2003_10

Proceedings of the 2003 International Radon Symposium – Volume II
American Association of Radon Scientists and Technologists, Inc.
October 5 – 8, 2003

MEASUREMENT OF RADON EXHALATION RATE FROM INDIAN GRANITE TILES

Sundar, S. Bala; Ajoy, K.C; Dhanasekaran, A., Gajendiran, V & Santhanam, R.

S. Bala Sundar, K.C. Ajoy, A. Dhanasekaran, V. Gajendiran, and R. Santhanam
Radiation Safety Section, Radiological Safety Division,
Indira Gandhi Centre for Atomic Research, Kalpakkam-603 102, Tamil Nadu, India.

ABSTRACT

Measurement of radon exhalation rate from different varieties of granite tiles quarried from various parts of India has been carried out. Seventeen varieties of widely exported granite tiles of dimensions 5 x 5 x 2.5 cm have been tested. Five samples were received for each variety. The samples were exposed for 24 hours in a leak tight mild steel chamber. Gas samples were then collected using Lucas cell and counted for alpha activity to evaluate, using standard procedure, the concentration of radon from which, radon exhalation rate was estimated. Powder samples of the tiles were subjected to gamma spectral analysis. The results obtained are presented and discussed.

Key words : radon, granite, Lucas cell

Corresponding author: S.Bala Sundar email : sbs@igcar.ernet.in

---

INTRODUCTION

Human beings have always been exposed to ionizing radiation from various natural sources of radiation and one of the major routes of internal exposures is through inhalation of radioactivity present in the atmosphere. The three primordial radionuclides, viz, ^{40}K, ^{238}U and ^{232}Th that are present in the building materials in varying concentrations cause both internal and external exposures to the residents. External exposure is caused by the gamma radiation from ^{40}K and the daughter products of ^{238}U and ^{232}Th. It is known that as a result of inhalation of ^{222}Rn, a daughter product of decay chain of ^{238}U, and its daughter products, the equivalent dose to the entire lung is 20 % and 45 % higher than the equivalent dose in other tissues.

Soil, natural gas, water, construction materials are some of the sources of radon. From the epidemiological study made on the mortality rate among uranium and non-uranium miners, the correlation between cumulative exposure to the short-lived radon daughters and the excess incidence of lung cancer has vividly demonstrated the existence of a positive relation (Ahemed.J.U.,1992). For this reason, an assessment of radon, exhaling from building materials assumes significance.

Several studies have been undertaken to evaluate the radon exhalation rate from building materials (Maged and Borhem, 1997; Abu-Jarad et al 1980). The Austrian Standard ONORM S 5200 has proposed that a type of building material is considered acceptable if in a room the annual effective dose does not exceed 2.5 mSv (Steger.F et al.1999).

Granite is a form of igneous rock, which is composed primarily of Quartz, Alkalie, and Felspar. India stands third in export of granite stone and first in granite stone production. In this paper, the results of radon exhalation measurements of different varieties of granites mined in southern parts of India are presented. These results are of general interest since granites are globally used as building, ornamental and monumental materials especially due to its elegant look, durability and scratch resistant properties.

MATERIALS AND METHODS

Seventeen varieties of granite tile samples of dimensions 5 x 5 x 2.5 cm each weighing about 120 – 150 g were collected. Five samples were received for each variety. Of these, two samples were crushed and sieved through one mm sieve and preserved for gamma spectral analysis and remaining three tiles were used for exhalation rate measurements.

(I) Radon exhalation measurements:

Lucas cells (Scintillation cells) were used for the estimation of radon exhalation rate (RER) from these materials (Somalai J. et al, IRPA, Poffijin A. et al, 1983). A cylindrical shaped of mild-steel container was fabricated for carrying out the measurement. The container was 10 cm in diameter with an internal volume 750 cc. Nozzles fitted with valves were provided for collecting samples with the Lucas cells.

The back diffusion process and leak rate , which hamper the exhalation measurement results, are significant for the sampling time more than 30 hours (Stranden, 1983). Hence, the residence time of the sample in the container was restricted to about 24 hours, to minimize back diffusion. The ratio of volumes of the container and sample was more than 10, which further reduced the probability of back diffusion (Hafez.A.F, 2001). In order to establish the leak rate of the container, a separate study was carried out. The chambers were pressurized upto 1.2 kg/cm^2 and sealed. The reduction in pressure was continuously monitored for about a month. A graph was plotted with the pressure against time (Fig 1). It was observed that the leak rate was 0.5% by volume per day.

The samples were kept in the containers and sealed. After allowing a growth time of 24 hours, gas samples were collected from the container in Lucas cell of volume 150 ml. After a delay of three hours to allow radon gas to attain equilibrium with its daughters, the Lucas cells were counted using a PM tube assembly. The efficiency of the counting system used in the study was 70%. From the counts, the concentration of radon gas collected in the Lucas cell was estimated using the following equation (Jha, et al, 2001):

$$Q = \frac{C\lambda}{3EV\, e^{-\lambda t}\,(1 - e^{-\lambda T})} \qquad (1)$$

Where,

Q is the radon concentration (Bq m^{-3})

C is the net counts in T seconds

λ is the decay constant of radon (s^{-1})

E is the efficiency of the counting system (fraction)

V is the volume of the Lucas cell (m^3)

t is the counting delay (s)

As stated above, it may be noted that radon is in equilibrium with its daughters; for the decay of each radon atom there will be simultaneous disintegration of its two daughters and hence the factor 3 is used in the equation.

From the sample surface area and residence time in the container, radon exhalation rate was calculated using the equation given below.

$$E = \frac{Q\, V_{eff}\, \lambda}{A\,(1 - e^{-\lambda\tau})} \qquad (2)$$

Where,

E is the radon exhalation rate (Bq $m^{-2}h^{-1}$)

Q is the concentration of radon (Bq m^{-3})

V_{eff} is the effective volume of the container (m^3)

λ is the decay constant of radon (h^{-1})

A is the surface area of the sample (m^2)

τ is the growth time (h)

The MDA for the exhalation rate for the above experimental conditions was estimated to be 0.10 Bq $m^{-2}h^{-1}$.

(II) Gamma spectral analysis

The crushed samples were homogenized and dried in an oven at 100 - 110° C for about 24 hours. The samples were then filled in standard 250 ml air tight PVC containers. The containers were sealed hermetically and externally using a adhesive tape and kept aside for about 30 days. This will ensure the equilibrium between ^{226}Ra and its daughters.

