidence of being much different from his home tap water. After further medical advice, Liebig eventually underwent the treatment and found relief. He concluded that an unknown constituent, perhaps 'something electric', was responsible for this effect.

Results published in 1864 also concluded that "electricity is the main reason for the effect of the sources on the organism" in Gastein. Thus, radon spas have been popular in quite different cultures and at times long before radon had been identified. It was also known for a long time that water from such sources, used long after having been bottled, did not have the healthy effects of 'fresh' water, thus indicating the presence of a fairly rapidly decaying factor in the water.

Even after it was first pointed out in England in 1903 and almost simultaneously in Germany in 1904 that radioactive gases are responsible for the therapeutic effects of such sources, more or less accidental 'discoveries' of positive radon health effects continue up to recently in areas where little or nothing had been known about radon therapy. For example, some former uranium mines around Boulder/Mont./USA such as 'Free Enterprise Radon Health Mine' started operation in the early 1950s. Some people even bring ageing cats and dogs for radon inhalation, and there were a few papers in popular journals [4,15] as well as a book on this subject [16]. Other, earlier attempts to establish radon therapy centres in Canada and the USA, including 'Lincoln Bath House' in Saratoga Springs/New York established in 1929, with the capacity to treat up to 4,500 people daily. There have also been 'Radium Springs' in Arkansas, Virginia, New Mexico, Georgia, Oklahoma, and British Columbia, but little is known about results of these spas (Muckerheide, pers. comm.).

3 The first decades of scientific studies on radon sources and therapy

The history of the radon discovery has been summarised earlier. The first publication about the radon in spa water (then called 'radioactive emanation', following a suggestion by Rutherford in 1900) appeared in two reports by Mache about the thermal sources of Gastein/Austria in 1904 [17,18]. Mache also introduced the first unit for radon activity concentrations, which was named after him (Mache-Einheit, ME) and mostly used in the German/Austrian literature, while the anglophonic countries preferred the 'Curie' that had been introduced in 1910. One ME corresponds to 364 pCi/L. Other units have occasionally been used, e.g. the 'Stat' (St), with 1 ME = 1 mSt/L, and the 'Eman', with 1 ME equivalent to 3,64 Eman. Other unusual units also appeared, and rather quickly disappeared. In summary, 1 Ci corresponds to 37 GBq, 1 Bq is 27 pCi, or 1 ME equivalent to 13,5 Bq/L. Other units are the potential Alpha-Energy Concentration (PAEC) and the Working Level (WL), from which the Working-Level Month has been derived as a product of concentration and exposure time. It is nowadays mostly used for minor exposures [19], and concentrations are usually presented according to the SI system in Bq/L for water, and Bq/m³ for air. In this review, all values have been translated into Bq.

In 1906, a list of the radon content in more than 30 sources in 11 spas in Austria, Bohemia, Germany and Italy was published [20], with values up to 80,000 Bq/L in Gastein/Austria, 70,000 Bq/L in Baden/Germany, and 182,000 Bq/L in Schlemma/Germany (Hindenburgquelle) [21]. Currently, the Wettinerquelle in Brambach/Germany is considered the world's strongest, but there are also Japanese claims to this record. The information about the activity of sources sometimes varies substantially due to specific conditions and uncertainties in the measurements, fluctuations in the source strength, evaporation of radon as a function of interaction time with the atmosphere, exact location, atmospheric condition, and many other factors. In one booklet [22], for example, values measured in March/April 1913 are given as 54,000 Bq/L in Schlemma/Germany in a source not available any more, 30,000 Bq/L in Brambach/Germany, 5,000 Bq/L on Ischia/Italy, and only 3,000 Bq/L in Gastein/Austria.

In some cases, high values have been claimed in order to make a spa more competitive. Regarding radon concentrations in the air of caves, former mine shafts, and other underground facilities, claimed radon concentrations require careful investigation with regard to the conditions and duration of the measurements. For example, in a 'hospital cave' in Hungary, variations between <1,000 Bq/m³ in winter and 22,000 Bq/m³ in summer have been measured. In another cave (Pal Valley Cave), the radon level dropped from 2,500 Bq/m³ to essentially zero within 3 hours due to a cold weather front on Dec. 21, 1994 [23,24]. Such pronounced fluctuations can to some degree be averaged by long term (3–12 months) integrating measurements by modern electronic or track etching detectors, but even then a reliability better than 20–30% can hardly be expected, and all values expressed in three or even four digit numbers indicate a profound lack of understanding radon metrology.

It should be emphasised that the interest in radon therapy had little or no relation to the popular fashion between about 1910 and 1940, mostly in Europe, to attribute a multitude of healing powers to radium. There have not only been external sources such as Ra-impregnated bed blankets and compresses, but also more importantly for Ra intake. For example, radium was added to many 'health food' items such as crackers, tea, coffee, and chocolate. A German patent of 1931 [25] describes how by adding radium bromide

radioactive chocolate can be made. There are numerous publications describing such unconventional ways of health applications of Ra as well as radon, e.g. in Ra-containing ‘emanators’ for producing radon drinking water. Many of these activities may nowadays be considered just as historical footnotes, while there seems, in the light of modern research on beneficial low-dose effects, to be more than a grain of truth in others, as hormesis has to be considered a central issue in modern toxicology [26].

Radon treatments can be carried out by inhalation from ‘natural’ sources, e.g. in mine shafts or caves, or by bathing in Ra-containing water. Drinking radon water became less common in recent decades. Of course, radon can also be produced independently from the availability of natural sources by extracting it from radium or other sources – first proposals for the therapeutic use in 1903 in England actually suggested the inhalation of thorium emanation for the treatment of tuberculosis [27] in 1904. First results of such a treatment have been published [28]. Radon uptake into the human body was studied in Germany [29]. The first radon treatments were carried out in Vienna, including experiments with the external application of uranium ore material, or uranium-containing sand in bathtubs in order to produce radon-containing water. The first specific application for acute and chronic rheumatism of joints was reported in 1907 in Bohemia [30], and a physician in Braunschweig/Germany [31] studied, using radon water made from Ra compounds, whether “in small concentrations emanation causes any constant reactions in the health of the human body”.

He treated patients for chronic joint rheumatism, and noticed that their reaction was very similar to those in spas. Further studies were summarised in two books by German scientists in 1912 and 1913 on radium therapy, biology, and research [32,33]. Many of these early studies were performed bathing in water prepared by long-time submersion of cloth-wrapped uranium ore residues in special water barrels. Several of the early investigators also looked for possible detrimental health effects, but could not find any. The first treatments with natural radon water (besides the traditional spas) at new locations selected for the high radon concentrations in the effluents of mines took place in St. Joachimsthal/Bohemia in 1906 with 43 patients. Almost all of them were treated for goat, chronic rheumatism, and neuralgic problems, and the results were described as ‘extremely successful’ [34]. In 1910 already 373, and 2,476 patients in 1913 came for treatment, and a governmental spa institution opened its facilities in 1911. Between 1910 and 1912, the world-famous ‘Radium Palace Hotel’ was built. It is still in operation with its facilities usually filled to capacity.

Around the same time, traditional spas with high radon concentration, such as Gastein/Austria and Baden-Baden/Germany, had started to offer specific radon treatments. Probably the first traditional spa that installed an overground radon inhalation facility ‘inhalatorium’ was Bad Kreuznach [35]. It reopened in 1974 [36]. Treatment has also taken place in mine shafts since 1912, and overground inhalation facilities were established in France.

In Brambach/Germany in 1910 at this time the strongest source was discovered (30,000 Bq/L). A typical example for the increase of patients in the new radon spas was the ‘Radiumbad Oberschlema’/Germany, also close to St. Joachimsthal, with a steady increase of patients from 300 in 1918 to 17,000 in 1943. In 1937, the Institute of Biophysics of the Kaiser-Wilhelm-Society in Frankfurt established a dependence especially for radon research in Schlema [37]. At the end of WW II, the activities in Schlema were abruptly stopped, because the area became one of the world’s largest uranium mining centres, supplying until 1989 about 240,000 t of uranium for the Soviet

nuclear arms programme. Only after the end of the Cold War, the Schlema Spa successfully reopened in 1998 [38].

