STUK

Control of radon in Finnish workplaces

Mika Markkanen

STUK - Radiation and Nuclear Safety Authority

FINLAND

STUK

Identification of workplaces

UNDERGROUND MINES

Regular monitoring since 1972

Specific regulations and action levels since 1975

Today:

- 10 operating mines
- About 250 underground workers
- Mean concentration 260 Bq/m^3 (weighted by number of workers)

STUK

Provisions on natural radiation in Finland

Radiation Act
(in force since 1992):

Radiation practices comprise:

- use of radiation
- operations and circumstances in which a person's exposure to natural radiation causes or may cause a health hazard.

STUK

Provisions on natural radiation in Finland

RADIATION ACT, Section 45

The employer

- **is required to investigate** the radiation exposure if it is found, or
- **if there is reason to suspect**

that the work involve radiation to such an extent that it might cause a health hazard.

STUK

Action levels for occupational exposures to natural radiation

Radiation Decree (amendment 1143/98):

- ***Radon in workplaces 400 Bq/m^3***
  - **authorisation for STUK to issue action levels for workplaces with lower occupancy**
- **Occupational exposure to other sources of natural radiation (excluding radon): 1 mSv/a**

STUK

Provisions on natural radiation in Finland

Radiation Act, Section 70

STUK shall issue general instructions on how to attain the level of safety defined in the Act.

ST-Guide 12.1: Radiation Safety in Practices Involving Exposures to Natural Radiation

ST-Guide 12.2: Radioactivity of Construction Materials, Fuel Peat and Peat Ash

ST-Guide 12.3: Radioactivity of Drinking Water

STUK

Guide ST-12.1 issued by STUK

Action levels for radon in workplaces:

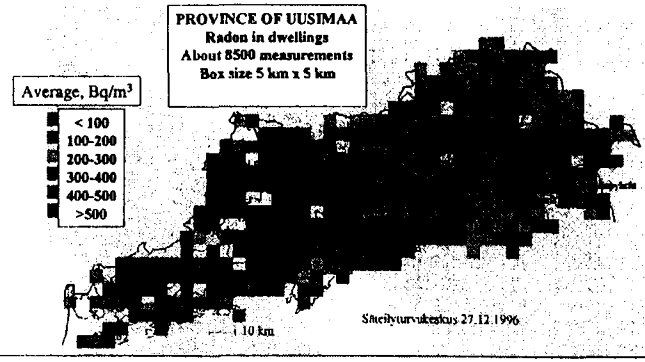
<u>Annual working hours</u>

Regular (1600 hours)	400 Bq/m^3
< 600 hours	1000 Bq/m^3
< 300 hours	2000 Bq/m^3
< 100 hours	6000 Bq/m^3

STUK

Identification of workplaces

Above ground workplaces in radon prone areas



STUK

Regulatory control of radon in workplaces

ST Guide 12.1:

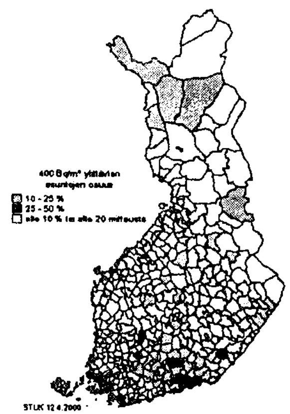
At identified radon prone areas there is "reason to suspect that radon in workplaces might cause a health hazard".

=> Radon measurements in workplaces compulsory
(unless it is evident that high radon concentrations can not occur, e.g. In an office on higher floors of a building)

STUK

Guide ST 12.1

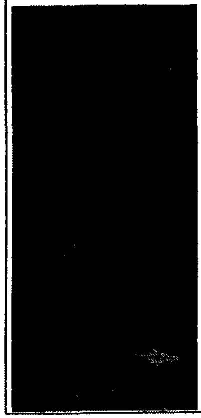
Municipalities in which the radon concentration in workplaces shall be measured



STUK • SÄTEILYTURVAKESKUS • STRÅLSÄKERHETSCENTRALEN • RADIATION AND NUCLEAR SAFETY AUTHORITY

STUK

Regulatory control of radon in workplaces



Radon campaign started in 1992:

Information on the employers obligation to measure radon:

- ***Articles in newspapers and journals***
- ***a TV campaign***

=> Did not work out: very few radon measurements were done

=> A more direct approach had to be adopted

STUK

Regulatory control of radon in workplaces

Starting from municipalities where highest concentrations expected:

A letter is sent to employers

- Information leaflet on radon in workplaces
- Fill-in reply form to be returned to STUK indicating:
  - radon measurement results, or
  - justification for not measuring radon

Up to now about 10000 employers contacted, about 1000 is contacted annually

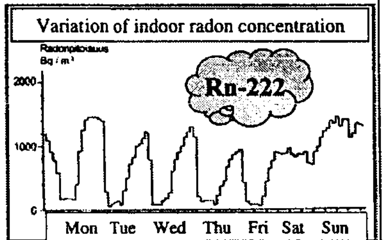
STUK • SÄTEILYTURVAKESKUS • STRÅLSÄKERHETSCENTRALEN • RADIATION AND NUCLEAR SAFETY AUTHORITY