The containers were subjected to gamma ray spectral analysis using 3" x 3" NaI (Tl) detector. The detector is shielded on all the four sides as well as at the top portion by 15-cm thick lead. Aluminum, cadmium and copper sheets in that order (graded lining) are also provided in between the lead shield and the detector so as to decrease the intensity of characteristic X-rays emitted by the high atomic number shield materials. 95% of background reduction is achieved by this arrangement. This system is situated in a nuclear counting facility, which is constructed using soil with low natural radioactivity. The system was calibrated using IAEA reference standards similar in geometry as that of the sample containers.

Each sample was counted for 20000 sec and the natural primordial radionuclides present in the tiles were identified. For the quantification, the peaks corresponding to

1.46 MeV (^{40}K), 1.76 MeV (^{214}Bi) and 2.61 MeV (^{208}Tl) were considered in arriving at the activity levels of ^{40}K, ^{238}U/ ^{226}Ra and ^{232}Th respectively. The activity of each radionuclide in the sample was determined using the total net counts under the selected photo peaks after subtracting appropriate background counts and applying appropriate factors for photo peak efficiency and weight of the sample. The MDA (3σ) for each radionuclide was established from the background radiation spectrum for a counting time of 20000 sec and the values were 8.5, 1 and 13.25 Bqkg^{-1} for ^{238}U (^{226}Ra), ^{232}Th and ^{40}K respectively.

RESULTS AND DISCUSSION

To estimate the leak rate of the chamber, plot between pressure and number of days is given Fig.1. The average volumetric leak rate was calculated using the formula (V.Barashko et.al, 2002).

$$\frac{\Delta V}{\Delta t}(cc/min) \approx V_0\left(-\frac{2\Delta H + \Delta B}{B_0}\right)\frac{H_{initial}}{(H_{final} - H_{initial})/2}\,\frac{1}{\Delta t}.$$

Where

Q is average volumetric flow rate in cm^{3}m^{-1}
* H is initial and final pressure difference in bar
* B is initial and final atmospheric pressure change during observation in bar
V is the volume of the chamber in cm^3
Δt is the time of observation in min

The volumetric leak rate was calculated to be 4.2±0.33 cm^{3}d^{-1}

The radon concentration inside the container varied from 60 to 485 Bqm^{-3}. The exhalation rate of the tiles varied from 0.24 ± 0.01 to 2.07 ± 0.07 Bq m^{-2}h^{-1} which are tabulated in Table 1.

Out of seventeen samples 11 were having ^{232}Th content above 1 Bqkg^{-1}, 10 samples were having ^{238}U content above 8.5 Bqkg^{-1} and all the samples were having ^{40}K.

The activity concentration of the primordial radionuclides in the tiles are given table.2 The ^{232}Th concentration varied from 17±2 to 212±2 Bqkg^{-1}, ^{238}U(^{226}Ra) concentration varied from 17 ±1 to 195±3 Bqkg^{-1} and the ^{40}K concentration varied from 132 ± 5 to 2116± 9 Bqkg^{-1}.

In order to compare the specific activities of the radionuclides, a common index is required to obtain the sum of activities. The index, which is called the radium equivalent activity , for the samples, was calculated using the formula (Beretka and Mathew, 1985).

$$Ra_{eq} = A_{Ra} + (A_{Th} \times 1.43) + (A_K \times 0.077) \qquad (4)$$

where, A_K, A_{Ra} and A_{Th} are the activities of Potassium, Radium and Thorium respectively, in Bq kg^{-1}. This formula is based on the estimation that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th or 4810 Bq kg^{-1} of ^{40}K produce the same gamma dose rate. The radium equivalent for the tested samples varied from 10 to 563 Bqkg^{-1}.

Fig 2 gives the correlation between radon exhalation rate and uranium content of the tile. An exponential fitting was done which yielded equation with a correlation coefficient 0.9469 given below.

$$E\,(\mathrm{Bq\,m^{-2}h^{-1}}) = 0.107 * \mathrm{Exp}\,(-0.0147 * X) \qquad (5)$$

where X is uranium activity concentration of the sample in Bqkg^{-1}. The calculated values using the above equation and the measured values are given in table 3. The variation between calculated and experimental values of radon exhalation rate may be attributed to the inadequacy of the number of samples with detectable uranium content and also to the fact that the porosity and the density of the samples, which influence the radon exhalation rate, were not normalized for the plot.

CONCLUSION

Out of seventeen samples nine samples were found to have higher thorium content upto a maximum of 10 times the uranium content. Due to this, estimation of thoron exhalation rate also assumes importance. Attempts are being made to study the thoron exhalation too.

Six samples showed radon exhalation rate above detectable level and these values are in good agreement with the reported values for Indian granite tiles (Mentazul I. Choudhury, JRNC, 1998, Al Jarallah, 2001). There exists a good correlation between the uranium content of the sample and radon exhalation rate. This implies that there exists a possibility to use the concentration of ^{238} U(^{226}Ra) as an indicator for the extent of radon exhalation.

REFERENCE

Abu-Jarad F., Fremlin.J.H. and Bull.R.,1980. A study of radon emitted from building materials using plastic alpha track detectors. Physics of Medical Biology 25, pp. 683-694.

Ahemed.J.U. (1992) Regulatory Approach Toward Controlling Exposure to Radon in Dwellings, Radiation protection and Dosimetry vol.45, pp 745-750.

Al Jarallah, 2001. Radon exhalation from granites used in Saudi Arabia Journal of Environmental Research 53, pp 91-98.

Barashko.V, Dolinsky.S, Ignatenko.M, Korytov.A and Procofiev.O, 2002. EMU CSC systems chamber leak rate measurements, internal report, university of Florida.

Beretka J. and Mathew P.J, 1985. Natural radioactivity of Australian building materials, industrial wastes and by products. Health Physics 48, pp.87-95.

Erling Stranden, (1983). Assessment Of The Radiological Impact Of Using Fly Ash In Cement, Health Physics vol. 44 no.2, pp 145 – 153.

Hafez.A.F, Hussein.A.S. and Rasheed.N.M., 2001. A study of radon and thoron release from Egyptian building materials using polymeric nuclear track detectors. Applied Radiation and Isotopes.54, pp 291-298.