The history of radioactive springs in Japan, which is one of the countries with most hot springs in the world, dates back to 1909, and a review on the mineral springs of Japan was already published in 1915. Most of them are radon springs, but some are also high in thoron. The best known are the springs of Misasa with a radon level up to 3,000 Bq/L in the Gunze-no-yu source, but there are other sources in Masutomi, Ikeda, etc. in which much higher concentrations, one of them believed to be with up to 130,000 Bq/L to be the strongest in the world. Many studies on various aspects of radon therapy including pharmacokinetics, clinical experiences, etc. (most of them written or directed by Oshima) were carried out in Japan [39].

Further progress in the investigation of radon sources also proceeded in Europe, e.g. in the Nahe Valley/Germany [40]. In other countries such as Israel, the radioactivity of sources was explored [41]. The search for new strong radon sources, and their possible use for establishing a radon spa, still continues. For example, the Fichtelgebirge in Northeastern Bavaria/Germany is known for high radon concentrations in water and air (values exceeding 700,000 Bq/m³ have been measured in the air of a public water supply facility in the city of Hof in this area). The creation of a radon spa has been considered there [42] and in other parts of Europe. Several international organisations are involved in the study and in promotion of radon balneology. The International Society for Medical Hydrology and Climatology (ISMH) is represented in 42 countries, with sections in Germany, France, Spain, Portugal, and Belgium [43]. This organisation issued in 1995 Guidelines for Radon Balneology [44], and an International Committee on Radon in Medicine (ICRM) exists within this society.

In the Association of German Radon Spa Physicians, about 14 German and Austrian radon spas treating approx. 75,000 patients annually are associated. A periodical since 1994 has been published almost completely devoted to radon balneology [45]. Furthermore, in 1991 a Radon Information and Documentation Center 'RADIZ' has been established by Aurand (Curiestr. 3, D-08301 Schlema/Germany, Phone/Fax x493772-22926, E-mail RadizeV@t-online.de), which maintains an archive of literature related to radon therapy and publishes brochures (about 20 so far) dealing with radon-related issues [46].

There are several recent books on radon therapy (e.g. [47]), and numerous national and international conferences have been largely devoted to radon therapy. To mention only a few which took place more recently:

- Physical, Biological, and Medical Effects of Low-dose Ionising Radiation, Bad Münster am Stein 1984 [48]
- Biological and Therapeutic Effects of Radon, Bad Hofgastein 1987 [49]
- Physical, Biological and Therapeutic Effects of Low-dose Ionising Radiation, Bad Münster am Stein 1989 [50]
- 2nd Biophysical Workshop
- Internat. Symp. of Techniques and Curative Treatment with Radon, Deneschi/Ukraine 1992 [51]
- Benefits and Risks of Low Doses of Ionising Radiation, Schlema/Germany, Oct. 4–6, 1993 [52]

- International Symposium O Radon in Health Resort Medicine, Ischia/Italy, April 5–10, 1994
- Radon and Health, Gastein (Austria 1998 [53])
- 3rd Biophysical Workshop on Medical and Biological Effects of Radon Balneology and Low Radiation exposures, Sept. 7–9, 2001 [54].

There have also been numerous international meetings in which emphasis was more on residential radon measurements under the aspect of possible lung cancer induction (e.g. [55–57]). The highly controversial issue of risk/cost/benefit assessment for residential and industrial radon, and the very substantial literature on this subject [1] is, however, not a topic of this review.

4 Radon therapy of degenerative diseases of joints and spine in Western Europe

Among the currently best known radon treatment centres with medical supervision are in

- Germany: Bad Brambach, Bad Kreuznach, Bad Münster am Stein, Schlemma, Sibyllenbad, Bad Steben
- Austria: Bad Gastein, Bad Hofgastein, Bad Zell
- France: Plombières
- Italy: Ischia, Meran
- Russia: Pyatigorsk
- Japan: Misasa.

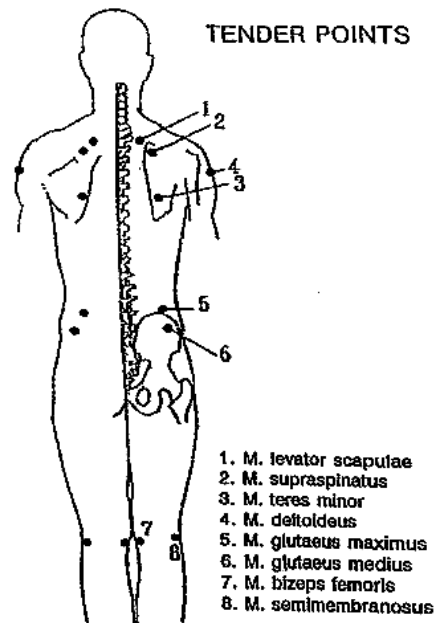
In addition, there are numerous less known radon therapy centres, for example, nine in Greece with radon concentrations up to 8,000 Bq/L in Ikaria [58], inhalation facilities in several health spas in France, as well as bathing sources in which radon is not the dominating component, but used in combination with minerals, SH₂, and CO₂.

Painful inflammatory or chronic rheumatic and arthritic diseases, such as rheumatoid arthritis, have historically been the first indications for radon treatment. They are among the most widespread health problems in humans even before the middle ages (see *Time* cover story of June 9, 2003: ‘The coming epidemic of arthritis’), and still remain the primary indication for radon therapy. There are also related illnesses, such as spondylitis ankylosans, a painful permanent bending of the spine known also as Morbus Bechterew. It occurs in around 0.1 to 5% of the population, depending on the geographic location. In Europe, the rate is around 0.2%, and it becomes evident between 16 and 40 years of age. Among the about 7,000 annual patients in Gastein/Austria, most are treated for this disease [59–61]. In a careful recent study, it has been found that the radon group showed a clear reduction in the pain and improvement of the spine flexibility up to nine months after the treatment [62]. Most of the current results of radon balneology have been published in German (e.g. [59]), with only recently some papers also appearing in English [61,63]. Of particular interest in the Morbus Bechterew therapy are studies about the combination of radon therapy and exercise treatment [64], which clearly show the superiority of the added radon treatment, with the longer lasting effect clearly compensating the higher cost of such a combination.

5 Current status of radon therapy and randomised double-blind studies

There still remained doubts about the effect of radon treatments in large parts of the medical and scientific community, because it contradicted the widespread regulatory paradigm of lung cancer inducing effects of the alpha radiation from radon down to very small doses. One of the problems in the quantification of pain-reducing effects is that there is no method that exists for precisely measuring chronic pain. There are, however, well-established methods such as the application of a defined spot pressure (in kg/cm²) to established pain-sensitive 'tender points' (Figure 1) on a scale between zero and unbearable pain, and using this scale as a rather well-reproducible cohorts test. Complicating factors may be confounders, such as other constituents of the mineral waters, and the difficulty to carry out double-blind studies in underground inhalation facilities.

Figure 1 Tender points used for testing the pressure sensitivity of patients with painful degenerative joint diseases by applying a variable pressure



This situation changed after 1990 with randomised clinical prospective double-blind studies, with neither the patient nor the medical staff knowing about the identities of those in the control (placebo) and the radon groups, and with both groups treated under otherwise identical conditions. Such tests are generally considered as 'the gold standard' in medicine for demonstrating therapeutic success. The pioneering work was done in the German radon spa Schlema in 1992, and repeated in Bad Steben in 1995, by Pratzel of Munich University [43,48,65,66]. The results of these tests carried out as schematically described in Figure 2 were rather unambiguous (Figures 3 and 4). The radon concentrations in the baths were 3,000 Bq/L in Schlema and 800 Bq/L in Bad Steben. In Schlema, the patients also received other standardised treatments such as massages and gymnastics, but not in Bad Steben.

