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Detection and Mitigation of Occupational Radon Exposure in Underground Workplaces

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ABSTRACT

The aim of this study was to unravel the occupational exposure to radon among underground workers. The possibility for radon mitigation by improving ventilation or by sealing was also investigated.

65 workrooms in 19 workplaces has been investigated in the ground floor, in basements and in underground spaces in southern Finland and in middle Finland. Radon concentration varied from 15 to 1636 Bq/m^3 during working hours resulting in annual dose of 0.09 to 10.3 mSv. The average radon concentration in all places studied was 359 Bq/m^3 (2.2 mSv) and the average in working time was 293 Bq/m^3 (1.8 mSv). Concentration of radon exceeding 400 Bq/m^3 (which is the occupational limit on annual average radon exposure in Finland) was detected in 13 (20 %) workrooms.

The mitigation methods utilized were enhanced ventilation, adjustment of exploitation time, and sealing yielding reduction of 45 - 75 % in radon exposure levels.

1. INTRODUCTION

Monitoring of occupational radon levels in workplaces has been a common practice in mines, but rarely accomplished in other working environment. A new Finnish law and regulations of radiation became valid in the beginning of 1992. These regulations /1/ includes all workplaces except mines and quarrys, which have their own previous regulations. In normal work (8 hours/day), the average annual radon levels shall not be over 400 Bq/m^3 in indoor air.These regulations are based on ICRP's recommendations. The newest regulations, which determine the occupational annual limit of radon to be 5 mSv, has been published by ICRP in 1993 /2/.

In China, Deng et al. /3/ have studied radon in 51 underground buildings, including hotels, restaurants, entertainment halls, shops and factories. Mean concentration of radon varied from 3 to 616 Bq/m^3 in these buildings. Increasing of depth and fissures in walls seemed to increase radon levels. In another Chinese study /4/ mean indoor air concentration of radon was 75 Bq/m^3 in underground buildings including a shop, a restaurant and a market. The annual average radon concentration was 93 Bq/m^3 in 74 subway stations in Korea /5/. The concentrations varied within a wide range from undetectable to 677 Bq/m^3. Radon levels in three adjacent rooms situated in the lower ground level of a multistorey office building were found to be from 73 to 130 Bq/m^3 in Switzerland /6/. The Finnish Centre for Radiation and Nuclear Safety (STUK) began a survey of radon levels in Finnish workplaces in 1993 /7/. So far, they have investigated about 3500 workplaces in cities, situating in areas, where radon levels have amounts exceeded 400 Bq/m^3 in dwellings. According to Annanmäki about in 30 % of studied workplaces radon levels were over 300 Bq/m^3.

Sealing, effective ventilation, pressurization and subslab depressurization have been found out to be effective mitigation methods for radon. In United States /8,9,10/ some studies have been conducted on radon problems and mitigation methods in schools. Those indicated that HVAC pressurization has the capability to provide both radon reduction and improved indoor air quality in new and existing buildings. According to Cohilis et al. /11/, effective ventilation with pressurization and sealing the constructions significantly (14 - 98 %) decreased radon levels in Belgian schools. Similar findings have been found by our group /12,13/.

2. MATERIALS AND METHODS

2.1 The workplaces

Radon concentrations vary largely in different parts of Finland. High radon concentrations have been detected in southern Finland, especially in areas with weathered granite and eskers. The underground spaces studied situated in southern Finland (15 places) and in middle Finland (4 places). Workplaces studied included different kind of offices and servicing rooms in schools, office buildings, telecommunication centres and military forces. Volumes of workplaces varied largely, from small office rooms of 20 m^3 to large research halls of 17 200 m^3.

