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Epidemiological study on the cancer mortality in an area with elevated radon daughter exposure

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Title of Project:

Epidemiological study of the cancer mortality in an area with elevated radon daughter exposure.

Institute where research is being carried out:

Division of Biophysics at the Institute of General Biology, Biochemistry and Biophysics, University of Salzburg, A-5020 Salzburg, Austria.

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Period of contract:

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Johanna Pohl-Rüling

CERTIFIED BY: P.M. [signature]

DESCRIPTION OF RESEARCH CARRIED OUT

Scope of Project

Epidemiological studies on the cancer mortality due to radon daughter exposure have been carried out hitherto amongst mining populations and for lung cancer only. However, radon daughter exposure is increasingly recognized as health risk in many non-mining environments, even in the "normal" environment. It has been argued that the risk factors derived from miners cannot be applied to non-mining populations due to significant differences, such as the presence of cocarcinogenic factors (diesel fumes, ore dust) in mines. Whilest it is self-evident that adjustments have to be made for differences in breathing characteristics and age-/sex-structure of the population, cocarcinogenic factors are also present in non-mining environments. Therefore information on the cancer induction in non-mining environments can only be derived from relevant epidemiological studies.

In many places of the world water or air containing naturally high levels of radon 222 is used for therapeutical treatment of various diseases. In these "radon spas" not only the patients but also employees and inhabitants receive an elevated radiation exposure due to inhalation of radon and decay products: at the collection and supply of water as well as during treatment in bath rooms, pools, etc. radon emanates from the water and also escapes from inhalation therapy facilities into the atmosphere of adjacent rooms and into free air. Therefore the indoor and outdoor atmosphere generally contains a higher than normal amount of radon and its decay products. For patients and tourists with only a short residence time in such places the additional radiation burden is only small, but it has to be considered for persons occupationally exposed due to radon therapy and for the inhabitants.

Scientific background

In the Austrian radon spas Badgastein and Bad Hofgastein many detailed studies of the environmental natural radioactivity have been carried out during about 20 years. Therefore the radiation exposure of the inhabitants and workers could be assessed with sufficient accuracy.

1) Radioactive environment of Badgastein

The spa Badgastein is over 600 years old and is situated in a narrow valley of the Central Alps. At present the population is 6 500 inhabitants (inclusive the hotel employees). The subsoil is composed of gneiss and mica-schist with an elevated content of natural radionuclides. The main contribution to the radioactive environment, however, results from the 19 thermal springs originating in the center of the town. 5 million liters of hot water with a mean concentration of 40 nCi/l radon 222 is supplied daily. The water from the well-heads is collected in large reservoirs and from there 4/5 of the water is delivered to about 120 hotels and treatment centers distributed over the whole town. During transport of the water a large portion of radon is lost into the atmosphere. In addition to that radon also escapes from the bathtubes and the treatment rooms into the air of the buildings and into the open air. Almost 160 mCi of radon diffuse daily into the atmosphere of this area, causing an exposure of the inhabitants due to the inhalation of radon and daughters.

In series of measurements over many years annual mean concentration values of radon 222, its short- and long-lived decay products and Pb 212 could be determined for numerous living-, working- and sleeping rooms, for the various therapeutic treatment facilities as well as for the open air. The methodology of measurements and the data have been published (1, 2, 3).

The air activities in the periphery (range of mean radon content in pCi/l: indoors 1-5 and outdoors 0.1-1.5) is lower than in the center where the springs originate (2-15 pCi/l in- and 0.5-3.5 outdoors). It is higher in the bathrooms (mean 90 pCi/l) and highest in the "Thermal Gallery". The latter is a former gold mine near Badgastein which has been used as a natural inhalation facility for therapeutic purposes since 1947. Temperature and relative humidity in this mine reach up to 41°C, respectively 99 %. The atmosphere contains radon 222 in a mean concentration of 3 000 pCi/l, whereby the short-lived decay products are 70 to 80 % in equilibrium (corresponding to about 22 WL). In direct connection with the entrance to the mine is a treatment house with rooms for medical examination and afterwards therapy recreation of the patients. Many employees are working all day in this house. The mean atmospheric radon content ranges from 8 to 150 pCi/l (0.04 to 0.9 WL).

2) Radioactive environment of Bad Hofgastein

The radon spa Bad Hofgastein near Badgastein is situated on a geological subsoil with a relatively low content of radionuclides and has no thermal springs. It receives its thermal water (about 1 million liters daily with a mean radon content of 41 nCi/l) from Badgastein by an 8 km long pipeline. This water is distributed from a central reservoir to the various spa hotels and treatment facilities.

