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RADON PROBLEMS IN SWEDEN. INVESTIGATIONS AND COUNTERMEASURES.

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Abstract

For some years radon has been of great concern in Sweden both as a source of occupational exposure in mines and other underground spaces and as a source of radiation exposures in dwellings for the population as a whole. The awareness of the problems in dwellings has lately increased to a considerable extent and appropriate measurements and possible countermeasures are under intensive discussion. The policy and general principles of the supervision especially at work places are described here with a brief description of the progress of the development work on measuring methods.

The radon problems

Radon problems in Sweden appear in mines, tunnels, underground defence installations, hydro-electric power stations, storage rooms, office buildings and dwellings. The radon sources are radium in the soil, in the bed-rock and in building materials and radon-rich water. The first radon measurements were made in the 1950's [1] in some hundreds of houses and apartments. In the 1960's the main interest was in radon in water in deep-bored wells in one area of Sweden which was then of serious concern due to the radiation doses caused by ingestion of radon-rich water [2]. In the 1970's, the interest in and efforts to deal with the radon problems have steadily increased, first with mines (ferrous and sulphide ore mines) and later extended to the major program on radon in dwellings now being run by the National Institute of Radiation Protection.

1. Mines

Since 1969, radon measurements have been carried out in mines, altogether in some 50 mines with about 5000 miners in 1978. The reason for the high radon levels in Swedish mines was the special ventilation system earlier used, with the fresh air intake via abandoned parts of the mine containing large amounts of crushed rock emanating large amount of radon. Radon-rich water has also been one of the sources of radon in mine air. By increasing the flow and changing the direction of the ventilation air, and by isolation of disused parts of the mine and enclosure of mine water, it has been possible to reduce the radon levels and the radon daughter exposure as is shown in Table Ia, Ib and Fig. 1.

Table Ia. Number of mines with the radon daughter levels shown.

Year	< 0.1 WL	0.1-0.3 WL	0.3-1 WL	> 1-3 WL
1969-70	25	8	18	4
1973	25	19	8	0
1974	25	12	8	0
1975	25	14	6	0
1976	29	12	5	0
1977	28	9	8	0
1978	32	11	4	0

Table Ib. Number of miners with the radon daughter levels shown.

Year	< 0.1 WL	0.1-0.3 WL	0.3-1 WL	> 1-3 WL
1969-70	1110	1560	2000	130
1974	1770	2340	360	0
1975	2170	2860	270	0
1976	2730	2345	225	0
1977	3620	1105	475	0
1978	4380	600	270	0

In 1972 it was shown that there was a significant excess of lung cancer among Swedish miners [3]. It has also been possible to demonstrate a correlation between the frequency of lung cancer and the radon daughter exposure [4]. Because of the long latency period for lung cancer, it is believed that this excess of lung cancer among the exposes miners will remain for many years to come. It is notable that this deleterious effect is one of the few statistically demonstrable cancer effects of radiation at work places. Even to-day, when the average exposure has been decreased to less than one third of the maximum permissible exposure, the miners constitute a group with an unusually high average occupational exposure in Sweden. The effective whole body dose equivalent is about 10 mSv(1 rem) per year compared with a normal average whole body dose for various groups of radiological workers in Sweden of less than 5 mSv(0.5 rem) per year. Continued efforts to reduce the radon daughter levels are therefore to be expected as well