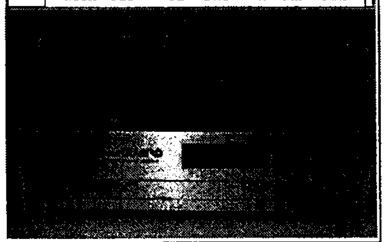
STUK

MONITORING OF RADON

Continuous monitoring ⇒

Integrating measurement ⇓





STUK

Monitoring of radon in workplaces

Finnish strategy for above ground workplaces:

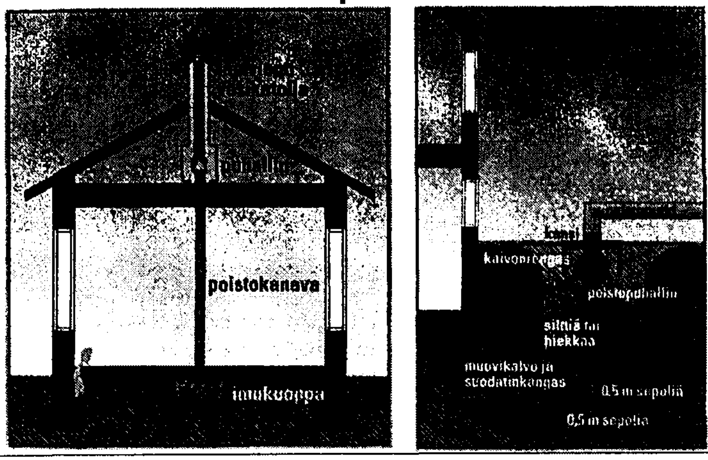
2 month integrating measurement during winter

< 400 Bq/m³	No need for further action
400 - 500 Bq/m³	Complementary measurement in summer, or an assessment of diurnal variations
>500 Bq/m³	An assessment of diurnal variations, or remedial actions
>2000 Bq/m³	Remedial actions

Remedial action is required where measurements show that the Action Level (400 Bq/m³) is exceeded

STUK

Subfloor depressurisation



STUK • SÄTEILYTURVAKESKUS • STRÅLSÄKERHETSCENTRALEN • RADIATION AND NUCLEAR SAFETY AUTHORITY

STUK

Applying the System of Protection of Workers

Only if remedial action is technically or economically unfeasible!

- Monitoring and recording of exposures
- Classification of areas
- Special instructions for work
  (e.g. Use of respiratory protective equipment)
- Dose limits (in regular work 20 mSv = 3000 Bq·m^{-3})

STUK • SÄTEILYTURVAKESKUS • STRÅLSÄKERHETSCENTRALEN • RADIATION AND NUCLEAR SAFETY AUTHORITY

STUK

Regulatory control of radon in workplaces

Results of the radon programme

- About 10000 radon measurements in workplaces
- Injunctions issued to about 900 workplaces to make further assessments on the workers exposure or to take remedial action
- In about 600 workplaces further assessment has shown that the action level is not exceeded
- Remedial action taken in about 200 workplaces

Mika Markkanen/15.4.98

STUK

Regulatory control of radon in workplaces

Radon remedies:

- Radon remedies in 200 workplaces
- Average reduction in radon concentration: 1500 Bq/m^3
- Average averted dose of a worker: 10 mSv per year
- Sum of averted occupational dose: 5 Sv per year

Mika Markkanen/15.4.98

Lessons learned (1/2)

- Only about 70% of enterprises reply to written requests to investigate exposures to radon (35% to 1. request + another 35% to 2. request)
- Registers of enterprises (addresses) are not always complete and up to date: coverage about 70-80% (?)

=> "Distance monitoring" covers only 50 - 70 % of enterprises

Lessons learned (2/2)

- Remedial action and further investigations require sometimes surprisingly long time:
  - Small delay in remedial action: the whole process might be delayed with one year (verifying measurements only during winter)
  - On-site visits might eliminate unnecessary delays

=> Co-operation with occupational safety and heath authorities established in 2000

- occupational safety inspectors are being trained to identify workplaces where radon measurements might be needed
- radon is included in inspectors' "checklist" as a matter to be considered in all inspections at different workplaces

STUK•SÄTEILYTURVAKESKUS•STRÅLSÄKERHETSCENTRALEN•RADIATION AND NUCLEAR SAFETY AUTHORITY

121

STUK

Provisions on natural radiation in Finland

ST-Guide 12.2: Radioactivity of Construction Materials, Fuel Peat and Peat Ash

Investigation level for building materials (based on the annual dose of 1 mSv):

$$I_1 = \frac{C_{Th}}{200\ Bq/kg} + \frac{C_{Ra}}{300\ Bq/kg} + \frac{C_K}{3000\ Bq/kg}$$

C_{Th}, C_{Ra} and C_K are activity concentrations in the material, expressed in Bq/kg

If $I_1 \leq 1$, the material can be used without restrictions.
If $I_1 > 1$, the responsible party is required to show specifically that the annual dose caused by the use of the material is less than 1 mSv/a.