2.2 Measurement techniques

Volumes, exploitation times of ventilation and ground work of workplaces, working hours and amount of employees were inquired by questionnaire. Radon levels were analyzed at breathing zone continuously by using the Lucas cell method /14/ with a Pylon AB-5 assembly which includes detector, photomultiplier and data collection system based on a microprocessor. The output data of the Pylon detector were processed with SP-55 software run on a PC. The interval of continuous measurement with the pump flow rate of 0.4 l/min was 30 minutes (averaged to one hour). The integrated long-term level of indoor radon was detected by the alpha track etch films /15/, which gives the average radon level during one month, including also nights and weekends, when the HVAC-system is not as effective as in the daytime. Alfa track etch films were analyzed by the Finnish Centre for Radiation and Nuclear Safety. The pressure difference across the wall was monitored by an electronic manometer together with a datataker averaging three minute intervals to one hour and the data was run on and analyzed by a PC. During daytime working hours air-exchange rates were measured by tracer gas technique and dilution method using Freon as a tracer gas and an infrared spectophotometer, Miran 1-A, as an analyzer. Doses were calculated by using working time of 2000 hours and equilibrium factor of 0.4 /2/.

3. RESULTS

3.1 Radon consentrations

Radon levels varied from 12 to 5000 Bq/m^3 and radon levels in working hours varied from 15 to 1636 Bq/m^3. Annual average doses were respectively from 0.09 to 31.5 mSv and from 0.09 to 10.3 mSv. Radon levels exceeded 400 Bq/m^3 daily in six workplaces in 16 working rooms of places (21 %) and during working hours in 13 working rooms of places (20 %) (table 1.).

	Measured time		In working hours	
Bq/m^3	frekv.	%	frekv.	%
0 - 199	41	63.1	39	60.0
200 - 399	8	12.3	7	10.8
400 - 799	10	15.2	7	10.8
800 -	6	6.1	6	9.2
Missing	-	-	6	9.2
Total	65	100.0	65	100.0

Table 1. Radon levels (Bq/m^3) with gategories.

	N= 65	Ave	Med	Min	Max	Stddev	Work.
Groundwork:							
Crawling space	1	1082	1082	1082	1082	-	1636
Ground floor	22	134	104	25	508	122	135
Basement	17	663	210	53	5000	1177	427
Cave	25	293	140	12	1647	376	316
Depth:							
0-3 m	32	385	117	25	5000	896	232
4-20 m	12	547	442	12	1647	503	736
21- m	15	140	128	30	412	103	120
Ventilation:							
Natural ventilation	2	2625	2625	303	5000	3321	303
M. exhaust	10	292	125	53	1802	534	294
M.exh. & suppl.	51	291	131	12	1647	354	300
Else	2	126	126	84	168	59	123
Whole data	65	359	133	12	5000	693	293

Table 2. The mean, median, minimum, maximum and standard deviation of measured radon levels (Bq/m^3) in 65 workrooms. 5 results are measured by alpha track etch film and the rest are measured by Pylon AB-5. (M.exhaust = mechanical exhaust, M.exh.&suppl.= mechanical exhaust and supply, work. = average in working hours).

3.1 Mitigation methods

There was six workplaces including 13 workrooms, where concentration of radon in working hours was over 400 Bq/m^3. Places were two telecommunication centres (including 8 rooms), a conservation hall of museum (2 rooms), an office of airport (1 room), an office of school (1 room) and an office of archives (1 room). The places had mechanical ventilation, except the school, which had mere mechanical exhaust. The other telecommunication centre located in depth of 17 meters, the other located in a basement, the conservation hall of museum located in cave, the office of airport and office of school located in groundfloor and the office of archives located in depth of 17 meters. The telecommunication centre in a basement (figure 1), the airport office (figure 2) and the school (figure 3) were mitigated during this study.