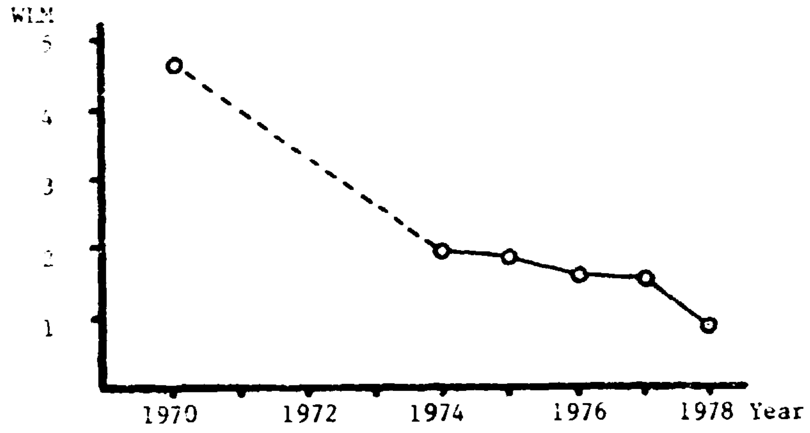

Fig. 1. Average radon daughter exposure of Swedish non-uranium miners. The dashed line represents a period of intensive countermeasures in the mines.

as an effective checking program on the radon situation, especially in new parts of the mines.

2. Tunnels

In cities, tunnels are used for telephone cables, electric cables and for the waste water system and they are big enough to allow entry for inspection and repair work. Because of insufficient ventilation and local occurences of radium-rich rock, relatively high radon levels have occured in these tunnels, thus producing an occupational hazard. The average radon daughter exposure for workers in tunnels is shown in Table II. Because of the extensiveness of the tunnel systems, reduction of radon levels is not always easily arranged (the total length of the tunnel systems is of the order of 100 km). However, the only practical method is forced ventilation during work in the tunnels and this is being put into practice.

Table II. Average radon daughter exposure of workers in tunnels.

Location	Annual exposure	Number of workers
Underground waste water tunnels	1.1 WLM	11
Telephone communication tunnels in Stockholm	0.4 WLM	15
Telephone communication tunnels in Gothenburg	0.5 WLM	19

3. Underground defence installations

The underground rooms in these installations are infrequently used in peace-time but are sometimes entered for inspection, repair work etc. Normally these rooms are poorly ventilated in peace-time and high radon levels may occur in some of them. A group of specialist workers carry out service work in these military installations and they spend a great deal of their total working time each year in these rooms. Special ventilation arrangements to reduce the radon concentration have therefore been necessary in some installations. In some rooms more extensive radon control measures have proved necessary.

The radon daughter exposures for three different categories of military personnel is shown in Table III. The number of workers is for reasons of secrecy expressed in percent.

Table III. Radon daughter exposure of military personnel.

Category	Annual exposure < 1.2 WLM	 1.2–3.6 WLM	 > 3.6 WLM
Service personnel	95 %	5 %	0 %
Administrative personnel	99 %	1 %	0 %
Others	100 %	0 %	0 %

4. Hydro-electric power stations

There are many hydro-electric power stations in Sweden and normally the generating equipment is installed in underground rooms. The ventilation air intake is sometimes contaminated with radon from leakage of radon-rich water into the air inlet channels. During the past two years the radon levels have been checked in these installations and the result is shown in Table IV. The number of workers concerned is of the order of 200. In some of the stations it has been necessary to increase or change the ventilation in order to decrease the radon levels. In the nuclear power industry the aim is to reduce the collective dose equivalent per installed electric power to less than 1 manrem/MW_e·year. It is an interesting observation than in some of hydro-electric power stations the occupational radon daughter exposure expressed as effective whole body dose equivalent did not fully meet the level of ambition specified for nuclear power.

Table IV. Radon daughter concentrations in underground hydro-electric power stations. Number of workers is of the order of 200.

Radon daughter concentration	< 0.1 WL	0.1–0.3 WL	0.3–1 WL	> 1 WL
Number of stations	68	5	3	2

5. Dwellings

During the last few years, measurements on natural activity in building materials and radon levels in air in dwellings have steadily increased in number and have attracted increasing attention. Some hundred thousands of houses in Sweden have been built of aerated concrete based on alum shale some of which has a relatively high natural radium concentration. These houses may have high radon levels, depending on the ventilation. Because of the cold winter climate in Sweden, high ventilation rates are uneconomical and the low ventilation rates often used can cause radon problems. The special efforts to conserve energy in the last few years have led to a general increase in the radon daughter exposure in houses. The collective dose equivalent in the bronchial epithelium from radon daughter exposure in dwellings in Sweden was about $2 \cdot 10^5$ manSv/year in 1950. That value had increased to about $5 \cdot 10^5$ manSv/year in 1975 [5] corresponding to about 40 Bq/m^3 (= 1 pCi/l) of equilibrium equivalent radon concentration. This exposure is expected to cause 200-1000 future cases of lung cancer per year, which is a remarkably high value against the background of the present incidence of around 2000 cases per year.