STUK

Provisions on natural radiation in Finland

ST-Guide 12.3: Radioactivity of Drinking Water

Investigation level based on the annual dose of 0.5 mSv for water intended for human consumption (applied to water works, not to private wells):

$$I = \frac{C_\alpha}{Bq/l} + \frac{C_\beta}{Bq/l} + \frac{C_{Rn}}{300\ Bq/l}$$

where C_α, C_β and C_{Rn} are the total alpha, total beta and radon concentrations, expressed in Bq/l

If $I \leq 1$, the water can be used for human consumption without restrictions.
If $I > 1$, the responsible party is required to show (nuclide specific analysis) that the annual dose caused by the use of the water is less than 0.5 mSv/a.

A binding order to take remedial action is issued when measurements show that the annual dose caused by the use of the water is likely to exceed 0.5 mSv/a.

M. Markkanen, M. Annanmäki and E. Oksanen

Radon in workplaces

The EU Member States have to implement the new Basic Safety Standards Directive (BSS) by May 2000. The Title VII of the Directive applies in particular to radon in workplaces. The Member States are required to identify workplaces which may be of concern, to set up appropriate means for monitoring radon exposures in the identified workplaces and, as necessary, to apply all or part of the system of radiological protection for practices or interventions. The BSS provisions on natural radiation are based on the ICRP 1990 recommendations. These recommendations were considered in the Finnish radiation legislation already in 1992, which resulted in establishing controls on radon in all types of workplaces. In this paper issues are discussed on the practical implementation of the BSS concerning occupational exposures to radon basing on the Finnish experiences in monitoring radon in workplaces during the past seven years.

Radon an Arbeitsplätzen. *Die EU Mitgliedsstaaten müssen die neue Grundnorm im Strahlenschutz bis Mai 2000 implementieren. Kapitel VII dieser Direktive ist der Radonproblematik an Arbeitsplätzen gewidmet. Die Mitgliedsländer sind aufgerufen betroffene Arbeitsplätze zu identifizieren und, soweit nötig, Strahlenschutzmaßnahmen für Anwendungen oder Interventionen zu ergreifen. Die Vorschriften der Grundnorm im Bereich der natürlichen Radioaktivität basieren auf den Empfehlungen der Internationalen Strahlenschutzkommission (ICRP) von 1990. Diese Empfehlungen wurden in der finnischen Strahlenschutzgesetzgebung bereits 1992 berücksichtigt und eine entsprechende Überwachung der Radonexposition an Arbeitsplätzen eingeführt. In der vorliegenden Arbeit werden Probleme der praktischen Implementierung der Grundnorm in bezug auf berufsbedingte Radonexpositionen auf der Grundlage der finnischen Erfahrungen bei der Überwachung von Radon an Arbeitsplätzen in den letzten 7 Jahren diskutiert.*

1 Introduction

The new Basic Safety Standards Directive (BSS) [1] covers work activities which involve the presence of natural radiation sources. The EU Member States are requested to identify by means of surveys or by any other appropriate means work activities which lead to significant exposure of workers or members of the public. Corrective measures to reduce exposures and a system of radiological protection have to be applied to occupational and public exposures where appropriate. The Member States have to implement the directive by May 2000.

The European Commission together with the Group of Experts referred to in the Article 31 of the Euratom Treaty has provided technical guidance and recommendations on the implementation of the directive's Title VII on natural radiation sources [2]. As radon in workplaces is the most important source of occupational exposure to natural radiation, the main emphasis of the guidance is on radon.

Regular monitoring of occupational exposures to natural radiation started in Finland in the early 1970's with radon measurements in underground mines and excavations. First regulations for controlling radon in underground mines were issued in 1975. The monitoring of aboveground workplaces commenced in a larger scale in 1992 when the new Finnish Radiation Act [3] took effect. The Radiation Act covers all work activities involving significant occupational and public exposures to natural radiation in accordance with the principles set in the 1990 ICRP Recommendations [4]. The Act and other provisions issued by the virtue of it cover the activities falling under the scope of Title VII of the new BSS Directive.

The purpose of this paper is to discuss some practical issues on the implementation of the BSS Directive concerning occupational exposures to radon based on the Finnish experience in monitoring radon in workplaces.

2 The BSS Directive and radon

The provisions on work activities involving exposures to natural radiation sources are given in Title VII of the Directive comprising Articles 40-42. The Articles 40 and 41 establish a stepwise system in which the Member States are required

- to identify, by means of surveys or by any other appropriate means, work activities which may be of concern,
- to set up appropriate means for monitoring exposure in the identified work activities and, as necessary,
- to apply all or part of the system of radiological protection for practices or interventions, as prescribed elsewhere in the Directive.