Jha.S, Khan A.H, Mishra U.C. (2001), A Study Of The Technologically Modified Sources Of Radon And Its Environmental Impacts In An Indian U Mineralized Belt. Journal of Environmental Radioactivity Vol 53, pp no.183 – 197.

Maged.A.F. and Borham.E., 1997. A study of the radon emitted from various building materials using alpha track detectors. Radiation Measurements 28, pp 613-617.

Mentazul I. Choudhury,(1998) Concentration Of Radio Nuclides In Building And Ceramic Materials Of Bungladesh And Evaluation Of Radiation Hazard. Jrnl. Radioanalytical and Nuclear Chemistry, vol 231,

Poffijin A., Bourgoignie.R, Marijns.R, Uyttenhove.J, Janssens.A and. Jacobs.R (1984); Laboratory measurements of radon exhalation and diffusion, Radiation Protection Dosimetry, vol 7, p 77-79.

Somalai.J, . Nemeth Cs, Kanyar.B, Kovacs.J; Variations of Radon Emanation of Coal-Slags with the Burning Temperature, Proceedings of IRPA 10.

Steger F. And Grun K.(1999),Proceedings of Radon in the Living Environment, Athens, Greece.

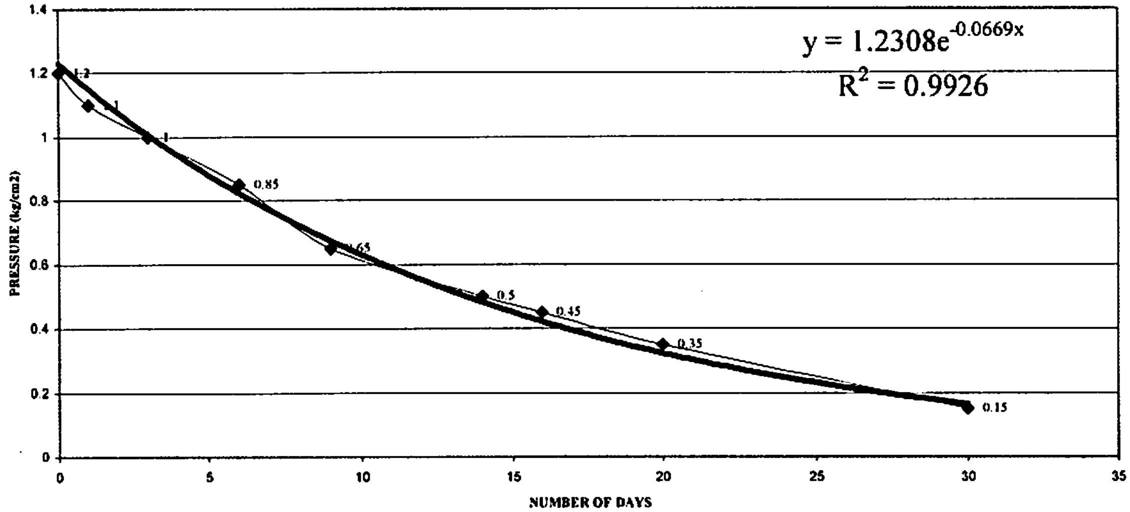


FIG1 GRAPH SHOWING PRESSURE DECREASE WITH TIME

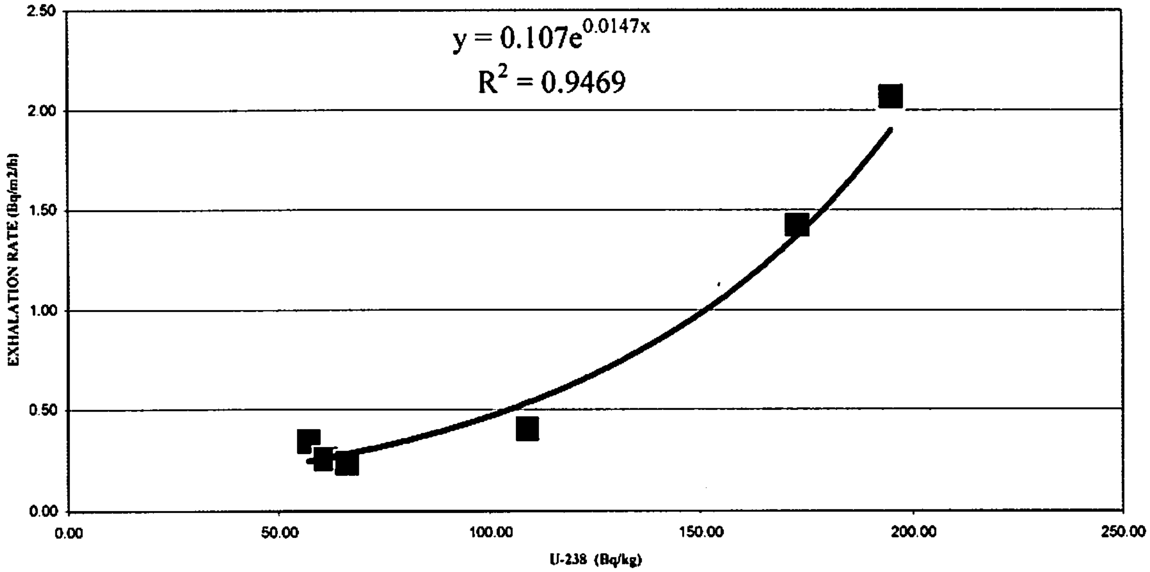


FIG.2. CORRELEATION BETWEEN URANIUM CONTENT AND EXHALTION RATE OF THE SAMPLES

TABLE 1 RADON EXHALATION RATE (RER) OF GRANITE TILES

SAMPLE CODE	RER (Bq $m^{-2}h^{-1}$)
S1	2.07±0.07
S2	0.26±0.05
S3	0.35±0.02
S4	1.42±0.05
S5	0.24±0.01
S6	0.41±0.03
S7	<0.10
S8	<0.10
S9	<0.10
S10	<0.10
S11	<0.10
S12	<0.10
S13	<0.10
S14	<0.10
S15	<0.10
S16	<0.10
S17	<0.10