As Bad Hofgastein receives only 40 mCi radon daily and because of its larger area, radon content within the buildings and in open air is essentially lower than that in Badgastein (with the exception of air activities in some treatment facilities) and has median values of 0.5 and 0.3 pCi/l respectively. The corresponding values in Salzburg city are 0.4 and 0.3 pCi Rn/l (3).

METHOD OF DOSE CALCULATIONS

The highest doses at the inhalation of radon and decay products receive the basal cells of the segmental and subsegmental bronchioles, which are also the biological targets for lung cancer induction. This dose depends not only of the decay product content in the air inhaled and the exposure time, but also from age, sex and living activities, the latter influence highly the respiratory minute volume.

To calculate the accumulated dose of the basal cells the following formula was used according to (4):

$$D_{acc} = B\,F_a\,\Sigma\,Rn_i t_i z_i \frac{\Phi_i}{\Phi_n}$$

where:

- D_{acc} accumulated dose (μrad) in the time (hr) under consideration
- B dose conversion factor for the basal cells of bronchus epithelium=16
- F_a age dependent dose modifying factor for the tracheobronchial dep. (5)
- Rn_i radon concentration at site i (pCi/l)
- t_i time (hr) spent at site i
- Φ_n standard mean respiratory minute volume for the "reference man" (13.8 l/min)
- Φ_i actual mean respiratory minute volume according to the physical activity
- z_i factor calculated from decay product ratio at site i.

The range of the annual bronchial doses to various groups of persons has been calculated with this formula, whereby the various Rn_i were taken from our numerous measurements of the radioactive environment in the area (see Table 1).

If the exposure to radon and daughters is one of the primary causes of lung cancer the lifetime exposure of persons who died from lung cancer could be higher than these of persons who died from other causes. Therefore we calculated the exposure to radon and daughter accumulated over lifetime for each single person who lived in Badgastein for at least 10 years and died between 1947 and 1980.

The procedure to achieve this accumulated lifetime exposure was the following:

1) The following data were <u>collected:</u>

T_O	calendar year of death
T_1	age at death
T_2	time spent in Gastein
S	sex
B	kind of occupation
H	classification of residence
K	cause of death
R	smoking habit

T_O, T_1, S, B (incomplete) and K were received from death certificates of Badgastein, Bad Hofgastein and other places whereever the respective person died, mainly Salzburg City, Schwarzach and St. Johann, but also many others.

T_2 was very laborious to obtain because Badgastein is a touristic center with about 1 million overnight lodgings per year and a rather big number of hotel personnel with fluctuating residence. Therefore the file cards of the local registration office which had to be looked through, are very numerous. The collection of H, R and partly also of B required a personal information by the registrans of birth, marriage and death who became aquainted with almost all of the residents during his long establishment.

2) The following quantities were derived:

from collected data (T_K, T_A), from many series of radon measurements in rooms, open air and at working places during 20 years D(H), D(F), D(B), and from the literature J(T), M(S), M(S, H), M(B):

T_1-T_2	years before residence in Badgastein
T_K	years spent at war during T_2, as function of the years T_O, T_1, T_2, 1939 and 1945
T_A	years of occupation during T_2, as function of T_1, T_2 and S (women retire with 60 and men with 65 years)
D(H)	annual mean radon content at the dwelling house. It was estimated according to numerous measurements in the region of Gastein taking into account the location of the building and the building period (houses built before 1950 generally represent constructions with higher radon exhalation rates)
D(F)	annual mean radon content in the open air at the residence place
D(B)	mean radon content at working place
J(T)	lung dose correction factor for children and youths. The bronchial dose up to an age of 16 years is higher than for adults
M(S,H,F,B)	respiratory minute volume as function of sex and living activity, whereby the latter is different for the stay at home (H), in open air (F) and during work (B).

3) The accumulated lifetime exposure, given in "mean radon content (incl. dose correction factors mentioned above) x lifetime in years" has been calculated as

$$E = e_1 + e_2 + e_3$$

whereby:

e_1 exposure during time spent outside of Badgastein as function of T_O, T_1, T_2, S, J(T), M(S). For the radon content overal means were used (D(H)=0.6, D(F)=0.3 pCi/l). The mean stay within houses was taken as 80 %. To the time (T_1-T_2) was added the time spent at war during T_2 and $T_2/12$ (it was considered that people spend a mean time of one month per year outside of the residence).

e_2 spare time exposure during residence in Badgastein as function of T_1, T_2, T_A, T_K, S, D(H), D(F), J(T), M(S,H,F). The mean stay within houses was taken as 85 % (it is cold in Gastein). $T_A/4$ is the mean time spent at place of occupation (≈2000 hrs working time per year), therefore 3/4 T_A has to be added to the life sparetime.

e_3 occupational exposure in Badgastein, as function of T_A, T_K, D(B), M(S,B).