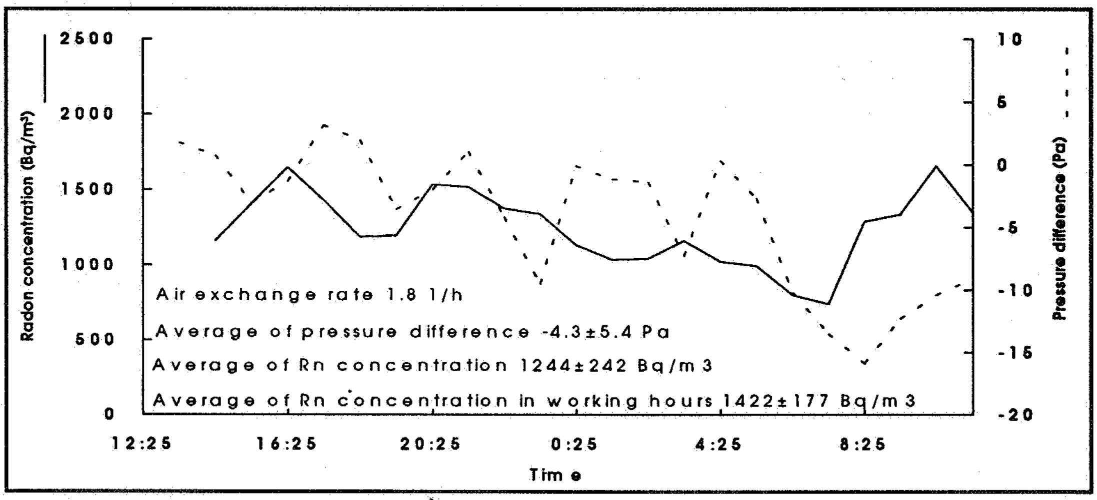

Figure 1a) Radon concentration (—) and pressure difference (- - -) in telecommunication centre, in a cross-linking room before mitigation

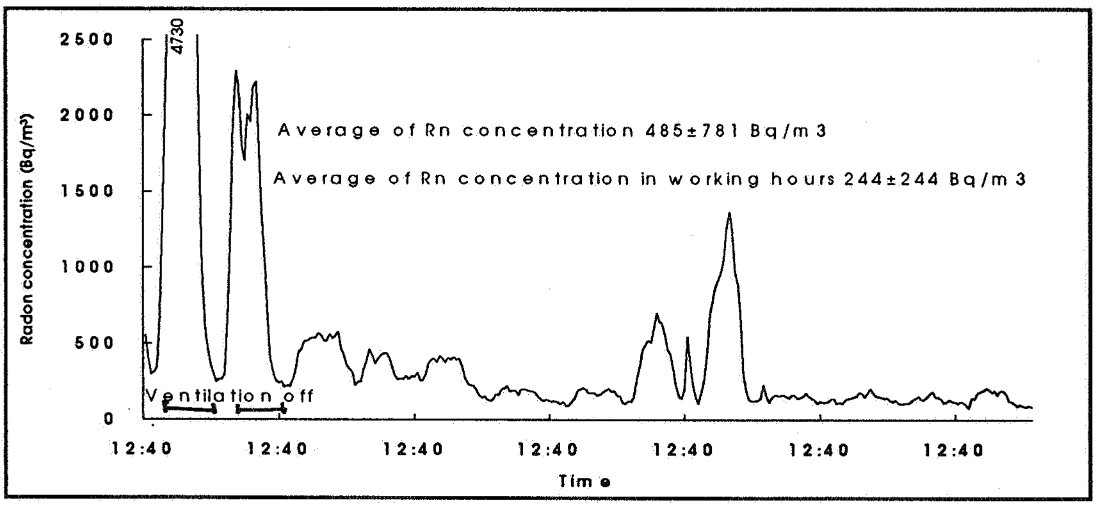

Figure 1b) Radon concentration in the cross-linking room after mitigation. The floor of the next room, where radon concentration was 5000 Bq/m^3 (measured by alfa track etch film), was sealed by a plastic carpet, and an additional exhaust air fan was installed in the room.