Figure 2 Schematic diagram of bar-code regulated double-blind bathing studies in radon water (verum), otherwise identical warm non-radon water (Kontrolle)

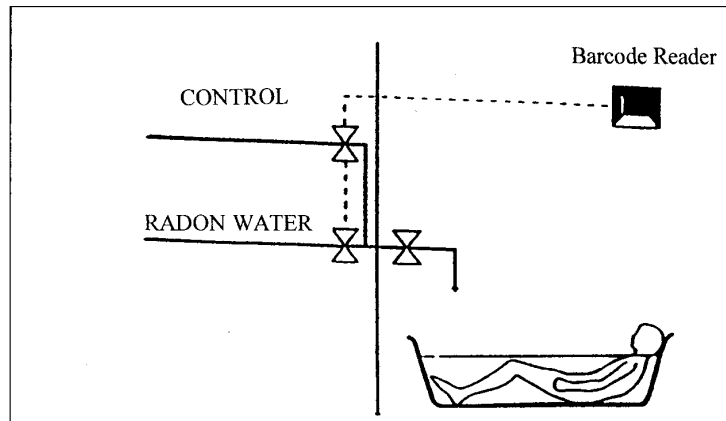


Figure 3 Tender point response of pain threshold with cervical spondylosis patients during a three week treatment, and (the two points at the right) 2 and 4 months after end of treatment, using radon and placebo tap water [48]

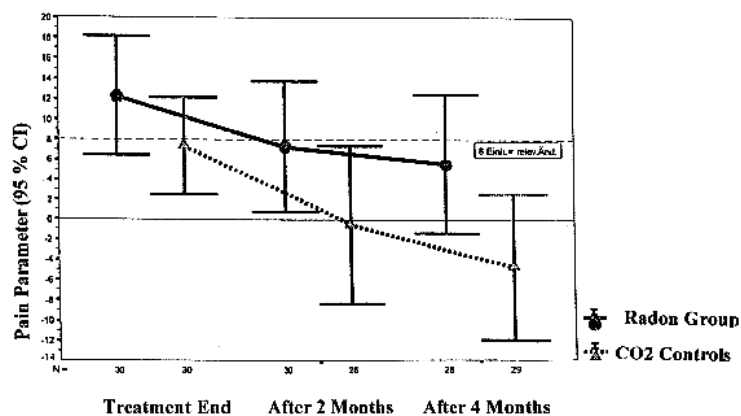
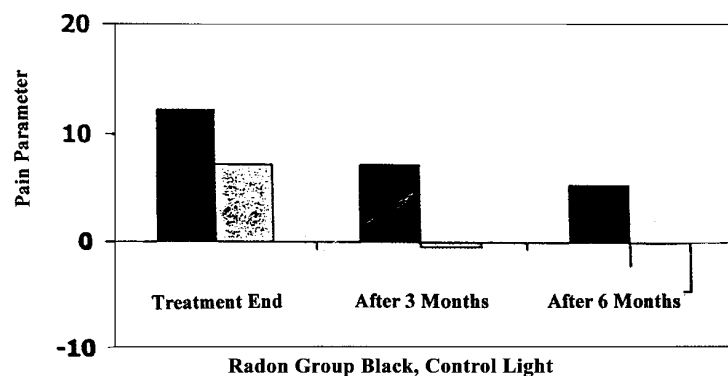


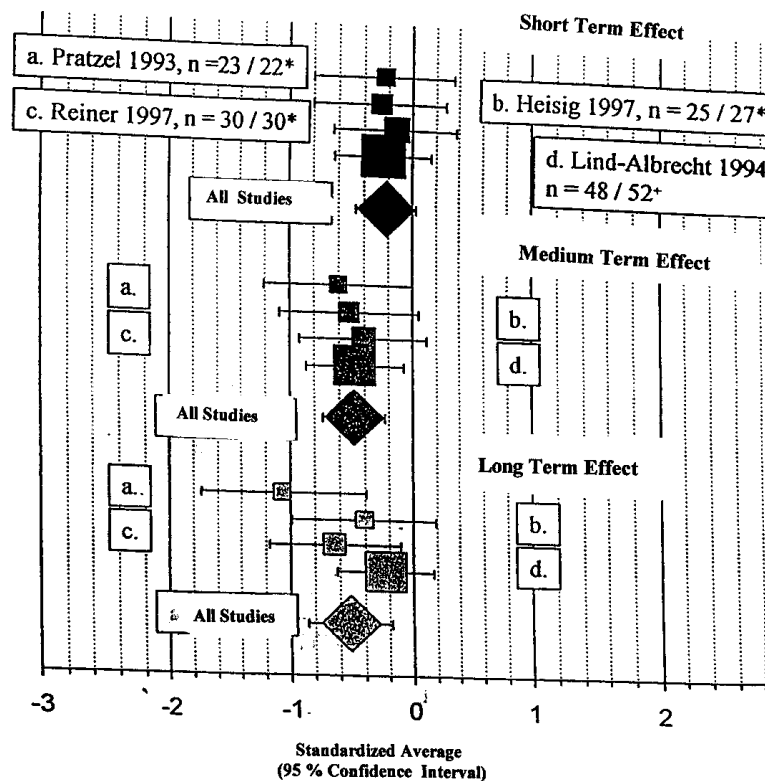
Figure 4 A complex 'painless parameter' comparing in a study the radon (black bars) with the control groups (light bars) at the end of the three-week treatment (left), and after 3 (middle), and 6 months after the treatment [67]



In natural sources, the situation is frequently complicated by the presence of confounders such as minerals, SH₂, and CO₂, which also may have biopositive effects interacting with those of radon. There are several studies on this subject. For example, in Bad Brambach/Germany, 30 patients each have been treated for rheumatoid arthritis with water containing both CO₂ plus radon, and with CO₂ only [67,68]. Using a combination of several indicators as a relieve parameter, there was no significant difference between the two groups at the end of the treatment, but there was a significantly longer lasting relief for the radon group than the CO₂ group three and six months after the treatment. In summary, the results of four randomised double-blind studies which were performed between 1993 and 1997 are shown in comparison with the control groups (Figure 5), the bars indicating the 95% confidence limits. Short term effects are given in the upper third, mid-term effects in the middle, and long-term effects in the lower part. The summary of all studies is given on the bottom line.

There also have been studies in which no positive radon effects could be demonstrated. For example, the indication 'peripheral circulatory disturbances' cannot be derived from radon effects on skin blood flow [69], and ergometric measurements of the heart frequency could not demonstrate relevant changes in the cardio-pulmonary system [70].

Figure 5 Summary of the pain-reducing effects found in four randomised clinical double-blind studies between 1993 and 1997, showing in comparison with the control groups (bars indicating the 95% confidence limits) the short-term effect (upper third), the mid-term (middle third), and the long-term radon effects. The summary of all studies is given in the bottom line



6 Radon therapy in the former Soviet Union

This topic, overlapping with and supplementing the progress in Western Europe, deserves special attention because of the volume of research as well as the number of applications. For example, around 1984 about 10 million (!) radon applications were delivered to one million patients annually in spas, sanatoriums, and in outpatient departments of the USSR health system [71]. The reasons which made it one of the most popular types of balneology among patients as well as physicians were the easy accessibility, safety, efficiency, and low cost of such treatments. It was carried out mostly with ‘artificial’ radon obtained from a wide network of radium sources from which the radon gas was locally extracted. Also in other countries such as Germany, radon emanation equipment for drinking or bathing at home was still available in the 1950s [72].

There are at least one thousand publications in Russian journals and conference proceedings on this subject, among them many by Andreev and his colleagues of All Union Research Center for Medical Rehabilitation and Physical Therapy in Moscow. Another centre of radon therapy and research was Pyatigorsk in the Caucasus Mountains with sources of 2,700 Bq/L. About one hundred of the more important papers became available in German translations, which, together with some reviews [73], are the basis of this brief summary.

The first investigations about radioactivity in Russian spas date back to 1902–1903. Therapeutic concentrations of radon in mineral waters were found in 1911 in Pyatigorsk and Tshaltubo. Between 1909 and 1914, well-equipped radiological laboratories in Omsk, Odessa, Moscow and St. Petersburg have been established, and they carried out investigations on radon therapy. In 1920 (after interruptions by WW I, revolution and civil war), a State Institute for Balneology was founded in Pyatigorsk. Around 1922–1923, in Petrograd (St. Petersburg), the first strong (1 g) radium sources had been used for distribution of radon to other treatment facilities. Careful studies on the preparation of radon sources, radon dosimetry, absorption properties, uptake through the skin, pharmacokinetics, etc. followed during the successive decades. In particular, because radon concentrations and other parameters including temperature, added CO₂ and other gases, could easily be varied with the ‘artificial’ radon sources, and with the compliance of the study groups being excellent, many systematic investigations in this area have been performed. During 1955–1960, hundreds of radon laboratories were established for the daily production of radon for therapeutic use.

After 1960, investigations centred on radiation protection issues related to radon therapy (organ doses, etc. [74]), radiobiology, new therapeutic equipment, pharmacokinetics of radon in the body [75], radon penetration through the skin [76], comparisons with placebo groups, etc. This also led to the demonstration of radiation hormesis. To quote from a summary report: “The received data irrefutably showed the presence of therapeutic effects of small doses of ionising radiation (hormetic curves in clinics) which cannot only be revealed, but assessed numerically by properly organised research”.