The directive applies in particular to work activities where workers are exposed to radon progeny. The directive does not apply to exposure to radon in dwellings or to natural levels of radiation, i.e. to radionuclides contained in the human body, to cosmic radiation prevailing at ground level or to above ground exposure to radionuclides present in the undisturbed earth's crust.

2.1 Radon in underground mines

The significance of radon as a source of radiation exposure was realised in the 1950's when it was discovered that exposures to radon (specifically to its decay products) could explain the excess in lung cancer detected among miners. The extensive mining and processing of uranium for military purposes during those days made radon a current issue leading to research work on radon dosimetry and to the development of methods for monitoring radon and its decay products. The first results indicating a significant excess of lung cancer among the uranium miners were obtained in the 1960's in the United States. High concentrations of radon exist also in non-uranium mines, in various under ground excavation works and other underground workplaces. Today, the epidemiological studies on uranium and non-uranium miners form the main source of information for estimating the risk (the dose) caused by exposures to radon [5].

In Finland, one of the first radon measurements in workplaces were made in 1972 in the underground excavation of the Helsinki Metro line. Concentrations between 4000 and 7000 Bq/m³ were measured, which gave a clear indication that the workers might receive significant doses. Since the regular traffic began in 1982, the concentrations have been monitored regularly in the Metro line. The annual average concentrations have been about 500 Bq/m³, at the maximum, in workplaces of no public admittance, and below 200 Bq/m³ in the remaining areas [6].

In the 1970's there were about 20 underground mines in Finland and the number of miners in them was about 1300. At that time radon concentrations were less than 400 Bq/m³ in about 50 % of all the measured places of work in the mines. Concentration exceeded 2000 Bq/m³ in about 20 % of the measurements. The highest detected concentration in a working area was about 37000 Bq/m³. Even higher concentrations were detected in some poorly ventilated unused areas of the mines. From those days the radon concentrations in mines have decreased significantly. Many of the large, poorly ventilated old mines have now been closed. It has been technically somewhat easier to arrange appropriate ventilation in the new, rather smaller mines operating today. A good general ventilation is also required by the use of diesel powered machinery. In addition, remedial action has been taken wherever regular control measurements have shown concentrations exceeding the action level.

Today there are 10 operating underground mines in Finland with about 230 underground workers. All underground mines are regularly inspected for radon, generally every second year. The mean radon concentration is about 250 Bq/m³ (weighted by the number of workers in each mine). The average radon concentration exceeds the action level of 400 Bq/m³ set for radon in workplaces in one mine at the moment. The concentrations in this particular mine are of the order of 1000–2000 Bq/m³ and temporally concentrations up to about 7000 Bq/m³ have been detected in some working areas. The reduction of radon concentration is technically difficult, if not almost impossible, because the radon originates from radon-rich bedrock-water entering the cavities in large amounts.

2.2 Radon in aboveground workplaces

The alpha track detector was adopted for radon measurements in the late 1970's. The method, being cheap and that the detector could be sent by post to the place of measurement, enabled the conduction of large surveys on indoor radon. Extensive surveys on radon in dwellings were made in the 1980's in many countries and they showed that very high radon concentrations exist also in homes. The national average radon concentrations in dwellings in different countries vary from some 20 up to slightly above 100 Bq/m³. A characteristic for indoor radon is its variability; the concentrations in some dwellings are more than an order of magnitude above the average. In addition, regional variations within one country are significant.

It has been recognised that high radon concentrations detected in aboveground buildings are in most cases caused by a radon flux from soil. Especially important is the convective flux enforced by the pressure difference caused by heating and mechanical ventilation. The highest concentrations are often related to very permeable soils (eskers and other gravel formations), fragmented rock or to uranium-bearing soils or bedrock. Many countries have issued recommendations and action levels for radon in dwellings. In this respect, most EU Member States have considered the Commission's Recommendation on radon in dwellings issued in 1990 which introduces a design level of 200 Bq/m³ for future constructions and a reference level of 400 Bq/m³ for consideration of remedial action in existing buildings [7].

When the issue of radon in dwellings was well recognised in the 1980's, less attention was paid to radon in ordinary aboveground workplaces. In many countries, the existence of high radon concentrations could certainly be expected on the basis of the results obtained in dwellings, but the aboveground workplaces were mostly neglected in radon surveys and in other radon research. It was generally thought that the exposures are not significant – compared to those received in dwellings – because of the smaller occupancy factor (2000 h at work and 7000 h in home). Nevertheless, considering all the efforts put on the protection of exposed workers (within practices), it seems strange how little attention was paid in 1980's, and even still in the 1990's, on the fact that in many countries a large number of workers were likely receiving occupational exposures exceeding the dose limits for exposed workers.

