

Radon in Finnish mines 1972–2010

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Abstract. Radon measurements in Finnish underground mines were started in 1972. In 1975, a limit for radon concentration was set at 1100 Bq/m³. In 1992, an action level of 400 Bq/m³ for radon, an average over the total number of annual working hours, was adopted. Since then regular radon inspections have been carried out in all underground mines. In 1972 there were 23 operating underground mines in Finland. In 2010 there were 10 underground mines in operation, most of them being small in size. In 2002 a survey was done to determine the average individual and collective doses of mine workers between 1975 and 2001 (Annanmäki et al. 2005). In 2011 the same survey was repeated to determine the average individual and collective doses of mine workers between 2002 and 2010. In 1975 the mean effective dose for a mine worker was 3.5 mSv, by 1985 it had decreased to 2.4 mSv and by 1995 to 1.7 mSv. By 2001 the mean effective dose was below 1 mSv at 0.9 mSv and by 2010 0.6 mSv. The average radon concentration in the Finnish mines is 90 Bq/m³ (results 2009-2010).

KEYWORDS: radon concentration, mine, mine worker, effective dose

INTRODUCTION

Radon measurements in Finnish underground mines were started in 1972. In 2002 a survey was done to determine the average individual and collective doses of mine workers between 1975 and 2001 (Annanmäki et al. 2005). In 1972 there were 23 operating underground mines in Finland. Today there are 12 underground mines in operation. The development of underground mine worker numbers in Finland is presented in Figure 1. In the beginning of the 1970's there were more than 1200 workers in the underground mines but this number has reduced to less than 700 today (688 by the end of 2010). The reduction in the number of underground mine workers from the 1970's and 1980's is mostly because of the use of new technologies and the automation of the tasks introduced into mining.

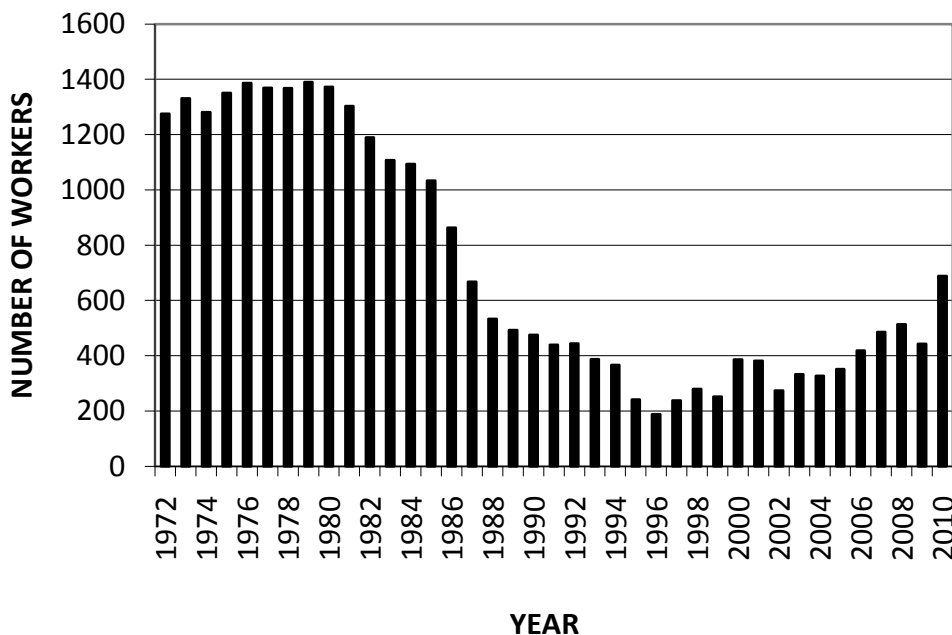


Fig. 1 Number of workers in the Finnish underground mines.

REGULATORY CONTROL

In Finland, the action level for radon is 400 Bq/m³ in workplaces where people are working regularly, which includes mines. In mines the radon concentration is considered as the annual mean of the radon concentration during working hours in different working areas of the mine.

In underground mines periodical inspections are made every two years and the aim is to do the measurements in different seasons due to the seasonal variation of radon concentration. The radon concentration tends to be higher in summer season as the natural ventilation is weaker due to positive temperature gradient. In summer time the temperature in the mine is lower than outside and therefore the warm fresh air from outside does not reach the mine.

If the radon measurements done during the periodical inspections indicate that the radon concentration in the mine is over the action level of 400 Bq/m³ remedial works has to be undertaken in order to get the radon concentration below the action level (STUK 2011).