During this period, the daily number of radon applications with improved equipment [77], under medical control, and according to governmental radiation protection regulations, increased up to 5,000 for each of the many radon treatment facilities [78]. Later, with the risks associated with very high radon doses becoming better known, risk/benefit assessments of radon treatments were studied in more detail [79,80]. There was limited access to international literature, and contacts with

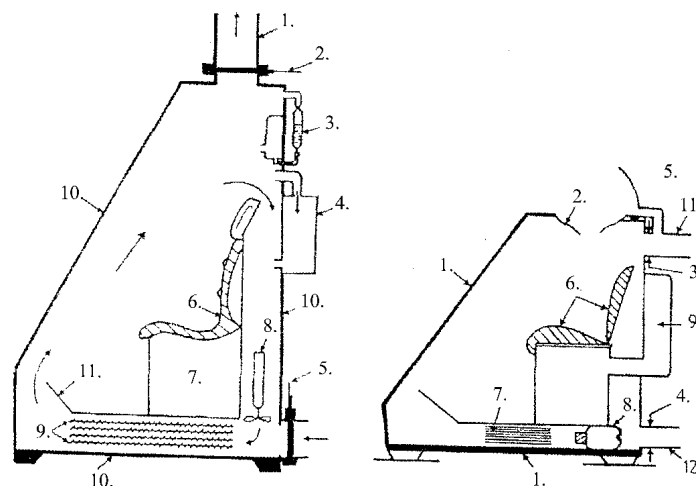
Western scientists (during WW II and the Stalinist post-War period, contacts with Western European scientists and references to their work) were prohibited. Not much is known about the current status of radon balneology in the former SU states, but it could also have suffered from the breakdown of social structures and governmental health services in the post-Soviet area.

There were many types of radon application there, including full or partial baths in bathtubs and swimming pools, with and without other balneological components being added; partial- or full-body air exposures, with or without air circulation (for two typical devices, Figure 6 after Bogoljubow 1990); inhalation (with or without decay products); irrigation of nose, mouth, rectum, vagina; and local applications (ointments, packages, etc.). The spectrum of indications which has been tried more or (often less) successfully is also very wide, including

- heart and circular problems (hypertonia, etc.)
- blood circulation (artherosclerosis, thrombophlebitis)
- pulmonary problems (bronchial asthma, chronic bronchitis)
- inflammatory or degenerative diseases of the skeleton (which is in Western Europe nowadays the primary indication)
- diseases of the nervous system (e.g. neurosis)
- chronic inflammations, sterility and climacteric problems in gynaecology
- skin diseases (psoriasis, neurodermitis, chronic eczema)
- gastritis, ulcus ventriculi.

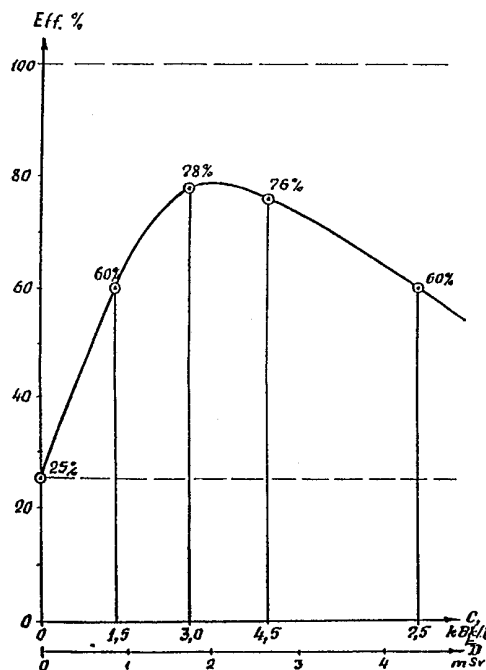
The best results were obtained with rheumatic diseases, in gynaecology, skin diseases and hypertension.

Figure 6 Boxes used in Russia for application (and research) of radon gas treatment including inhalation (left), and for exposure of the body skin only (right), including (left) the radon gas production (3), air heating devices (10 left, 7 right), radon control chamber (left 4), etc



The contraindications in the SU clinics have been similar to those in Western Europe: Acute infections, psychic diseases, pregnancy, tumours, active tuberculosis, epilepsy, acute serious diseases of internal organs, infected open wounds, and haematological irregularities. Alcohol was also forbidden during the treatment, and a classification of radon concentrations in water used for treatments has been used, with low concentrations up to 500 Bq/L, medium concentrations up to 3,000 Bq/L, and higher concentrations above this level. Among the many interesting results of the Russian studies, those about the relation between radon concentration and desirable health effect (Figure 7) are of particular interest [81]. Obviously, the dose-effect relation in patients with recidivous rheumatism (in the state of minimal process activity, using 15 baths of 10 min. each) shows a clear maximum in the improvement of the patients around 3,000 Bq/m³, corresponding to a skin dose of about 2 mSv.

Figure 7 Dose-effect relation in patients with recidiv. rheumatism in the state of minimal activity during treatment with 15 times 10 min. radon bathes. Ordinate: Improvemnt in each group as a summary of different parameters; abscissa: radon concentration in kBq/L in the water and skin dose (in mSv) during total treatment



In another study [82], various rheumatic diseases have been investigated in, for instance, groups of 148 patients each with cervical pain syndrome. In response to 12 baths at different radon concentrations, and in comparison with the control group with ordinary water, 25% showed improvement with normal water, 40% at 500 Bq/L, and 55% at 5,000 Bq/L. However, undesirable side effects were observed above 2,500 Bq/L. Further summaries of the substantial Russian activities in radon balneology are scattered in the literature [83–85].

7 Mechanism and pharmacokinetics of radon effects

There are at least three reasons why the positive effects of low radiation exposures have not yet been fully explained:

- experiments on the molecular or cellular level are difficult to extrapolate to the effects on the whole organism, which involve complex compensation and repair mechanisms such as apoptosis, adaptive response, bystander effects, and positive stress stimulation
- epidemiological studies frequently fail in the low-dose range because of serious confounders, such as smoking in the case of lung cancer, or too large populations required to obtain conclusive results
- in the current structure of public and governmental support for radiation effects research, emphasis is on detrimental health effects, with biopositive (therapeutic) aspects frequently being ignored as disturbing for the official paradigms, governmental regulations, and official anti-radon campaigns.

This general situation explains to some extent why the experimental animal and human studies regarding the mechanism of biopositive radon effects has, despite intense research in many countries, not yet been able to completely clarify the mechanism of therapeutical radon effects. There is a long history of metabolic and radon effect studies which is impossible to cover in a brief review. As an example, a study about the effect of radioactive thermal water on the inactivation of noradrenalin [86] may be mentioned, or “the stimulation of natural killer cells, anti-oxidant compounds, and DNA repair enzymes, and a decrease in C-reactive protein” [66].

According to Russian research, the radon in bathing water penetrates the skin and forms a depot accumulating up to 60% of the radon uptake, and reaching 20–30% of the radon concentration in the water. The radon is then absorbed in the fatty tissues, and the radon daughter products are accumulated in the kidneys. The organ doses for a 15 min. bath at 1,500 Bq/L have been calculated at 0.1 mSv for the skin, 0,003 mSv for the kidney, and 0,0015 mSv for body fat. Two hours after bathing, only 10% of the original radon intake still remained in the body. Short-lived radon daughters contribute about 70% to the absorbed dose. Diffusion of free radicals produced in the skin may contribute to the effect by affecting skin receptors and regulatory mechanisms.

Recently, the more general explanations such as stimulation of the immune system [87] have been replaced by more detailed studies including the influence on Langerhans cells, increase in the encephaline level, reduction of oxygen radicals in the neutrophils and macrophages, influences on homeostasis, factors influencing the attachment of leukocytes at joint tissues, etc. For example, in a series of animal (rat) experiments by a Japanese group [88], the effect of inhaled radon on the activity of an important enzyme, superoxide dismutase (SOD) in different tissues has been investigated as a function of the radon concentration, showing substantial stimulating effects in liver and kidney. In summary, unlike the essentially pain-relieving non-steroid drugs, the radon effect is by most experts nowadays considered primarily based on a stimulation of the defensive immune system, and therefore to be classified as not only evidence-based, but at least partially explainable modern medicine on the cellular and whole-body levels.