TABLE 2 NATURAL RADIOACTIVITY CONCENTRATION PRESENT IN THE TILES

SAMPLE CODE	^{232}Th Bqkg^{-1}	^{238}U (^{226}Ra) Bqkg^{-1}	^{40}K Bqkg^{-1}	Ra$_{eq}$ Bqkg^{-1}
S1	74±2	195±3	989±11	377
S2	133±2	61±2	963±10	325
S3	85±3	57±3	893±12	247
S4	212±2	173±2	1128±10	563

S5	79±2	66±2	824±9	242
S6	17±2	109±2	1848±8	276
S7	108±2	<8.5	1489±8	343
S8	33±1	<8.5	1030±6	127
S9	20±1	<8.5	439±5	62
S10	154±2	<8.5	1430±6	330
S11	101±2	17±1	1784±7	299
S12	<1	<8.5	147±4	11
S13	111±2	19±2	2116±9	341
S14	<1	<8.5	147±4	11
S15	<1	<8.5	224±6	17
S16	<1	<8.5	139±3	11
S17	<1	<8.5	132±5	10

TABLE 3 COMPARISON OF RADON EXHALATION RATES

SAMPLE CODE	^{238}U(^{226}Ra) Bqkg^{-1}	RER (Bq m^{-2}h^{-1})		ERROR
		EXPERIMENTAL	CALCULATED	
S3	57.00	0.35	0.25	+29
S2	61.00	0.26	0.26	0
S5	66.00	0.24	0.28	-18
S6	109.00	0.41	0.53	-31
S4	173.00	1.42	1.36	+4
S1	195.00	2.07	1.88	+9

Proceedings of the 2003 International Radon Symposium – Volume II
American Association of Radon Scientists and Technologists, Inc.
October 5 – 8, 2003

INVESTIGATION AND REDUCTION OF PERSONNEL RADON EXPOSURE LEVELS IN BAVARIAN WATER SUPPLY FACILITIES

M. Trautmannsheimer, S. Körner

Bavarian Environmental Protection Agency,
D-86177 Augsburg, Germany

ABSTRACT

Water supply facilities in Bavaria (Germany) were investigated with regard to radon concentrations in groundwater and indoor air as well as radon exposure to the staff working in these buildings.

500 water supply facilities were asked to take a groundwater sample and expose several track-etch detectors in order to obtain the mean room concentration of the main staff work places. In addition, the personnel had to wear a track-etch detector during the time they spent in the supply facilities.

About ten percent of the process controllers in the East Bavarian crystalline region are subjected to an annual effective dose of more than 20 mSv.

The management of supply facilities where process controllers were subjected to very high annual radon levels were asked to take remedial action. In one specific case, these measures reduced the annual effective dose of a process controller from 100 mSv to about 6 mSv.

INTRODUCTION

Exposure to radon is normally the main contributory factor to the annual effective radiation dose of the population. Apart from the level of radon exposure in housing, there are some work places where increased exposure can be expected. Especially high radon activity concentrations have been measured in mines [1], visitor caves [2,3], radon spas [4,5] and water supply facilities [6-10]. Therefore in May 1996, the European Commission passed the Council Directive 96/29/Euratom [11], laying down the basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. The annual recommended upper limit for natural radiation for a worker is 20 mSv. This basic safety standards concerning radon exposure at work places are implemented in the revised German radiation protection regulation [12] became effective in August 2001.

In 1995, the Bavarian State Ministry for State Development and Environmental Affairs set up a research project to study the level of radon exposure to which the staff of the Bavarian water supply facilities were subjected. Bavaria is the largest and most southern state of the 16 states of the Federal Republic of Germany. After various preliminary investigations a questionnaire was sent to all 2,600 Bavarian water supply facilities.

Process controllers, supervisors and cleaning staff were asked to provide information about the type of facility, the number of buildings, water extraction and ventilation in their supply facilities. They were also asked to answer questions about their typical work processes and the length of time spent in the potable water reservoirs and in the water purification buildings. About 50 percent of the water supply facilities returned the questionnaire containing data of 1,000 employees and 9,000 buildings. From this data it was calculated, that approx. 4,500 persons work in about 20,000 buildings for the Bavarian water supply facilities [13]. These persons stay in the supply buildings for regular inspections and cleaning of the potable water reservoirs, water purification units and collecting galleries. The average duration of stay in the water purification for back-washing is about 2 hours per week. Back-washing is a special working process to clean the filter material of the water purification systems and is normally the major contributory factor to the length of time spent by the process controller in these work places. In addition to this regular stay, the elevated reservoirs have to be cleaned thoroughly about once a year. The cleaning is often done by special staff or external companies.

Bavaria, which has an area of 70,600 km^2, can be partitioned into ten main geological regions according to the geological formations and the main aquifers. Taking into account the results of the radon soil gas measurements [14] and the information of the mean uranium and radium contents in the ground, the ten regions can be classified according to their "radon potential". The highest potential is assigned to the East Bavarian region (no. 5) and region no. 10 with its mainly granite substructure (Fig. 1).

RADON MEASUREMENTS METHODS IN WATER SUPPLY FACILITIES

From each region, a total number of more than 500 water supply facilities proportional to the size of the region was selected for radon (Rn-222) measurements. The processing plant workers were asked to take a 1 litre ground water sample in a radon tight PET bottle. For the sampling, a water hose was fixed at a tap of the raw water pipe and pushed down to the base of the bottle in order to fill the bottle very slowly and without turbulence. Preliminary experiments revealed that the loss of radon gas during this filling procedure is negligible [15]. The process controllers were advised to fill the bottle completely in order to avoid leaving an air space. After filling, the sample was immediately sent to the gamma spectroscopy lab at the