In underground mines the radon concentration can be effectively reduced by arranging adequate ventilation in the workplaces, i.e. conducting fresh air directly to the workplace or ascertaining adequate ventilation of workplaces at the far end of long drift tunnels. Reducing the amount of radon released from ground water by preventing water leaks can also be helpful.

If countermeasures do not work, individual doses of mine workers must be assessed and the operator (mining company) must arrange the monitoring of radon in a way that the radiation exposure of each worker can be determined. The individual doses are assessed by measuring the radon concentrations in different working areas and by recording the working hours of the mine workers in those areas. In monitoring radon exposure, the radon concentration is, in general, measured quarterly.

MEASUREMENTS

During the years different equipment have been used to measure concentrations of radon and its short-lived daughter products. However, the measurement methods themselves have remained the same. Radon is still measured with grab sampling using Lucas-type chambers.

The samples have then been counted with devices equipped with a photo multiplier and an electronic counter. The devices are calibrated every two years.

In the beginning of the radon measurements in mines also radon daughter concentration was measured together with radon. Since 1993, only radon concentrations have been measured.

Radon measurements are usually made in working areas or future working areas but also in places not in daily or active use but in which high radon concentrations might occur. The number of radon measurements taken per mine are nowadays usually from 10 to 15 depending on the size of the mine and number of different working areas. Earlier the number of measurements could be up to 30 mainly because of the mines were larger in size.

CALCULATION OF THE DOSE

To calculate the effective dose the mean radon concentration of the mine has to be known. The mean concentration was calculated as an arithmetic mean of concentrations measured in different working areas of the mine. According to the previous study (Annamäki et al. 2005) the equilibrium factor F

varied from 0.2 to 0.9, the average of all the annual mean values for years 1972–1992 being 0.64. This value has been used also for calculating the doses presented in this study.

The effective dose (E) was calculated by using the equation (Markkanen et al. 2000):

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

where C is the mean radon concentration (Bq/m^3) in the working places of a mine,
 F is equilibrium factor
 T is the annual working hours underground

This equation uses the dose conversion coefficients given in ICRP publication 65 (ICRP 1993).

RESULTS

Regular measurements of radon concentration, in Finnish mines, have been made in all underground mines for almost 40 years. Since 1992 radon in underground mines has been under regulatory control and the measurements have been carried out as periodical inspections.

During the 1980's and 1990's the old poorly ventilated mines were closed and today the radon concentration action level of $400 Bq/m^3$ in working areas is exceeded only in a few mines. In individual radon concentration samples the action level $400 Bq/m^3$ was, exceeded more often (in 2009–2010 about 22 % of the results were over $400 Bq/m^3$). Most of these measurements were made in places which were not considered as working areas, or where the work was only occasional. Today the average radon concentration weighted by the number of workers in each mine is $90 Bq/m^3$ (results of the years 2009–2010) in the Finnish mines. The average radon concentration was $110 Bq/m^3$ during the years 2000–2001. Because it is evident that radon concentration can exceed the action level in some of areas of the mines it is important to continue with the periodical inspections. The results of the average radon concentration are presented in Figure 2.

The average individual dose to underground mine workers was calculated using equation (1) to calculate a mine-specific individual dose. The average of the mine-specific doses was then calculated using the number of workers in each mine as a weighting factor. The results are presented in Figure 3.

The collective dose of Finnish mine workers was derived by summing up the product of the mine-specific individual dose and the number of workers. The results are presented in Figure 4.

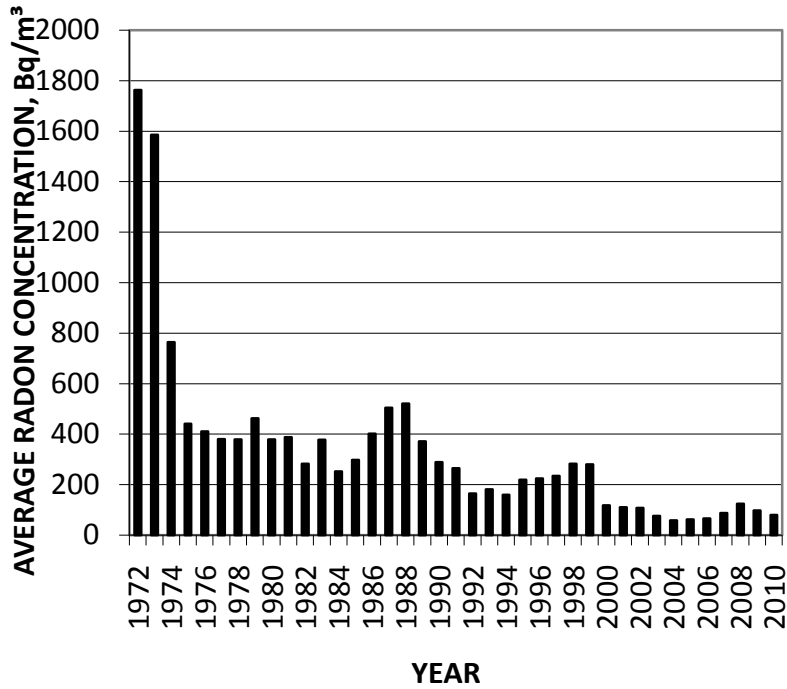


Fig. 2 Average radon concentration (Bq/m³) in Finnish mines 1972-2010.