There are recent studies on the surprisingly long-lasting radon progeny activity on skin and hair after exposure to the humid warm air in the Gastein mine shaft [89]. Due to these high adhesive properties, the period of exposure of the Langerhans cells is extended, with perhaps systemic effects mediated by their alteration. On the other hand, as demonstrated in measurements of radon exhalation rates in persons submersed in radon water and other investigations such as the transfer of unattached radon daughter products from the pulmonary tract to the blood of humans [90], the half-life of radon in the body has repeatedly been confirmed to be in the order of only 20–60 min. to a few hours, depending somewhat on the aerosol size distribution in case of inhalation. Radon accumulates primarily in fatty tissues. In one of those studies, the transfer of radon through the skin to the lungs and exhalation has been examined in humans, resulting in an almost complete exhalation 50 min. after the commencement of a 24 min. bath [91].

Already in 1911, an increased excretion of purin bases and uric acid in urine was observed as a result of radon treatments, which was not only a positive aspect for the treatment of gout, but also seemed to indicate a destruction of nucleoproteids [92]. It was recommended to restrict the radon concentration in drinking treatments to 14,000 Bq/L. In the same year, it was reported that the oral application of radon leads to a fast transfer to placenta, foetus, and mother's milk [93]. Those studies [94] indicate an early interest in potential radon health risks. On the other hand, it was shown that fractionated alpha radiation (2–4 h/d), in addition to the normal environmental exposure, did not increase, but decreased the number of chromosome aberrations due to a stimulation of repair mechanisms [95].

8 Dose levels, administrative questions, and outlook

The annual effective dose equivalent to patients (assuming one sequence of radon treatments) is usually in the order of 0.1 to 3 mSv and thus within the normal fluctuations of natural background exposure levels. However, the treatment personnel (doctors, nurses, drivers of patient trains) may receive up to approx. 100 mSv according to one study [58]. In other investigations [96], the skin dose amounted to less than 1–3 mSv for a series of applications in baths, 1 mSv lung dose by inhalation, and <0.1 mSv for the stomach for drinking radon water. Other authors (e.g. [97]) confirm these values. Nevertheless, one of the problems for the more widespread use of radon therapy are governmental radiation protection regulations, which are based on the ICRP/IAEA/NCRP/EU assumption of the hazards associated with radon. It was well established in recent years that there is a threshold around 600 to 1,000 Bq/m³ in air for the permanent intake, in particular at home and at the working place in areas of high natural U/Ra geological situations, for the lung cancer induction by radon in humans. However, essentially all observed effects can be attributed to cigarette consumption (see recent reviews, based on investigations by Conrady and Martin et al. [1,3]).

Nevertheless, the new 'radon protection' regulations to be legally enforced in several countries make it difficult or impossible to establish new radon treatment facilities there. In others (such as Austria, Czechoslovakia, and Germany) with a long tradition in this field, radon therapy with natural water or air sources is at least tolerated by the authorities, as long as the personnel working there is supervised by personnel monitoring devices according to the regulations for 'radiation workers', using passive polymer track

etching detectors, or new electronic systems. The practice of producing 'artificial' radon by extracting the gas from radium sources seems not to be legal any more [98].

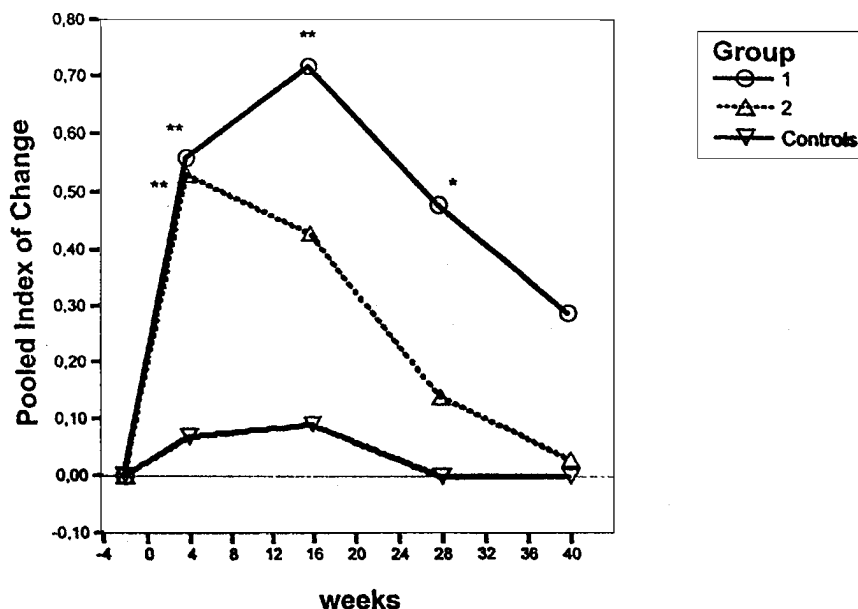
Among some other problems in the more widespread application of radon balneology are:

- The radiophobic syndrome caused by anti-nuclear political and media campaigns scaring many potential patients.
- National health insurance systems, with increasing financial problems due to the demographic and economic situation in Western Europe, are in the process of reducing their services by excluding from their coverage 'natural treatments' such as mineral and radon spas.
- Governmental organisations split between those responsible for radiation protection, and others in charge of public health. While the first promote the public 'dangers' due to even low residential and professional radon exposures [1,99], the health authorities are becoming reluctant to promote research in areas which some public health administrators still consider not part of evidence-based medicine.
- Last but probably not least, the influential lobby of the pharmaceutical industry is more interested in promoting the profitable large-scale use of non-steroid antirheumatic drugs, and has succeeded in convincing most of the medical community of this form of therapy instead of exploring the drug-free and relatively inexpensive radon treatments.

In conclusion, radon, which is the largest contributor to natural population exposures, has been declared by several international and national radiation advisory bodies and regulators to be a powerful carcinogen causing, for example, 37,000 lung cancer deaths p.a. in Germany. At the same time, it has been successfully used as an effective evidence-based therapy against rheumatic and arthritic degenerative diseases for many centuries even without being known, and even more so after its discovery about one century ago. It is well known that the same physical or chemical agent may, depending on dose and other factors, have detrimental as well as beneficial health effects. Obviously, hormetic effects of stressants including ionising radiation are more the rule than the exception in all areas of pharmacology, toxicology, etc. as well as for radiation effects [26,100].

Regarding radon therapy, it could for precautionary reasons be assumed that there may indeed be some negative effect at very high radon levels, and on particularly sensitive persons, such as children and pregnant women, who may thus be excluded from treatment. On the other hand, the beneficial effects on people with painful degenerative joint and spine problems far outweigh such minimal, and to a large degree hypothetical, potential risks, and should not prevent the therapeutic application of radon under medical control, for the benefits of the patients as well as from a cost reduction point of view ([101] – Figure 8).

Figure 8 Pooled index of change as a function of time (in weeks) in three patient groups for Morbus Bechterew treatment: Controls at home; group 2 with exercise treatment only; and group 1 (upper curve) for exercise plus radon treatment [101]



There is also increasing evidence of hormetic effects on the occurrence not only of lung cancer at above-average residential radon rates [102], but also on other types of unpleasant health effects such as the occurrence of birth defects [103]. Therapeutic radon uses appear to deserve further investigation, and could promote the understanding of beneficial radiation health effect in the low to medium dose range in general.

Acknowledgements

This review has been partially supported by the Low Dose Research Laboratory of the Central Research Institute of the Electric Power Industry (CRIEPI), Tokyo, Japan. The author gratefully appreciates valuable information and references from several colleagues, in particular Pratzel and Cameron.

References and Notes

- 1 Becker, K. (2003) *Health Effects of High Radon Environments in Central Europe: Another Test to the LNT Hypothesis*, Nonlinearity in Biology, Toxicology and Medicine, Vol. 1, No. 1, pp.3–350.
- 2 It was impossible to comprehensively analyse all publications on this subject. Many of them, in particular historical and Russian publications, are not accessible electronically and/or ISBN/ISSN. Also, the multitude of media reports, newspaper articles and other less reliable sources has not been quoted, but several earlier reviews are included up to early 2003, containing a large number of additional references. The reader may also consult 'Radon Balneology' under PubMed www.ncbi.nlm.nih.gov.