Bavarian Environmental Protection Agency for analysis. To obtain the activity concentration of Rn-222 for the analysis, the gamma lines of Bi-214 and Pb-214 were used. Since no sample is measured earlier than one day after sampling, these nuclides are in virtually radioactive equilibrium with Rn-222 during the measurement and therefore they should have the same activity as Rn-222. Several track-etch detectors were sent by mail to the water supply facilities. They were exposed for a period of two weeks in order to get the mean room concentration of the main working places of the staff. In addition, the processing plant worker had to wear a personal track-etch detector for two months, which was fixed to his clothes, during his stay in the supply facilities. From the recorded measurements, his individual, effective dose was estimated. When not in use, the personal detector was stored near a reference detector at a place with low radon concentration. An instruction sheet was enclosed to aid the selection of a suitable storage place. Sites such as car garages, car boots or well ventilated areas such as rooms with constantly open windows, office rooms outside the supply facilities and roofed balconies were recommended. In spite of the fact that track-etch detectors cannot be switched off, the exposure resulting purely from the stay in the water supply facilities can be calculated by the exposure of the reference detector and the protocol of the duration of stay. From the results of these two month measurements the annual dose of the processing plant worker was estimated. Track-etch detectors were used for measuring the indoor radon concentration levels and the radon exposure levels of the personnel. These track-etch detectors, about 3,000 in number, were obtained and evaluated by the GSF - National Research Centre for Environment and Health, Neuherberg, Germany. These are CR39 type detector foils in a diffusion chamber [16,17]. The system was also successfully tested for short time exposure measured in minutes. It is insensitive to thoron. The measuring error (2-sigma standard deviation) is about 25 % and almost unaffected by the recorded exposure. Much larger errors can occur by the calculation of the personal exposure of the processing plant workers. In order to keep the error level below 30%, the average radon concentration at the storage place must be below 200 Bq m^{-3}. Concentration can be checked by the exposure of the reference detector. About 10% of the measurements with personal detectors had to be repeated because of poor measuring precision. In this case, the processing plant worker was advised by telephone how to find a better storage place.

RESULTS FROM RADON MEASUREMENTS

The results of about 550 measurements of raw water samples from the whole of Bavaria are shown in Fig. 2. The process controllers were asked to take a raw water sample from the incoming water in a water purification unit or potable water reservoir. Generally, this water is a mixture taken from several springs and wells. Due to operational reasons, the amount of water from the various springs and wells can vary. Therefore, the radon concentration in the raw water can also show time variations. As expected, region 5 shows an increased average radon concentration in the raw water samples. Due to the small area of region 10 with its granite substructure, most supply facilities in this region obtain their water from aquifers outside the area. The raw water concentrations in these supply facilities are therefore similar to the concentrations in the other non-granite regions.

Around 1,250 measurements were taken in order to obtain information about the indoor concentrations in the water supply facilities (Fig. 3). As not every room in the buildings could be supplied with an track-etch detector, the process controllers were asked to place the detectors mainly in potable water reservoirs, water purification units and rooms where staff spent long periods of time. In all regions, there are some rooms with concentrations higher than 3 kBq m^{-3} . Taking into account that the normal annual working time is 2,000 h per year, indoor air concentrations of more than 3 kBq m^{-3} can lead to an effective dose above the limit of 20 mSv per year. Region no. 5 revealed the highest concentrations and therefore the median is significantly higher than that of the other regions. Indoor radon gas concentrations of up to 1200 kBq m^{-3} were observed. Some higher values in region no. 10 may be caused mainly by radon transported directly from the air into the ground soil and thus into the collecting galleries of one supply facility via cracks and holes in the concrete foundations. The main purpose of this research project was to obtain information about the annual radon exposure levels of the staff in the Bavarian water supply facilities. About 500 measurements were taken over a period of 2 months. From these data, a linear estimate of the annual exposures was made. Under "normal conditions" (equilibrium factor of about 0.4, unattached fraction of about 5 to 10%) an exposure of 2 and 6 MBq h m^{-3} is equivalent to an effective dose of 6 and 20 mSv, respectively [18]. In accordance with the regulations of the Council Directive 96/29/Euratom, continuous supervision of persons with annual exposure levels of between 6 and 20 mSv is recommended. An effective dose above the limit of 20 mSv per year is, according to the directive, not allowed. Fig. 4 shows the estimated percentage of personnel subjected to an effective dose above these limits. In all geological regions, exposure levels of over 6 mSv per year can occur. About 10% of the staff in the granite region of East Bavaria (region no. 5), and in the rest of Bavaria about 2% of the staff are subjected to exposure levels of over 20 mSv per year.

EFFECTIVE MEANS TO REDUCE STAFF EXPOSURE

Due to very high radon activity concentrations and annual exposure of process controllers remedial actions were undertaken in an East Bavarian water supply facility (Fichtelgebirge). The radon activity concentration in the ground water is about 900 Bq L^{-1} and indoor concentrations of up to 50,000 Bq m^{-3} were measured in the water purification building. Besides the filter basins, this building contains a laboratory, workshop, restroom, storage room and a control centre (Fig. 5). Therefore the amount of time spent by the controller in this building is relatively high and a annual radon exposure of 110 mSv was estimated. The exposure of the process controller was measured with personal track-etch detectors changed and evaluated every month. In order to reduce the radon exposure of the process controlers a ventilation system and a glass wall between the filter basins and the control centre was installed. The ventilation system is normally operated at half power. If the process controller has to inspect the filter basin room, he raises the ventilation power to 100 percent 15 minutes before he enters the room. These effective means reduced the annual radon exposure of the process controller to about 6 mSv (Fig. 6). The increase of the exposure in April after the structural alterations is due to the cleaning and painting of the filter basins. This service and maintenance has to be performed about every five years.

CONCLUSION

Prediction of the radon exposure levels of the staff without measurements is very difficult because exposure levels are influenced by 1.) radon concentration in the untreated ground (raw) water, 2.) characteristics of the buildings and work processes such as ventilation of the rooms, fraction of room volume to water surface of the basins, water flow through the basins, turbulent filling of the basins (cascades), enhanced radon production by special work processes (back-washing, filling times of the reservoirs), 3.) length of time spent in the water supply facilities.

In general, the most reliable method to evaluate radon exposure of the staff in a water supply facility, is to use personal track-etch detectors or electronic devices small enough for the staff to carry comfortably on their person. The calculation of exposure levels from the different indoor air concentrations and from the time spent in these areas is very approximate. Due to frequent and short stays in different buildings, the exact recording of the time spent in these places is usually too difficult for the personnel to carry out. An estimate of the time they spend in these areas given by the personnel involved, is also likely to be inaccurate. In addition, the radon concentration levels while the process controller is in the building can be different from the measured average concentration because the ventilation and the radon production rate (special work processes) are influenced by the process controller.

In all geological regions, exposure levels over 6 mSv per year can occur. In the granite region in East Bavaria about 10 % of the staff of region no.5 and in the rest of Bavaria

about 2% of the staff of all regions except no. 5 workers are subjected to exposure levels of over 20 mSv per year.
To reduce the exposure levels, it is very important to provide detailed information for the water supply facilities, because there are usually simple ways in which to minimise the time spent in the buildings. Other effective means to reduce the exposure levels of the staff are optimisation of the ventilation or air-conditioning systems, separation of frequently used working places from basins or water purification systems and the avoidance of turbulence whilst filling the basins.