One drawback of neglecting aboveground workplaces in radon surveys is that the epidemiological studies now being done on the health effects of radon in dwellings are interfered by radon exposures received in workplaces. It will be difficult to correct this source of error in the studies in a representative way. It has been preliminarily estimated that the exposure caused by radon in workplace to the employed population in Finland is on the average about 20–30 % of that at homes. Shared to the whole population the exposure in workplaces generates about 10 % of the total radon exposure [8]. Perhaps something similar can be expected also for other countries, but it should be noticed that such estimates are always country-dependent as factors affecting the estimates include e. g. statistics on working hours and occupancy at home, as wells as, estimates on the regional ratios of concentrations in workplaces and in homes.

3 Identification of affected workplaces

All below ground workplaces have a potential for high radon concentration. It is very unlikely that surveys or other research could provide sufficient means to categorise underground workplaces to those where measurements are needed and to others where they are not. Therefore, all underground workplaces which are used for working on continuous basis should be tested for radon. These include e. g. mines, underground excavations, underground installations, show caves and tourist mines. An other somewhat clear category of workplaces where high indoor radon concentrations are likely to exist are facilities utilising large amounts of ground or bedrock water. These include e. g. water treatment plants, baths and perhaps also some industries.

Earlier surveys on radon in dwellings provide a starting point for identifying areas where high radon concentrations in aboveground workplaces might exist. Defining radon prone areas might be a useful tool for targeting monitoring. The ICRP suggests that radon prone areas might be those parts of the country where at least 1 % of dwellings have radon levels more than ten times the national average as determined by appropriate statistical sampling [5]. The technical guidance on the implementation of the BSS points out that also alternative approaches could be considered to define a "manageable number" [2].

In Finland, countrywide surveys on radon in dwellings have been conducted since the early 1980's. These results are

Table 1. The percentage of radon measurement results exceeding 400 Bq/m³ and 800 Bq/m³ in Finnish municipalities where earlier surveys had shown that more than 25 % of radon concentrations measured in dwellings exceeded 400 Bq/m³ (Category I), data from reference [8]

Municipality	Percentage (%) exceeding 400 Bq/m³		Percentage (%) exceeding 800 Bq/m³	
	Work-places	Single family houses	Work-places	Single family houses
Hollola	34	41	16	19
Lahti	12	36	4	20
Lempäälä	14	28	3	6
Loviisa	23	27	7	8
Nastola	19	37	8	18
Tampere	6	27	2	16
Other Catergory I municipalities	18	34	7	13
All Caterory I municipalities	13	33	5	15

now being used for targeting monitoring of radon in workplaces. Table 1 shows percentages of radon measurement results exceeding 400 Bq/m³ and 800 Bq/m³ in workplaces and single-family houses in some radon prone areas in Finland. In most municipalities or cities, the results are quite alike, but the cities of Tampere and Lahti show significant discrepancies in the concentrations between workplaces and dwellings. The reason for this is the significant variability in the local geology and the divergent displacement of workplaces and homes within the city area. There are more homes than workplaces on the eskers (ridge of gravel) and vice versa on the clayey flats (former lake bed). The ICRP suggest that same boundaries should be used for radon prone areas for workplaces and dwellings [5]. The results indicate, however, that radon prone areas for workplaces and dwellings do not always coincide.

4 Action levels

A radon action level is a concentration of radon gas above which action is taken. The ICRP recommends [5] that the action level for workplaces should be set by the national authorities within the range of 500-1500 Bq m^{-3}. The corresponding range of annual effective dose is 3–10 mSv. The IAEA recommends [9] that the action level for remedial measures at workplaces should be set at 1000 Bq/m³. The guidance provided by the Article 31 Group of Experts recommend that within the European Union, the action level for workplaces should be set in the range from 500 to 1000 Bq/m^{-3}, basing on the criterion that it would be desirable for the action level not to exceed the dose level at which special actions are required to protect workers involved in practices – i.e., the criterion for classifying category A workers [2]. It was recognised, however, that the national authorities could also select an action level below the specified range if they judge that this is desirable and will not lead to an impractical radon programme.

Several countries have set action levels for radon in workplaces. Åkerblom [10] has collected the following data from the EU Member States. The levels are expressed in radon concentration, Bq/m³

Country	New workplaces		Existing workplaces	
	Advisory level	Enforced level	Advisory level	Enforced level
Austria	200	–	400	–
Denmark	–	400	–	400
Finland	–	400	–	400
Greece	200	–	400	–
Ireland	200	–	200	–
Sweden	–	200	–	400
UK	–	400	–	400

It might be useful to establish separate action levels for workplaces where the occupancy is low. In such working areas it might be sufficient to monitor and control access to the area in stead of remedial action. One possibility is to define the action level in the form of radon exposure (radon concentration multiplied with the annual occupancy time). For example an action level of $8 \cdot 10^5$ Bqh/m³ would allow the average concentration of 400 Bq/m³ in regular work (2000 h/a) but a significantly higher concentration in workplaces with low occupancy. The disadvantage of this approach is that unambiguous interpretation of the action level is difficult in cases where the occupancy may vary from year to year, e.g. 800 hours in one year and 1500 hours during the next year. In order to avoid such problems, the occupancy factor should be considered only in cases where the occupancy is exceptionally low. In Finland, the action level of 400 Bq/m³ is adjusted for low occupancy in the following way:

Estimated annual working hours	*Action level*
Regular work	400 Bq/m³
Less than 600 hours	1000 Bq/m³
Less than 300 hours	2000 Bq/m³
Less than 100 hours	6000 Bq/m³

5 Radon measurements and further action

Radon concentrations in workplaces vary within time. In most workplaces diurnal and seasonal variations are detected. Usually the action level for radon is defined as an annual average radon concentration during working hours. In principle, this could be measured by wearing a dosemeter on the clothing during working hours and for the whole year. If passive devices are used (e.g. alpha track detectors), the dosemeter should be stored in a radon free place outside the working hours. It is obvious that more simple procedures need to be adopted for screening purposes, i.e. for checking whether there is a factual possibility that the action level might be exceeded.

The radon concentrations in aboveground workplaces are usually slightly higher during winter than during summer. In addition, usually the concentrations during working hours are lower than those averaged over a longer period of time [11]. If the result of a long term measurement during winter does not exceed the value of the action level, it is very unlikely that the action level would be exceeded. The measurement should last at least a few months in order to average out short-term variations in radon levels. An alpha track measurement during winter is thus ideal for screening purposes. If the measurement result is less than the action level, no further actions are likely to be needed.

Further measurements and evaluations are needed if the long term measurement during winter indicate a concentration exceeding the action level. If the concentration is exceeded only slightly then the next step would be to check with a complementary measurement during summer whether the annual variation is such that the annual average does not exceed the action level. Alternatively an assessment can be made on the diurnal variations with continuously recording electronic equipment with the aim of checking whether the concentrations during working hours are significantly lower than the long term average. This can occur especially where mechanical ventilation is operated during the working hours only.

Long term measurements, such as the alpha track measurements, can very seldom be used in underground mines or excavation works due to their special working environment involving moisture, dirt, dust and darkness. There are rare places where the detector could be placed for a long time. Under these circumstances grab samples and short-term measurements might be the only possibility. Their representativeness can be increased by performing various measurements in different working areas and within time.

If the measurements show that the radon concentration is above the action level and occupancy is not very low then remedial action to reduce the radon level should be taken. If remedial measures are successful in reducing radon concentrations below the action level then no further action is needed other than re-testing if substantial changes are made in the construction or use of the building. Where the reduced radon level relies on active measures, such as a fan, then its efficient operation needs to be checked occasionally [2].

In most cases radon concentrations can be reduced successfully and in a cost effective way. In some rare cases it might occur that remedial action is technically impossible or its costs would rise unreasonably high compared to the averted dose. An example of such a case might be the underground mine mentioned above where high radon concentrations are caused by radon-rich bedrock water entering irresistibly into the mine. In such cases the BSS Directive implies that the principles of protection of workers should be applied, as appropriate. These would include recording of doses, health surveillance of workers and the classification of areas, as appropriate. It should be noted that even in this case the dose limit for exposed worker (BSS: 100 mSv averaged over 5 years) should not be exceeded.

In multi-storey buildings high radon concentrations are usually related only to the floor laying directly against the soil. Radon concentrations on the upper floors are usually such low that radon measurements are not necessary.

6 Remedial action

There are various methods for reducing radon concentrations in a building. The most common principles are:

- To increase the ventilation rate. This method is suitable if the ventilation is discovered poor also on the basis of some other criteria (poor indoor air quality in general). Increasing the ventilation further from what would otherwise be considered appropriate will increase heating and cooling costs. Increasing the ventilation might also decrease the pressure of the building and thus increase the radon input.
- To reduce the pressure differential between the building and the soil by adding new fresh air vents or by adjusting the ventilation system.
- To reduce the pressure differential between the building and the soil by soil depressurisation. This can be achieved by using a fan to withdraw air from the soil under the floor.
- To ventilate the crawl space (where such exist) underneath the floor.
- To reduce the concentration of radon progeny by filtration.

Choosing an appropriate method for reducing radon concentration is affected by the construction and the nature of the source, especially the characteristics of the underlying soil. A site specific assessment made by a specialist is often needed for finding an optimum solution.

The primary option for reducing exposure caused by radon progeny should be the reduction of the radon concentration. However, the exposure can also be decreased by using respiratory protective equipment. In workplaces where radon concentration is relatively high, but the annual working hours are rather low, the use of respiratory protective equipment could be justified instead of remedial action.