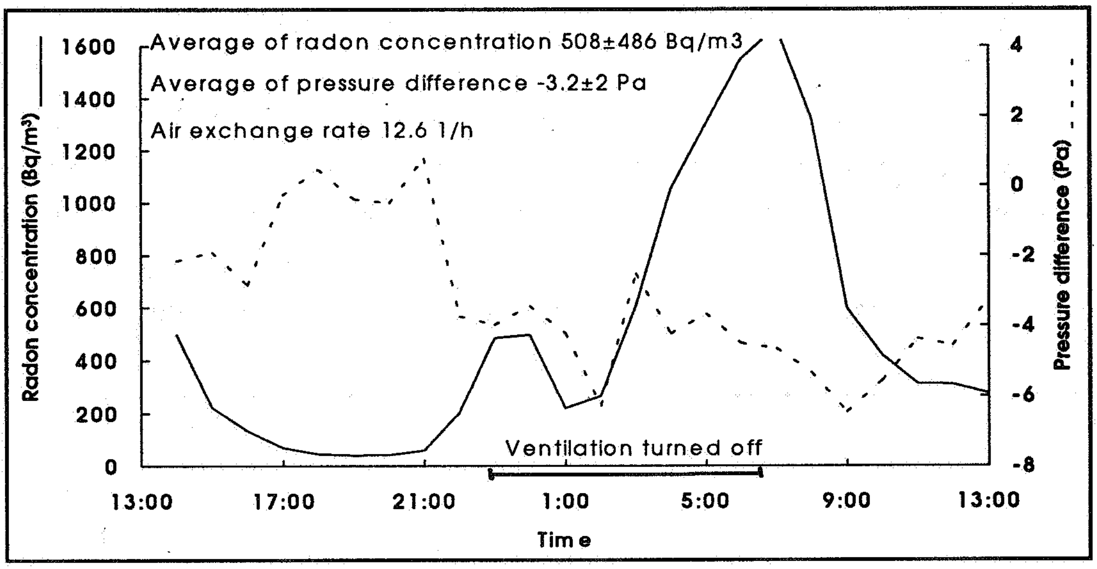

Figure 2a) Radon concentration (—) and pressure difference (- - -) in the office of airport before mitigation.

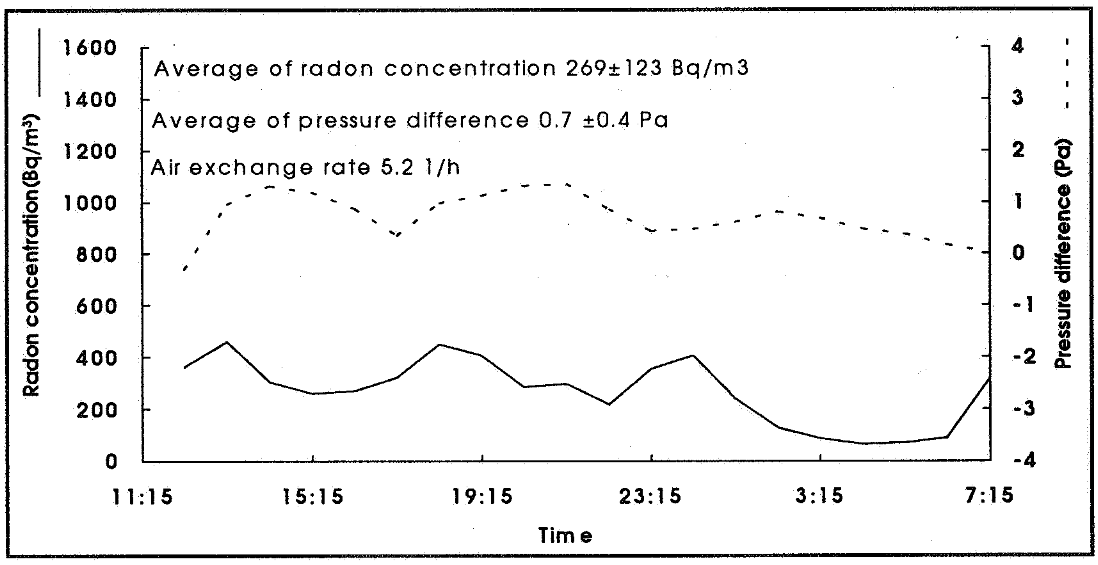

Figure 2b) Radon concentration (—) and pressure difference (- - -) in the office of airport after mitigation. Working hours in this room was 24 hours. The exploitation time of ventilation was adjusted to operate also for 24 hours.