Acknowledgements - This work was supported by the Bavarian State Ministry for State Development and Environmental Affairs.

REFERENCES

[1] Mulloy KB, James DS, Mohs K, Kornfeld M. Lung cancer in a non-smoking underground uranium miner. Environ Health Perspect 109(3):305-309; 2001.

[2] Szerbin P. Radon concentrations and exposure levels in Hungarian caves. Health Phys 71(3):362-369; 1996.

[3] Kobal I, Ancik M, Skofljanec M. Variation of ^{222}Rn Air Concentration in Postojna Cave. Radiat Prot Dosim 25(3):207-211; 1988.

[4] Kobal I, Fedina S. Radiation doses at the Radenci health resort. Radiat Prot Dosim 20(4):257-259; 1987.

[5] Szerbin P, Koteles G, Stur D. Radon concentrations in Rudas thermal bath, Budapest. Radiat Prot Dosim 56(1-4):319-322; 1994.

[6] Drane WK, York EL, Hightower JH, Watson JE. Variation of Rn-222 in public drinking water supplies. Health Phys 73:906-911; 1997.

[7] Fisher EL, Fuortes JF, Field RW. Occupational exposure of water-plant operators to high concentrations of radon-222 gas. J Occup Environ Med 38(8):759-764; Aug 1996.

[8] Henshaw DL, Perryman J, Keitch PA, Allen JE, Çamplin GC. Radon in domestic water supplies in the UK. Radiat Prot Dosim 46(4):285-290; 1993.

[9] Loomis DP. The relationship between water-system size and Rn-222 concentration in North Carolina public water supplies. Health Phys 52(1):69-71; 1987.

[10] Savidou A, Sideris G, Zouridakis N. Radon in public water supplies in Migdonia basin, central Macedonia, Northern Greece. Health Phys 80:170-174; 2001.

[11] 96/29/Euratom, Council Directive: basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation: The Commission of the European Community; Official Journal No. 159, 29/06/1996: 1-114; 1996.

[12] Verordnung über den Schutz vor Schäden durch ionisierende Strahlung (StrlSchV) vom 20. Juli 2001. Bundesgesetzblatt, Teil I, 1713-1848; 2001 (in German)

[13] Trautmannsheimer M, Schindlmeier W, Hübel K. Radon exposure levels of the staff in the drinking water supply facilities in Bavaria, Germany. Proceedings of the 5th Intrenational Conference on "High Levels of Natural Radiation and Radon Areas: Radiation Dose and Health Effects", 1225C: 81-86; 2002. ISBN 0-444-50863-5

[14] Kemski J, Klingel R, Siehl A. Classification and mapping of radon affected areas in Germany. Environm Int 22(Suppl.1): 789-798; 1996.

[15] Trautmannsheimer M, Schindlmeier W, Börner K. Radon concentration measurements and personnel exposure levels in Bavarian water supply facilities. Health Phys. 84(1):100-110; 2003

[16] Bartlett DT, Gilvin PJ, Still R, Dixon DW, Miles J C H. The NRPB radon personal dosimetry service. J Radiol Prot, 8(1):19-24; 1988.

[17] Bartlett DT, Gilvin PJ, Dixon DW, Solanki HL, Miles JCH. The performance of the NRPB radon personal dosemeter. Rad Prot Dos 17:139-142; 1986.

[18] Smith H. Protection Against Radon-222 at Home and at Work. ICRP Publication 65, Annals of the ICRP: The International Commission on Radiological Protection. Pergamon Press; 1994.

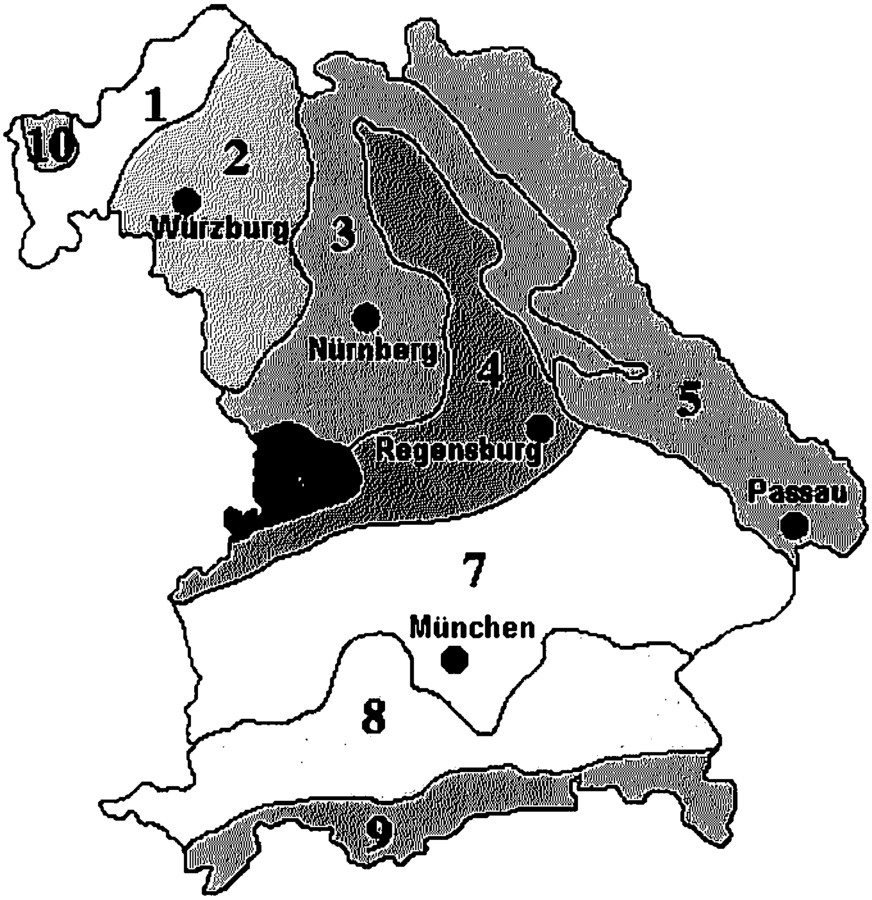


Fig. 1: The ten main geological regions of Bavaria. The regions with the highest "geogenic radon potential" are region no. 5 and region no. 10.
Rock types of the regions: new red sandstone (1); shell limestone, Keuper (2); franconian Keuper (3); upper Jurassic, Dogger, Cretaceous (4); granite, gneiss (5,10); ejection material of the Ries meteorite (6); sediment rocks, molasses (7); young moraine (8); Trias, Jura, Tertiary (9).