The degree of protection against radon progeny depends on the type of respiratory protective equipment used. Some results on the filtering efficiency of various types of equipment are given in Table 2. Simple disposable equipment reduce the concentrations of radon decay products in inhaled

Table 2. Filtering efficiency for radon progeny of some respiratory protective equipment (data from reference [12]); the actual degree of protection is usually significantly lower because of some unfiltered air is inhaled through leaks between the protective equipment and the face, especially in the case of simple disposable equipment

Product	Classification[1]	Type	Number of tests	Filtering efficiency[2]
1	P1	disposable	7	8 % ... 33 %
2	P1	disposable	7	90 % ... 95 %
4	P1	disposable	5	93 % ... 99 %
4	P2	disposable	3	98 %
5	P2	half mask and a cartridge filter	10	95 % ... > 99 %
6	P3	Full mask and a cartridge filter	13	> 99 %
7	P3	Filter and a fan integrated into a helmet	3	> 99 %

[1] Classification:
P1: protection against mineral dust, particulates exceeding 1 µm
P2: protection against dust and fumes, particulates exceeding 0.3 µm
P3: protection against dust, radioactive compounds, bacteria and viruses; used with a full mask covering the face

[2] Filtering efficiency = 100 % $(A_2-A_1)/A_2$, where A_2 is the total alpha energy concentration in air and A_1 is the corresponding, but filtered concentration

air by 8–99 %, depending on the type of filter material used. A better degree of protection is obtained by using equipment comprising a mask and a cartridge filter. Usually the factual degree of protection is lowered because some unfiltered air is inhaled through leaks between the protective equipment and the face, especially in the case of simple disposable equipment. The comfort in use, especially a low inhaling resistance, is one of the most important criterion in selecting an appropriate piece of equipment.

Cockpits of loading trucks and other machinery used in underground mines are mechanically ventilated and often the incoming air is filtered in order to limit the dust concentration inside the cockpit. Also some radon progeny is filtered. Experiments in a Finnish mine showed that concentrations of radon progeny in a cockpit of a loading truck was 11–35 % (average 20 %) of that outside the truck [12]. However, the reduction of dose is not necessarily as significant because the fraction of unattached radon progeny is probably higher inside the cockpit because of the lower amount of dust particles in the air.

7 Dose assessment

Normally, workers dose caused by radon need to be assessed only when the action level is exceeded despite of attempts to reduce the radon concentration i.e. the remedial action should be taken first and the system of protection of workers be applied only if the actions are not successful in reducing radon concentrations sufficiently.

The BSS Directive [1] establishes a conversion factor for the effective dose per potential alpha energy exposure for radon progeny. The factor is 1.4 Sv per $J h m^{-3}$ for radon in workplace. By definition, the ratio of potential alpha energy exposure to the equilibrium equivalent exposure is $5.56 \cdot 10^{-9}$ $J h m^{-3}$ per $Bqhm^{-3}$ [5]. On these bases the effective dose (E) can calculated using the formula:

$$E = 7.78 \cdot 10^{-9} \frac{Sv}{Bq \cdot h \cdot m^{-3}} \cdot F \cdot T \cdot C \qquad (1)$$

where
E is the effective dose (Sv),
F is the equilibrium factor (dimensionless ratio of equilibrium equivalent concentration of radon progeny and the radon gas),
T is the occupancy time (h) and
C is the radon concentration (Bq m^{-3}).

Unless more detailed assessments have been made on the annual working hours and the equilibrium factor, it is usually assumed that F = 0.4 and T = 2000 h. By applying these values the radon concentrations in workplaces causing effective doses of 6 and 20 mSv are about 1000 and 3000 Bq m^{-3}, respectively.

It should be noted that the conversion factor of the BSS is based on ICRP recommendations [5] where it is recognised that there is, at present, a discrepancy of a factor of about two to three between risk estimates from dosimetry and from epidemiology and conversion factors may change in time. But as the BSS has adopted the conversion factor mentioned above, it should be used e.g. for dose recording of exposed workers where such is needed.

8 Experience in regulatory control and monitoring of radon in workplaces

In its 1990 recommendations [1], the ICRP recommended that high exposures to radon in workplace can be regarded as the responsibility of the operating management and should be considered as occupational exposure. The ICRP 1990 recommendations were considered in a major revision of the Finnish radiation protection legislation which took effect from the beginning of 1992. The Radiation Act imposes that radiation practises include, in addition to the use of radiation, "operations or circumstances in which person's exposure to natural radiation causes or may cause a health hazard". An action level of 400 Bq/m³ for radon in workplaces was issued by STUK by the virtue of the Act. An employer is required to measure the radon concentration in the working premises if it is suspected that the action level might be exceeded.

A monitoring program for radon in workplaces was started in 1992. Monitoring was focused on radon-prone areas. The 455 municipalities of Finland were classified into four categories based on 24400 radon measurements made earlier in detached one-family houses. Catergory I included municipalities where more than 25% of the radon concentrations in dwellings exceeded 400 Bq/m³. The corresponding percentages exceeding 400 Bq/m³ in categories II, III and IV were 10–25 %, 1–10 % and < 1 %, respectively. The number of municipalities in categories I, II, III and IV were 14, 68, 154 and 224, respectively. Monitoring was focused first on municipalities in category I, but was very shortly extended also to category II. Today, the criterion for compulsory radon measurement in workplace is that the work place is located at an area where at least 10 % of the dwellings exceed 400 Bq/m³ (categories I and II).