- 3 Becker, K. (2001) 'How much protection against radon do we need?', *Centr. Europ. J. Occup. and Environm. Medicine*, Vol. 7, Nos.3–4, pp.168–177.
- 4 Bethell, T. (2002) *Underdosed – Could Toxins and Radiation be Good for You?*, The American Spectator, July/August 2002, pp.54–60.
- 5 Cole, L.A. (1993) *Element of Risk – The Politics of Radon*, AAAS Press, ISBN 0-87165-513-2.
- 6 Radon Epidemiology – A Guide to the Literature Survey Series – A Radon Health Effects Bibliography (1988) 'U.S. Dept. of Energy', *Office of Health and Environm. Research*, DOE/ER-399, DE89 006398.
- 7 Eichholz, G.g., Huber, J. and Ennenmoser, O. (2002) 'Radon in health saps', *Health Phys. J.*, Vol. 727.
- 8 Jöckel, H. (2002) 'Radon als Kurmittel', in 3. *Biophysikal. Arbeitstagung Schlema 2001*, pp.22, 23.
- 9 Deetjen, P. (1997) 'Epidemiology and biological effects of radon', in Pratzel, H.G. and Deetjen, P. (Eds.): *Radon in der Kurortmedizin (ISBN 3-9804437-2-8)*, pp.33–39.
- 10 Sunta, A. (1997) 'Geschichte der Balneologie auf Ischia', in Pratzel, H.G. und Deetjen, P. (Eds.): *Radon in der Kurortmedizin (ISBN 3-9804437-2-8)*, pp.211–213.
- 11 Genchi, A. and Colombo, E. (1997) 'Concentration of radon in wells and sources in Alpine region', in Pratzel, H.G. and Deetjen, P. (Eds.): *Radon in der Kurortmedizin (ISBN 3-9804437-2-8)*, pp.214–219.
- 12 a) Schüttmann, W. (1987) 'Aus den Anfängen der Radon-Balneotherapie', in Dörtelmann, W. (Ed.): *75 Jahre Radonstollentherapie in Bad Kreuznach*, Druckerei F. Fiedler, Bad Kreuznach; b) Schüttmann, W. (1987) 'Zur Entdeckungsgeschichte des Radons', *Isotopenpraxis*, Vol. 24, No. 4, pp.158–163.
- 13 Windischbauer, A. (1959) 'Von der Wirkkraft der Gasteiner Therme', *Wien. Med. Wochenschr.* 109, Nr., Vol. 38, No. 39, pp.753–755.
- 14 Van Tubergen, A. and van der Linen, S. (2002) 'A brief history of spa therapy', *Am Rheum. Dis.*, Vol. 61, pp.273–275.
- 15 Singer, M. (2001) *The Radon Cure*, The New Yorker, July 16, 2001, pp.40–43.
- 16 Lewis, W.L. (1994) *Arthritis and Radioactivity – A story of Montana's Free Enterprise Uranium-Radon Mine (ISBN 0-89716-330-0)*.
- 17 Mache, H. (1904) 'Über die im Gasteiner Wasser enthaltene radioaktive Emanation', *Physikal. Zeitschrift*, Vol. 5, No. 15, pp.441–444.
- 18 Mache, H. (1904) 'Über die Radioaktivität der Gasteiner Thermen', *Wiener Sitz.ber. Akad. d. Wiss.*, Vol. 113, pp.1329–1352.
- 19 Rühle, H. (1992) 'Radon – alte und neue Einheiten für Aktivität und Strahlenexposition', *Radiz-Information*, Vol. 1, No. 92, Radiz, Schlema/Germany.
- 20 Sieveking, H. (1906) *Die Radioaktivität der Mineralquellen*, *Berl. Klinische Wochenschrift*, 4. Juni 1906, 779 ff., und 11. Juni 1906, 809 ff.
- 21 Ebert, M. and Kessler, W. (1990) *Schlemas Wässer wirkten Wunder – Radiumbad Oberschlema stärkstes Radiumbad der Welt*, Gemeindeverwaltung Schlema ca. 1990.
- 22 Ebert, M. (Ed.) (1999) *Vom Radiumbad Oberschlema zum Kur – und Gesundheitsbad Actinon*.
- 23 Szerbin, P. (1996) 'Natural radioactivity of certain spas and caves in Hungary', *Environment. Internat. J.*, Vol. 22, Suppl 1, No. 5, pp.389–398.
- 24 Szerbin, P. (1997) 'Radioactivity of some specific underground workplaces in Hungary', in Katase, A. and Shimo, M. (Eds.): *Radon and thoron, 17th Tohwa Internat. symp.*, Fukuoka 1997, pp.407–412.
- 25 Senftner, V. (1931) *Verfahren zur Herstellung radioaktiver Schokolade*, German Patent 633959, Appl. 1931, issued 1936.

- 26 Calabrese, E.J. and Baldwin, L.A. (2003) 'Toxicology rethinks its central belief', *Nature*, Vol. 421, No. 13, Feb., pp.691–692.
- 27 Soddy, F. (1903) A method for applying the rays from radium and thorium to the treatment.
- 28 Sharp, G. (1904) 'Two cases of lung phthisis treated with the emanation from thorium nitrate', *Brit. Med. J.*, Vol. I, pp.654–655.
- 29 Elster, J. and Geitel, H. (1904) 'Über die Aufnahme von Radiumemanation durch den menschlichen Körper', *Physikal. Z.*, Vol. 5, pp.729–730.
- 30 Kraus, E. (1907) 'Beitrag zur therapeutischen Wirkung der radioaktiven Uranpecherzrückstände und des Uranschlickes beim chronischen und akuten Gelenkrheumatismus und seinen Folgeerkrankungen', *Verh. Kongr. Inn. Med.*, Vol. 24, pp.471–478.
- 31 Loewenthal, S. (1906) 'Über die Einwirkung von Radiumemanation auf den menschlichen Körper', *Physikal. Zeitschr.*, Vol. 7, pp.563–564.
- 32 Loewenthal, S. (Eds.) (1912) *Grundriß der Radiumtherapie und der biologischen Radiumforschung*, Wiesbaden.
- 33 Lazarus, P. (Ed.) (1913) *Handbuch der Radiumbiologie und -therapie*, Wiesbaden.
- 34 Gottlieb, L. (1907) 'Die Wirkung und Anwendung der Joachimsthaler radioaktiven Grubenwässer', *Zbl. Ges. Ther.*, Vol. 25, pp.169–173.
- 35 Aschoff, K. (1912) *Zur Einweihung des neuen Radium-Inhalatoriums* (Faksimile by Raabdruck, Bad Kreuznach 1974).
- 36 Muth, H. (1974) *Die Radon-Inhalationstherapie in Bad Kreuznach seit 1974* (no bibliographic details given).
- 37 Schüttmann, W. und Aurand, K. (1991) 'Die Geschichte der Außenstelle Oberschlema des Kaiser-Wilhelm-Instituts für Biophysik Frankfurt/M', *BfS Schriften*, Vol. 3, No. 91, ISSN 0937-4469.
- 38 Schüttmann, W. (1994) 'Über das Für und Wider bei der Radontherapie aus historischer Sicht', *Radiz-Information*, Vol. 5, No. 94 (Radiz e. V., Curiestr. 3, D-08301).
- 39 Morinaga, H. (1958) *Radioactive Hot Springs in Japan, paper presented in Atti del Congresso Internazionale di Idrologia e Climatologia*, Lacco Ameno/Ischia, Oct.1958, Rizzoli Grafica, Milano/Italy 1962.
- 40 Wagner, W. (1938) *Der Radiumgehalt und die Radioaktivität der Mineralquellen der Nahetalbäder Bad Kreuznach und Münster am Stein*, T.H. Darmstadt (without further bibliographical details).
- 41 Rosenblatt, D.B. and Lindemann, H. (1952) *Science*, Vol. 116 (Dec. 19), pp.689, 690.
- 42 Bach, G., Reul, K. and Sansoni, B. (1989) *Gebiete mit erhöhter natürlicher Radioaktivität, VI Diskussion über die Errichtung eines Radon-Heilbades in Fichtelberg-Neubau*, Rep. Jül-Spe-536, ISSN-7639.
- 43 Pratzel, H.G. (1994) 'Aktuelle Aspekte der Kurortmedizin', *Intern. Environm. Consult. Newsletter*, Vol. 1, No. 94, pp.2–9.
- 44 Pratzel, H.G. (1995) 'Über die Wirksamkeit von Radonanwendungen', *Rheuma-Journal*, Vol. 2, pp.19–24.
- 45 Sansoni, B. (1994) *Internat. Environment. Consult. Newsletter* (ISSN 0942-4016).
- 46 Ebert, M. (2001) *10 Jahre RADIZ 1991–2001*, Radiz-Information 19/2001 Schlema.
- 47 Pratzel, H.G. et al. (1997) 'Wirksamkeit und Verträglichkeit von Radonbädern bei Patienten mit schmerzhaften degenerativen Erkrankungen von Wirbelsäule und Gelenken', in Pratzel, G. and Deetjen, P. (Eds.): *Radon in der Kurortmedizin ISMH*, Verlag (ISBN 3-9804437-2-8), pp.114–143.
- 48 Dirnagl, K. (Ed.) (1984) 'Z., Physikalische, biologische und medizinische Wirkungen niedrig dosierter ionisierender Strahlung', *Z. Phys. Med. Baln. Med. Klim.*, Vol. 13, Sonderheft 1.