According to our calculations the

"corrected" lifetime exposure in pCi x l^{-1} x years corresponds to 1.4 rem equivalent dose to the basal cells of the bronchial epithelium*.

The corrected lifetime exposure was calculated individually for 1367 deaths, with a residence time in Badgastein of ≥10 years.

RESULTS OBTAINED

1. Bronchial dose and lung cancer risk estimation for various population groups

Table 1 shows the mean population sizes and the corresponding ranges of bronchial dose for various population groups. This table also contains the corresponding range of the risk factors (r_t), which was calculated as shown in the following: the most reliable risk factor for lung cancer induction ranges from 20 to 45 x 10^{-5} per Working Level Month (WLM) radon daughter exposure as given by the UNSCEAR report 1977 (6). As this value is derived from investigations on uranium miners with additional lung burdens (diesel fume, ore dust, etc.) the lower value seems to be more justified for a normal environment. One WLM exposure causes a bronchial dose of about 10 rem** for a miner (light/hard work), therefore we used r_t = 2 x 10^{-5}/rem. This dose depending risk factor avoids the problem of different respiratory minute volumes for miners and other population groups. Its influence on dose as well as age and sex dependence is already taken into account in our dose calculations.

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* The factor 1.4 refers to the standard mean respiratory minute volume. Miners have a conversion factor of about twice of this value (1 WLM≈10 rem).

** corresponding to our dose calculations, using QF=20 for alpha-irrad. (4, 5).

It is not possible to calculate an "expected number of lung cancer deaths" from these risk factors, as parts of the population were not exposed long enough to the dose rates given in Table 1 (the risk factor r_t is valid for exposure times of at least 40 years).

2. Observed cases of death and their lifetime bronchial dose

Within the 34 years investigated 1366 residents died from several causes of death at ages of 40 years. As younger persons rarely die from cancer, none from lung cancer, they were excluded for comparison with the control population. Altogether 56 lung cancer cases occured, including two miners from the Thermal Gallery and two other miners, who mainly worked in the nearby region of the "Naßfeld" with other galleries with high radon content. As their accumulated doses were much higher than that of the other persons (Tables 1, 2) they were categorized separately.

The results show an annual lung cancer incidence rate for Badgastein of 30 per 10^5 living people of all ages and 108 per year for 10^5 persons older than 40 years. These values are not statistically different from the mean observed lung cancer cases in the whole Federal Province of Salzburg (presently 430 000 inhabitants), i.e. 32 and 98 respectively.

For this comparison, however, it has to be considered that the main part of the Badgastein inhabitants (group (1), Table 1) receive only about twice the exposure of a normal environment (mean value for group (1) 3.9 rem/yr, for Salzburg city 2 rem/yr).

Therefore a kind of case-control study has been carried out comparing the exposure of lung cancer deaths with these of other deaths. The results are given in Table 2. It can be seen that for the population group (1) there is no significant difference between the mean individual dose rates. However, for groups (2) to (6), and even more so for the miners, the persons who died of lung cancer received a higher dose than those who died of other causes.

From the mean lifetime dose rates and the population sizes as given in Table 2, the number of expected lung cancers was calculated for the 34 year-period of observation. The results show that the number of expected values for the non-mining population is about 30 % of the number of observed cases. The number of actually radon daughter induced lung cancer cases, however, will be lower still as it was found in Salzburg (7). Therefore it seems that the risk factor, as derived from miners, may not be directly applicable to the general public with a different population structure with regard to sex and age.

CONCLUSIONS

Due to the elevated amount of radon decay products in the air of working- and living rooms in radon spas there is a radiation induced risk for lung cancer development.

The number of persons envolved is, however, relatively small and therefore the increase in the total lung cancer induction will not be significantly evident in most cases.

The investigation in Badgastein presented here revealed that for those population groups with increased radiation burden the mean individual annual lung dose was higher for the victims of lung cancer as compared to the victims of other death causes.

This demonstrates that radon daughter inhalation may be responsible for lung cancer induction even in a non-mining environment. However, the absolute value of the risk factor, r_t, as derived from investigation on uranium miners, may be lower in the case of a normal population.