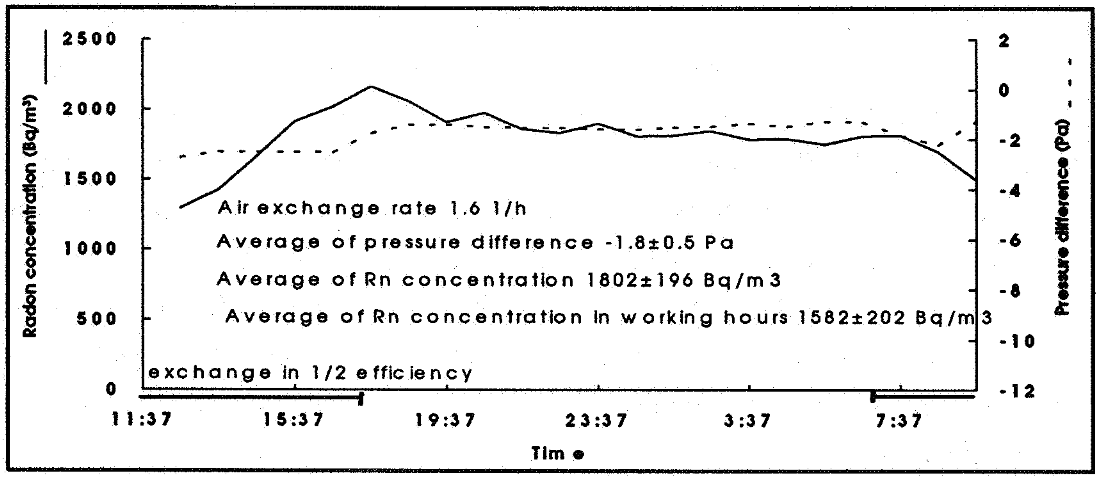

Figure 3a) Radon concentration (—) and pressure difference (- - -) in the office of school before mitigation

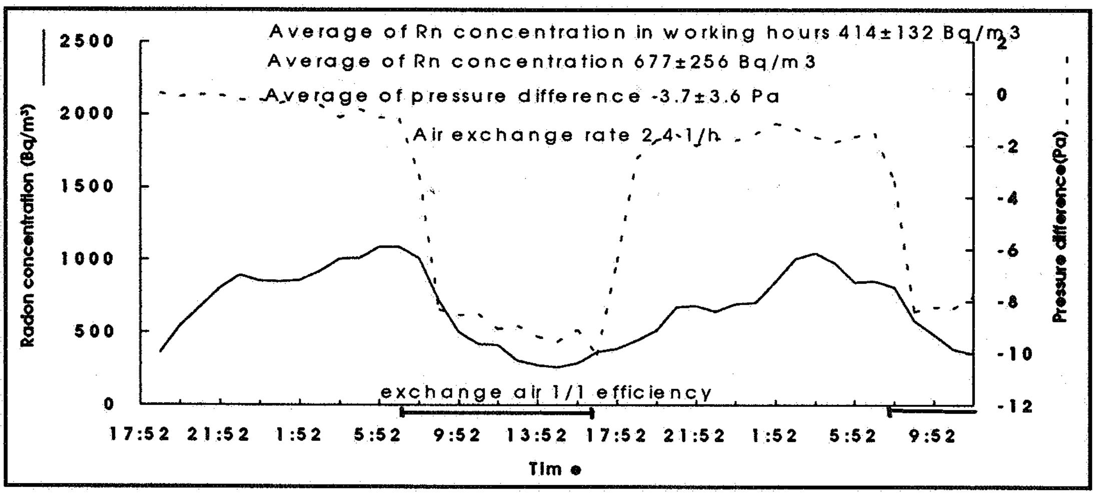

Figure 3b) Radon concentration (—) and pressure difference (- - -) in the office of school after mitigation. The mechanical exhaust ventilation was adjusted to operate more effectively, and the crawling space was naturally ventilated.

4. CONCLUSIONS

There was not any markable statistical associations between depth or ventilation system and radon concentration. The correlation between radon concentration and ground work of basement was positive but not high.

To effect the existing ventilation in underground workplaces was found to be a cheap and an easy and effective technique to mitigate radon in indoor air. Radon gas drift to indoor air is suggested to decrease, when amounts of exhaust and supply air are in balance, and constructions are sealed. The source sites have to be ventilated separately and the constructions between spaces have to be sealed. The exploitation time of ventilation should be enough long to decrease radon concentration to the action level in the beginning of working hours after weekends and nights, when ventilation is usually turned off. Ventilation of a crawling space caused a substitutional air coming from outdoor air and diluted radon gas under the school office. An optimal combination of these mitigation methods reduced the radon concentrations 45 - 75 %.

ICRP's recommendations for the occupational annual radon exposure is 20 mSv per year averaged over a period of 5 year with the effective dose not exceeding 50 mSv in any single year /2/, were not exceeded in the workplaces studied after mitigations.

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