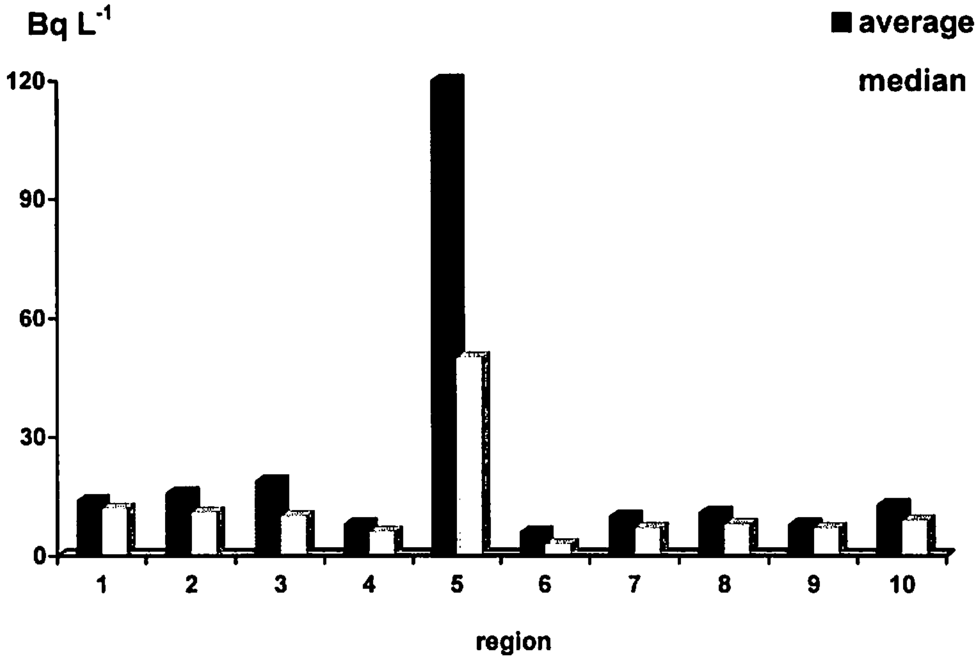


Fig. 2: Mean radon activity concentration in ground water in the different geological regions of Bavaria.

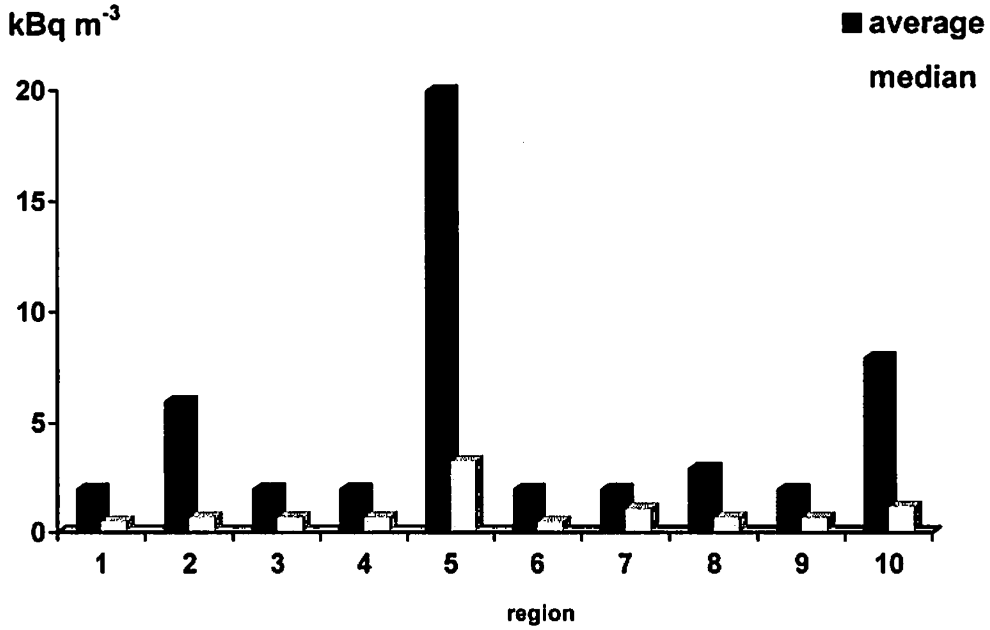


Fig. 3: Mean radon indoor activity concentration in the Bavarian water supply facilities (averaged over each geological region).