- 49 Deetjen, P. (Ed.) (1988) 'Biologische und therapeutische Effekte von Radon', *Z. Phys. Med. Baln. Med. Klim.*, Vol. 17, Sonderheft 1.
- 50 Deetjen, P. (Ed.) (1990) 'Physikalische, biologische und therapeutische Effekte niedrig dosierter ionisierender Strahlung', *Z. phys. Med. Baln. Med. Klim.*, Vol. 19, Sonderheft 2.
- 51 Sansoni, B. (1992) 'Grußworte bei der Eröffnung des internat. Symp. Über Balneotechnik und Heil Anwendung radonhaltiger Medien', *Internat. Environm. Consult. Newsletter*, Vol. 1.
- 52 Aurand, K. et al. (Ed.) (1995) *Nutzen und Risiko bei der Einwirkung kleiner Dosen ionisierender Strahlung*, Dresden (ISSN 0949-8540).
- 53 Deetjen, P. and Falkenbach, A. (Ed.) (1999) *Radon und Gesundheit*, ISBN 3-631-35532-7.
- 54 Schlema (2002) 3. *Biophysikal. Arbeitstagung*, Medizinische und biologische Wirkung der Radonbalneologie und niedriger Strahlendosen, published by Radiz Schlema e.V. (e-mail RadizeV@t-online.de).
- 55 Burkart, W. et al. (Ed.) (2002) *High Levels of Natural Radiation and Radon Areas : Radiation dose and Health Effects*, *Excerpta Medica Int. Congr. Ser. 1225*, ISBN 0-444-50863-5.
- 56 Peter, J. et al. (Ed.) (2002) *High Natural Radiation and Radon Areas : Radiation Dose and Health Effects*, BfS-Schriften 24/2002, ISBN 3-89701-808-X.
- 57 Serenio, O. (Ed.) (2002) *Leitfaden zur Messung von Radon, Thoron und ihren Zerfallsprodukten*, SSK-Veröffentl, Band 47 (ISBN 3-437-21478-0).
- 58 Kriditis, O. et al. (ca. 1986) *Investigation of radiation exposures in Greek radon therapy centres and Athens residences*, Report, CEC Contract BI6-114-GR (TT).
- 59 Falkenbach, A. (1996) 'Kurmedizinische Behandlung mit Radon', *Heilbad und Kurbad*, Vol. 48, No. 8.
- 60 Falkenbach, A. and Wolter, N.J.G.B. (1997) 'Radon-Thermalstollen-Kur zur Behandlung von Morbus Bechterew', *Forschende Komplimentärmed*, Vol. 5, pp.277–283.
- 61 Falkenbach, A. (2001) 'Radon therapy in Bechterew disease. Benefits and risk factors', *Dtsch. Med. Wochenschr.*, Nov 30, Vol. 126, No. 48, pp.1379–1380.
- 62 Lind-Albrecht, G. (2002) 'Therapieeffekte und Langzeitverlauf der Radonanwendung bei Morbus Bechterew', in 3. *Biophysikal. Arbeitstagung, Schlema 2001 'Medizinische und biologische Wirkungen der Radonbalneologie und niedriger Strahlendosen*, Radiz Schlema (RadizeV@t-online.de), pp.24–27.
- 63 Franke, A. et al. (2000) 'Long-term efficacy of radon spa therapy in rheumatoid arthritis – a randomized, sham-controlled study and follow-up', *Rheumatology*, Vol. 39, pp.894–902.
- 64 Van Tubergen, A. and Hidding, A. (2002) 'Spa and exercise treatment on ankylosing spondylitis – fact or fancy?', *Best Practice Res. Clinic. Rheumatics*, Vol. 16, No. 4, pp.653–666.
- 65 Pratzel, H.G. (1992) 'Die klinische Wirksamkeit von Radonbädern ist bewiesen', *Heilbad und Kurort*, Vol. 44, pp.11, 12.
- 66 Pratzel, H.G. and Deetjen, P. (Eds.) (1997) *Radon in der Kurortmedizin – Zum Nutzen und vermeintlichen Risiko einer traditionellen medizinischen Anwendung*, ISMH Verlag, ISBN 3-9804437-2-8.
- 67 Reiner, L. (1998) *Wirksamkeit und Verträglichkeit von Radonbädern bei Patienten mit Rheumatoid Arthritis*, Dissertation, Univ. München.
- 68 Skorpea, P. (1999) *Wirkungsverstärkender Effekt von Radonbädern durch Kohlensäure?*, Dissertation at the University of Munich.
- 69 Knorr, H., et al. (1990) 'Radon und Hautdurchblutung', *Z. Phys. Baln. Med. Klim.*, (Sonderheft 2) Vol. 19, pp.99–102.
- 70 Leiner, G. and Aigner, A. (1984) *Ergometrische, mechanokardiographische und spirometrische Untersuchungen an Patienten mit PCP*, M. Bechterew bzw. Arthrosen während.

- 71 Bogoljubov, W.M., Andrejev, S.V. and Rjasanzev, K.M. (1984) 'Struktur und organisatorische Grundlagen des radontherapeutischen Netzes in der UdSSR', *Z. Phys. Baln. Med. Klim (Sonderheft 1)*, Vol. 13, pp.40–43.
- 72 Aures, R. (2003) 'Radium-Trinkkuren für Gesundheitsbewusste', *Strahlenschutzpraxis*, Vol. 9, No. 1, p.62.
- 73 Legler, B. (1994) 'Wirksamkeitsuntersuchungen bei der Anwendung von Radon in den Bädern der ehemaligen Sowjetunion', in Aurand, K. *et al.* (Eds.): *Nutzen und Risiko bei der Einwirkung kleiner Dosen ionisierender Strahlung* (ISSN 0949-8540), pp.173–185.
- 74 Andreev, S.V. (1973) 'Die Bestrahlung des menschlichen Organismus bei der Radonbehandlung', in *Kurfaktoren in der Prävention und Behandlung von chronischen Erkrankungen*, Moscow, pp.12–18.
- 75 Andreev, S.V. (1971) 'Über die Speicherung der langlebigen Zerfallsprodukte des Radons im Patientenkörper bei Radonapplikationen, Fragen d. Kurwiss', *Physiotherapie*, Vol. 5, pp.397–401.
- 76 Andreev, S.V. (1989) 'Haut und die Eindringtiefe der Wasserbad-Inhaltsstoffe in den Organismus während der Balneotherapie', in *Fragen der Kurwissenschaft und Physiotherapie*, Verlag Zdorowje, pp.15–21.
- 77 Gussarov, I.I. *et al.* (1980) *Eine neue Vorrichtung zur Verabfolgung der Radoninhalationen bzw. der Radonluftbäder in Bad Pyatigorsk*, Fragen d. Kurwiss. Physiother. (Moscow), pp.66–69.
- 78 Gussarov, I.I. and Andreev, S.V. (1972) *Edit., Sammlung der instruktiv-methodischen Unterlagen zur Organisation und Durchführung von Radontherapie im therapeutisch-präventiven Heilanstaltensystem des Ministeriums für Gesundheitswesen der UdSSR*, Verlag Medicina, Moscow, p.144.
- 79 Gussarov, I.I. and Andreev, S.V. (1983) 'Zum Risiko-Nutzen während der Radontherapie', *Fragen der Kurortmed. Physiother.*, Vol. 4, pp.60–65.
- 80 Bogoljubov, and Andreev, S.V. (1985) 'Zum Problem der Risikoeinschätzung während der Radontherapie', *Kurortwiss. Physiother.*, Vol. 20, No. 1, pp.27–33 (Sofia/Bulgaria).
- 81 Davidova, O.B. (1984) 'Einfluss von künstlich hergestellten Radonbädern mit verschiedenen Radonkonzentrationen auf Erscheinungsformen des Rheumatismus mit verzögertem Verlauf', in *4. Tagung d. Physiotherapeuten u. Kurortärzte der Russ. Föderat*, 17–19. Okt., Sverdlovsk, pp.102, 103.
- 82 Strelkowa, N.I. *et al.* (1980) *Anwendung von Radonbädern verschiedener Konzentration in der neurologischen Praxis*, Allunions-Symposium für Radontherapie, Chmelnik.
- 83 Tauchert, D. (1972) 'Aspekte der Radon-Therapie in der Sowjetunion – Bericht über einen Studienaufenthalt in der UdSSR', *Z. f. Physiotherapie*, Vol. 24, No. 1, pp.73–79.
- 84 Bogoljubov, V.M. and Andreev, S.A. (1994) 'klinisch-biologische Aspekte der Radontherapie', *Internat. Environm. Consult. Newsletter*, Vol. 1, No. 94, pp.16–22.
- 85 Davydova, O.B. *et al.* (1994) 'Therapeutische Anwendungen von Radon-Luft-Bädern', *Intern. Environm. Consult. Newsletter*, Vol. 1, No. 94, pp.23–33.
- 86 Wense, Th. (1955) 'Die Wirkung des radioaktiven Thermalwassers von Badgastein auf die Inaktivierung des Noradrenalin in vitro', *Strahlentherapie*, Vol. 98, No. 3, pp.464–473.
- 87 Soto, J. (1997) 'Wirkung von Radon auf das Immunsystem', in Pratzel, H.G. and Deetjen, J. (Eds.): *Radon in der Kurortmedizin* (ISBN 3-9894437-2-8), pp.103–113.
- 88 Ma, J. *et al.* (1996) 'Effect of radon exposure on superoxide dismutase activity in rats', *J. Radiat. Res.*, Vol. 37, pp.12–19.
- 89 Falkenbach, A. *et al.* (2002) 'Radon progeny activity on skin and hair after speleotherapeutic radon exposure', *J. Environm. Radioact.*, Vol. 62, pp.217–223.
- 90 Butterweck, G. *et al.* (2002) 'Experimental determination of the absorption rate of unattached radon progeny from respiratory tract to blood', *Radiat. Protect. Dos.*, Vol. 102, No. 4, pp.343–348.