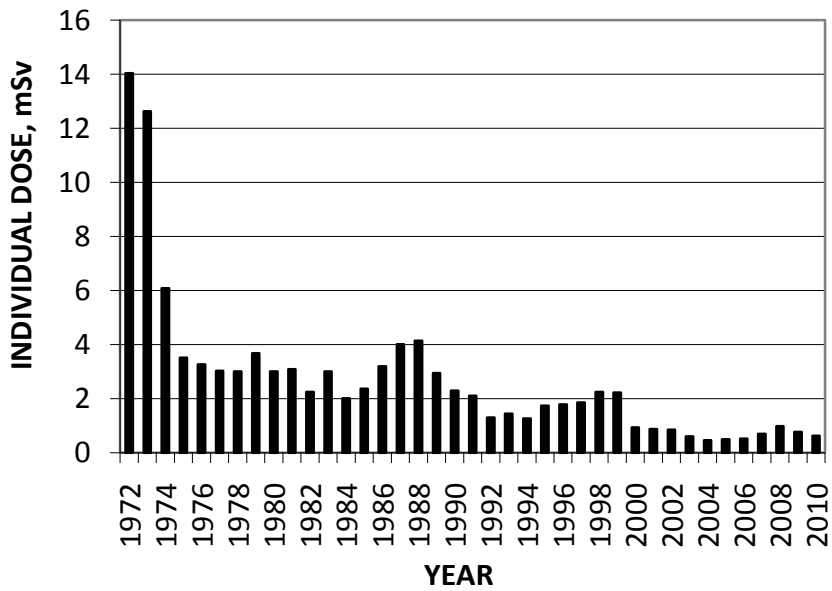


Fig. 3 Average individual dose received in the Finnish underground mines.

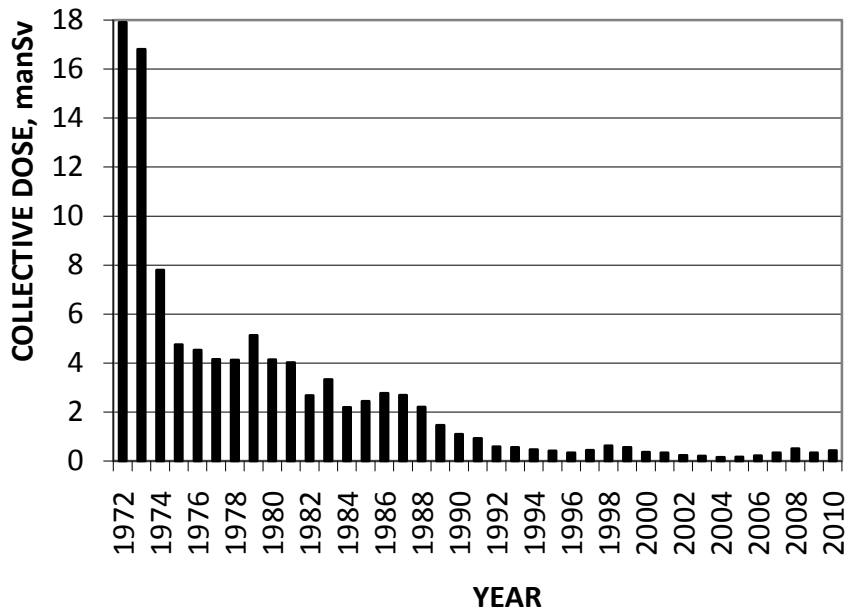


Fig. 4 Collective dose received in the Finnish underground mines.

DISCUSSION

In the future it is relevant to measure the equilibrium factor, to verify that it is still in the same level than at the time of the previous survey.

In the mines where the radon concentration in all the measured working areas has been several years less than 20 Bq/m^3 the radon concentration is measured once every four years. In Finland there is only one such a mine in operation. With this exception, it has been noticed that that radon concentrations in the mines tend to vary during the periodical inspections (although underneath the action level), this is why the periodical inspection frequency will be kept at two years.

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