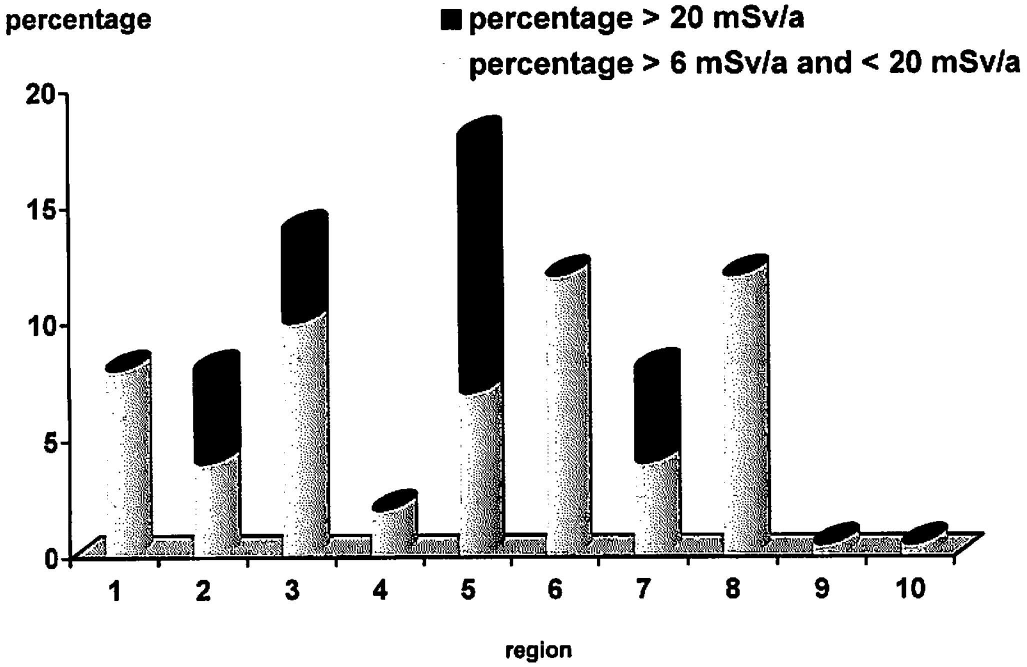
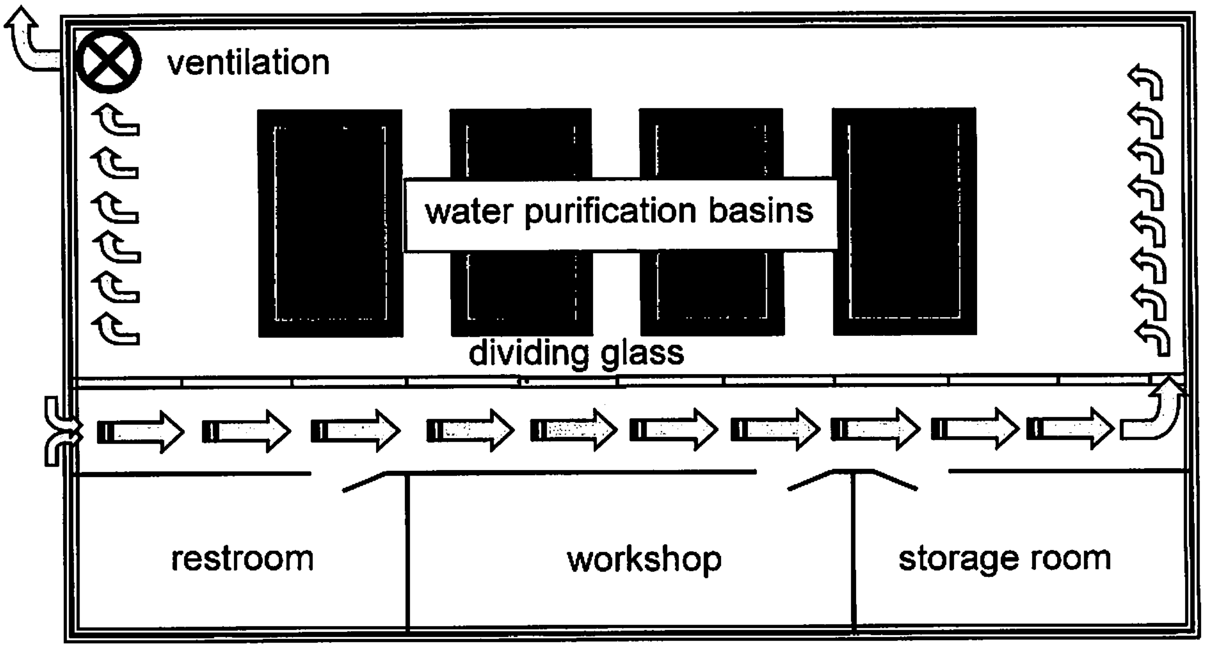


Fig. 4: Effective annual dose distribution amongst the Bavarian water supply facility personnel. This effective dose is from radon exposure during working time in the supply facilities.



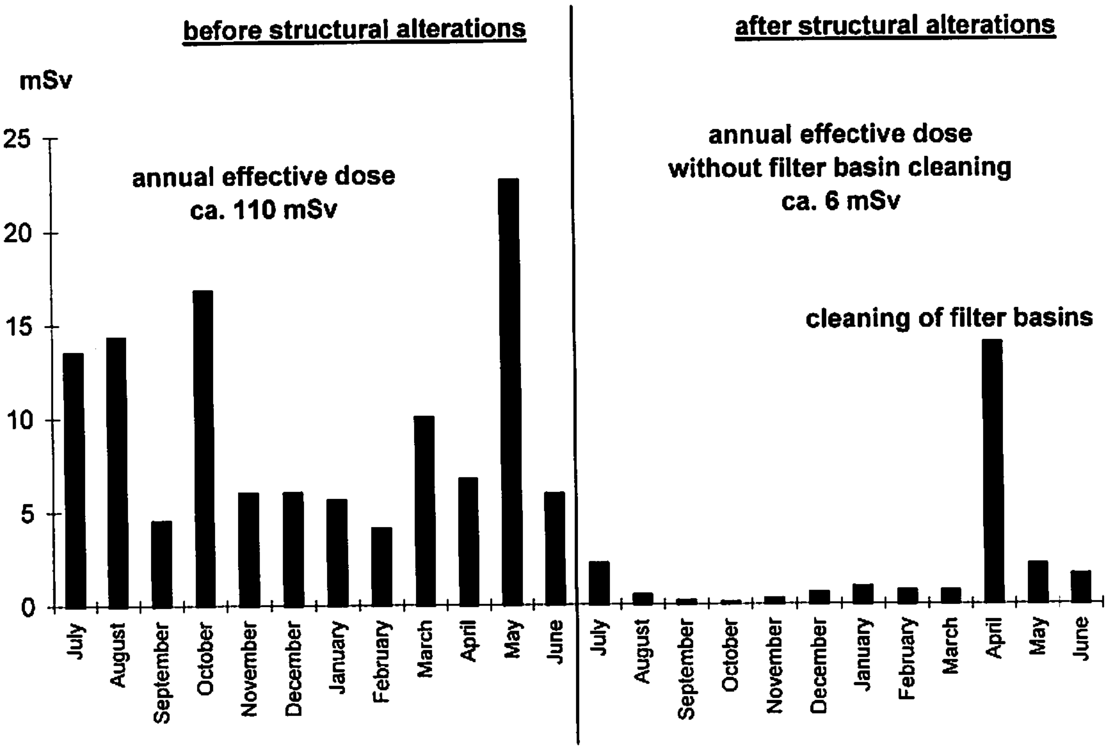


Fig. 5: Ground view of a water purification building of a supply facility in the East Bavarian region.

Fig. 6: Monthly effective dose of a process controller before and after structural alterations in the water purification building.