- 91 Grunewald, M. and Grunewald, W.A. (1995) 'Radon Transfer während der Balneotherapie in der Best'schen Wanne', *Phys. Rehab. Med.*, Vol. 5, pp.189–195.
- 92 Mesemitzky, P. (1911) 'Über die Schädigung des Organismus durch hohe Dosen von Radonemanation', *Radiolog. Mitt. Bad Kreuznach*, Vol. 3, pp.21–31.
- 93 Lazarus, P. (1911) 'Therapeutische Methodik der Radiumemanation auf den menschlichen Körper', *Berlin. klinische Wochenschr.*, Vol. 48, pp.21–31.
- 94 Schraub, A. (1958) *Biophysikalische Untersuchungen zum Problem der Radon-Inkorporation*, Habilitationsschrift, Universität Frankfurt/M.
- 95 Pohl-Rüling, J. et al. (1979) 'Chromosomenaberrationen nach Inhalation von Radon und seinen Zerfallsprodukten', *ZBK*, Vol. 4, pp.437–443.
- 96 Andreev, S.V. (1995) 'Mißverständnis oder Absicht?', *Internat. Environm. Consult. Newsletter*.
- 97 Tempfer, H. et al. (2003) 'Biophysical mechanism and radiation dose in radon therapy', *Proceed. 7th Internat. Symp. Nat. Rad. Environm. (NRE VII)*, Rhodes/Greece, May 2002, Elsevier Conf. Series, in print
- 98 Ulrich, W. (1994) 'Über die rechtliche Zulässigkeit der Gewinnung und Anwendung radonhaltiger Heilgase in Heilbädern und Kurorten der B.R. Deutschland', *Internat. Environm. Consult. Newsletter*, Vol. 1, No. 94, pp.10–15.
- 99 Schüttmann, W. (1997) Radonbalneologie im Spannungsfeld der Strahlenschutzpolitik, in Pratzel, H.G. and Deetjken, P. (Eds.): *Radon in der Kurotzmedizin* (ISBN 3-9804437-2-8), pp.9–32.
- 100 Henrikson, T. and Maillie, H.D. (2003) *Radiation and Health*, ISBN 0-415-27162-2, 128.
- 101 Van Tubergen, A. et al. (2001) 'Combined spa-exercise therapy is effective in patients with Ankylosing Spondylitis: A randomized controlled trial', *Arthritic Care & Res.*, Vol. 45, pp.430–438.
- 102 Conrady, J. et al. (2002) 'Die Schätzung des Lungenkrebsrisikos durch Radon bei Nichtrauchern', in 3. *Biophysikal. Arbeitstagung*, 7–9 Sept. 2001, Schlema, pp.196–208.
- 103 Leichsenring, G. (2002) 'Analyse prae- und neonatologischer Daten des Zeitraumes 1955–1989 aus dem Landkreis Aue', in 3. *Biophysikal. Arbeitstagung*, 7–9 Sept. 2001, Schlema, p.211.

Bibliography

- Allen, H.S. (1903) 'Radio-active gas from bath mineral waters', *Nature*, Vol. 68, p.343.
- Andreev, S.V. and Selenezkaya, V.S. (1989) 'Hormesiskonzeption im Rahmen des Problems der stimulierenden Wirkung von geringen Dosen chemisch-physikalischer Reize. Fragen d. Kurortwissenschaft', *Physiotherapie u. Heilbäderkultur*, Vol. 6, pp.68–75.
- Becker, K. (2000) 'Is residential radon dangerous?' in *The Effects of Low and Very low Doses of Ionizing Rad. on Human Health, Excerpta Medica Internat. Congr. Series 1203*, pp.173–191 (ISBN 0-444-50513-x).
- Bogoljubow, O.B., Dvydowa, S.V. and Andrejew (1990) 'Radon-Luftbäder in der UdSSR: Forschung und Einsatz', *Z. Phys. Med. Baln. Med. Klim. (Sonderheft 2)*, Vol. 19, pp.90–98.
- Booklet published by Gemeindeverw. Schlema et al.
- Dautwitz, F. (1905) 'Beitrag zur biologischen Wirkung der radioaktiven Uranpecherzrückstände aus St. Joachimsthal', *Wien. Klein. Wschr.*, Vol. 18, p.1104 – see also Heilkunde, Z.f. (Prag, Wien) (1906) Vol. 27, pp.81–96.
- Falkenbach, A. (2000) 'Therapeutische Radonexpositionen', *Phys. Med. Rehab. Kuro*, Vol. 10, pp.199–205.

- Ischia (1958) *Atti del Congresso Internazionale de Idrologia a Climatologia*, Lacco Ameno/Ischia, Oct. 1958, publ. Rizzoli Grafica, Milano/Italy 1962.
- Kosmath, W. (1937) *Die Radioaktivität im Luftmilieu von Bad Gastein, der Budapester Radiumbäder: Gellert, Imre, Rudas und neuartige biologische Versuche in Baden bei Wien. Compte-rendu des Travaux du I. Congres Internat. Des Stat. Balneaires*, Budapest 7–14 Oct.
- Pratzel, H.G. (1995) *Leitsätze der Radon-Balneologie*, ISMH Leaflet.
- Pratzel, H.G. and Deetjen, P. (Eds.) (1997) *Radon in der Kurortmedizin* (ISBN 3-9804437-2-8).
- Radium (ca. 1930) *Radium and its Uses in Medicine – Concise Information with Special Reference to Micro-Radiation* (further bibliographical details not given).
- Schlema (1992) 2. *Biophysikal*, Arbeitstagung, Schlema, Sept. 1991, BfS-ST-3/92.
- Schüttmann, W. (1990) 'Das Strahlenrisiko des Patienten bei der Strahlentherapie', *Z. ärztl. Fortbildung* 84, 1244-1249.
- USSR (1988) *Allunionsregel und Normen für Strahlenschutz für Radonlaboratorien und –Heilanstalten ab 1.1.1989 bis 31.12.2000*.