At first, it was thought that monitoring of workplaces could be initiated simply by bringing into publicity the employer's obligation to monitor radon at the radon prone areas (category I and II). Various articles were published in journals, news papers and other media. Also a television campaign was launched informing about radon exposures and on the employer's obligation to take action. This did not work out: much less radon measurements were made by the employers than what was expected. A more direct approach had to be adopted. This was done by mailing information directly to workplaces and reminding the employers of their responsibilities concerning radon exposure of workers. The letter included a leaflet about facts on radon in workplaces and a fill-in reply form to be returned to STUK indicating the actions to be taken for assessing the workers exposure to radon. During 1992–1997 STUK contacted about 7000 private and municipal employers in this way; today about 1000 employers are contacted every year. It has emerged that there is no need to measure radon in about two-thirds of the workplaces. Typical reasons for exclusion are:

- the premises are situated in the upper floors of the building;
- the company has no employees (the owner being the only worker); and
- the work is done elsewhere (truck drivers, hired cleaners, construction workers, etc.).

Altogether almost 10000 radon measurements in workplaces have been made so far and injunctions to take remedial action or to make further assessments of the concentrations have been issued to about 800 work sites in which the first result measured during winter exceeded the action level of 400 Bq/m³. Further action depends on the measured concentration. If the concentration exceeds the action level only slightly (400–500 Bq/m³), the employer is requested to make a complementary measurement during the summer to check for the seasonal variations. If the concentration exceeds 500 Bq/m³ the employer is requested to either investigate the actual radon concentrations during working hours with a continuously recording electronic equipment or to take remedial action. In about 500 cases a complementary test during summer or an assessment using continuously recording equipment showed that the annual average concentration during working hours was most likely less than 400 Bq/m³, despite that the first long term measurement during winter had exceeded this value.

About 150 workplaces locating in radon prone areas were remedied during 1992–1997. The average reduction in radon concentration was 1500 Bq/m³. Using the dose conversion mentioned above, the average averted individual dose was 10 mSv/a. Many of the workplaces were rather small, typically the remedy was for the benefit of only a few workers. Despite of this, the averted annual dose sums to about 4 manSv/a, a figure comparable to the sum of registered doses received by all occupationally exposed workers in Finland (only within practices, the radon exposures are not included). There is no doubt that radon in ordinary aboveground workplaces is the most significant source of occupational exposure to radiation in Finland. The positive thing is that something can really be done to reduce these exposures.

(Received on 30 November 1999)

References

1 Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. Official Journal of the European Communities L-159 of 29. 6.1996

2 Recommendations for the implementation of Title VII of the European Basic Safety Standards Directive (BSS) concerning significant increase in exposure to natural radiation sources. Radiation Protection No 88, European Commission, Luxembourg, 1997

3 Radiation Act. In: The Statues of Finland, 592/91. Helsinki, 1991

4 ICRP Publication 60. 1990 Recommendations of the International Commission on Radiological Protection. Annals of the ICRP 21, 1-3. Oxford: Pergamon Press, 1991

5 ICRP Publication 65. Protection Against Radon-222 at Home and Work. Annals of the ICRP 23, 2. Oxford: Pergamon Press, 1993

6 *Annanmäki, M.* and *Oksanen, E.*: Radon in the Helsinki Metro. Radiation Protection Dosimetry 45 (1992) 179

7 Commission Recommendation of 21 February 1990 on the protection of the public against indoor exposure to radon. Official Journal of the European Communities L-80 of 27.3.1990, p. 26

8 *Oksanen, E.; Annanmäki, M.* and *Markkanen, M.*: Radon at Workplaces in Radon-Prone Areas. In: Indoor Air, An Integrated Approach, (*Morawska, L.; Bofinger, N. D.* and *Maroni, M.* eds.), pp. 153–156. Elsevier Science Ltd., England, 1995

9 International Basic Safety Standards for Protection Against Ionising Radiation and for the Safety of Radiation Sources. IAEA Safety Series 115, Vienna, 1995

10 *Åkerblom, G.*: Radon Legislation and National guidelines. SSI Rapport 99:18, Swedish Radiation Protection Institute, 1999

11 *Hämäläinen, A.* and *Oksanen, E.*: Comparison of methods suitable for radon monitoring in work places. Report STUK-B-STO 26, STUK – Radiation and Nuclear Safety Authority, Helsinki, 1992 (in Finnish)

12 *Oksanen, E.; Markkanen, M.; Annanmäki, M.*: Reduction of alpha energy exposure by using respiratory protective equipment. Report STUK-B-VALO 62, STUK – Radiation and Nuclear Safety Authority, Helsinki, 1990 (in Finnish)

The authors of this contribution

M. Markkanen, M. Annanmäki and *E. Oksanen*, STUK – Radiation and Nuclear Safety Authority, P. O. Box 14, FIN-00881 Helsinki, Finland