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POPULATION GROUPS	MEAN POPUL. SIZE (appr.)	DOSE TO BRONCHI-OLES (rem/yr)	r_t (per yr exp.) · 10^5
(1) INHABITANTS OF BAD-GASTEIN (PERIPHERY)	4 500	2 - 8	4 - 16
(2) INHABITANTS OF BAD-GASTEIN (CENTER)	600	4 - 16	10 - 40
(3) INHABITANTS OF BÖCKSTEIN	200	3 - 15	8 - 30
(4) BATH ATTENDANTS	120	7 - 35	14 - 70
(5) THERMAL GALLERY SPA HOUSE PERSONNEL	30	4 - 40	8 - 80
(6) THERMAL GALLERY DOCTORS, INSPECTORS	10	20 - 120	40 - 240
(7) THERMAL GALLERY MI-NERS, TRAINLEADERS	10	240 - 320	480 - 640
(8) OTHER MINERS	30	50 - 150	100 - 300

TABLE 1 CALCULATED RANGE OF THE ANNUAL BRONCHIAL DOSES AND THE INDIVIDUAL RISK FACTOR r_t FOR LUNG CANCER INDUCTION

POPULATION GROUPS	MEAN POPULATION SIZE	CAUSE OF DEATH	NUMBER OF DEATHS IN 34 yrs	MEAN LIFETIME (yrs)	MEAN INDIVIDUAL DOSE RATE (rem/yr)	EXPECTED LUNG CANCER IN 34 yrs
(1)	4500	LUNG CANCER	38	67	4.3	12
		OTHER CANCER	169	66.6	3.7	
		OTHERS	727	72.2	4.0	
(2) - (6)	960	LUNG CANCER	14	63	8.9	4.1
		OTHER CANCER	78	67.6	6.1	
		OTHERS	304	71.2	6.3	
(7), (8) (MINERS)	40	LUNG CANCER	4	59.5	111	1.6
		OTHER CANCER	5	80.2	60	
		OTHERS	28	65.2	52	

TABLE 2 NUMBER AND CAUSE OF DEATHS AND EXPECTED RADON DAUGHTER INDUCED LUNG CANCER CASES (FOR PEOPLE OVER 40 YEARS) FOR VARIOUS GROUPS OF THE POPULATION. FOR ALL OBSERVED DEATHS THE MEAN LIFETIME AND THE MEAN INDIVIDUAL DOSE RATE PER YEAR WERE CALCULATED

SUMMARY

In many countries water containing considerable amounts of Radon 222 is used in so-called "Radon Spas" for therapeutical purposes.
As this noble gas is deemanated from water upon contact with air, the indoor and outdoor atmosphere generally contains a higher than normal amount of radon and its decay products. Although this will not be dangerous for tourists and patients who stay only a short time in these places, it might contribute to the risk of lung cancer induction for residents.

In the Austrian radon spas Badgastein and Bad Hofgastein many detailed studies of the environmental natural radioactivity have been carried out during about 20 years. Therefore the radiation exposure of the inhabitants and workers could be assessed with sufficient accuracy.

For several population groups in this area the accumulated annual doses to the basal cells of the segmental and subsegmental bronchiols (receiving the highest dose at inhalation of radon and daughters, and target for lung cancer) were calculated. The calculation takes into account the respiratory minute volume (varying due to the living activities during work, free time and rest), age and sex, with QF = 20 for α irradiation. The range of the mean group doses are 2 - 8 until 240 - 320 rem/yr. From these doses the risk factors for lung cancer induction, r_t, were estimated under the assumption of $r_t = 2 \times 10^{-5}$ per rem (due to $r_t = 20 \times 10^{-5}$ per WLM and 1 WLM ~ 10 rem). According to definition r_t is valid for exposure times of a least 40 years. As parts of the population in each group was not exposed long enough it is not possible to receive the "expected number of lung cancer deaths" from these data.

If the exposure to radon and daughters is one of the primary causes of lung cancer the life time exposure of persons who died from lung cancer

could be higher than these of persons who died from other causes. Therefore we calculated the exposure to radon and daughter accumulated over life time for each single person who lived in Badgastein for at least 10 years and died between 1947 and 1980.

The procedure of data collecting and claculating the exposure from 20 various particulars is given. The lifetime bronchial doses of 1366 residents, died between 1947 and 1980 from several causes of death were calculated. Altogether 56 lung cancer cases occured. From that the annual lung cancer incidence rate for Badgastein (30 and 108 per 10^5 living people of all ages and for persons over 40 years respectively) is not statistically different from the mean observed lung cancer cases in the whole Federal Province of Salzburg (32 and 98 respectively).

Finally a kind of case-control study has been carried out comparing the mean annual life-time exposure of lung cancer deaths with these of other. It can be seen that for the higher exposed population groups and even more so for the miners the persons who died of lung cancer received a higher dose than those who died of other cancer and other death causes. Therefore radon daughter inhalation may be responsible for lung cancer induction even in a non-mining environment.

From the mean lifetime dose rates and the population sizes the number of expected lung cancers was calculated for the 34 year-period of observation. The results show that the number of expected values for the non-mining population is about 30 % of the number of observed cases. The number of actually radon daughter induced lung cancer cases, however, will be lower still as it also was found in Salzburg city. Therefore it seems that the risk factor, as derived from miners may not be directly applicable to the general public with a different population structure with regard to sex and age.