6. Water

Radon in water has sometimes proved to be a significant source of radon in air in dwellings. If the radon concentration in water is about 400 kBq/m^3 (10 nCi/l) the average radon (-daughter) concentration in houses is expected to be increased by about 40 Bq/m^3 (1 pCi/l) [6]. Drinking-water from bored wells often contains radon in excess of 40 kBq/m^3 (1 nCi/l) and such water is therefore in general of potential interest as a source of radon in air in dwellings. Many measurements on radon in water have already been made in Sweden in order to investigate the significance of this radon source.

The principle of measurements and surveillance

The measurements of radon in water are made by measuring the gamma radiation from a 5 l bottle containing the water sample [2]. The measurements of radon and radon daughters in air are performed by conventional techniques using an ionization chamber for radon and a ZnS detector technique for radon daughters collected on filters. Radon samples are collected in pre-evacuated 4.8 l propane cylinders. These cylinders are usually evacuated at the Institute, sent by post to the customer, filled with air at the place of interest and sent back to the Institute for measurement. By using predetermined equilibrium factors for the radon daughter/radon activity relationship, the radon daughter activity is estimated. The measurement technique is described in more detail elsewhere [7].

In discussing appropriate measuring techniques it is pertinent to ask the purpose of measurements. It may be one or more of the following:

1 General investigation of the radon (radon daughter) problem at places of interest. The purpose is to get an idea of the order of magnitude of the problem. Measurements on radon only, which are easier to make than those on radon daughters, are sufficient in this case;

2 Analysis of the causes and sources of high radon (radon daughter) concentrations. Correlations are studied between the activity and such parameters as materials, ventilation, time etc. to obtain a basis for countermeasures. Radon measurements are sufficient in most cases;

3 Surveys of the radon daughter exposure of the population as a whole, of groups of workers, of members of the public in certain types of houses etc. and its change with time after countermeasures have been taken or after any other change in the conditions of exposure. Radon measurements combined with a few or several radon daughter measurements to obtain general relationships are normally sufficient;

4 Checking individual exposures in order to be able to judge the compliance with given instructions and recommendations. Individual radon daughter dosimeters are preferable in this case. Frequent on-the-spot measurement of radon daughters is often a good substitute and is also the most common method in mines. In places with fairly constant radon (radon daughter) levels and ventilation, radon measurements combined with predetermined equilibrium ratios between radon daughter activity and radon activity may be sufficient.

Based on these principles the radon and radon daughter problems in tunnels, in underground defence installations and in hydro-electric power stations have up to now been analysed and quantified by radon measurements on air samples mostly complemented with some visits to the place of interest for radon daughter measurements to check the equilibrium factor. The methods for radon measurements used by the Institute for several years have proved to be quite practicable and reliable.

In the case of dwellings, all sampling and measurements have up to now been made during visits by the Institute staff. Measurements on radon daughters at work places have also involved visits to the places concerned by members of the Institute staff with pumps, filters, alpha-detectors etc. However, a new method allowing some of the sampling to be made by unskilled persons is now being tested. The basis ides is very simple. A special holder ("radon-daughter dosimeter") containing a filter and a TLD or film has been constructed to be connected to an evacuated sampling cylinder. When the cylinder is opened, the air passes through the radon daughter dosimeter, the radon daughters are caught on the filter and the radon passes to the cylinder. The principle of the design is seen in Fig. 2. It can be used with one film or five TLD pellets, two of which may be used for background determination and three for radon daughter measurement. The sensitivity of the method is shown in Fig. 3.

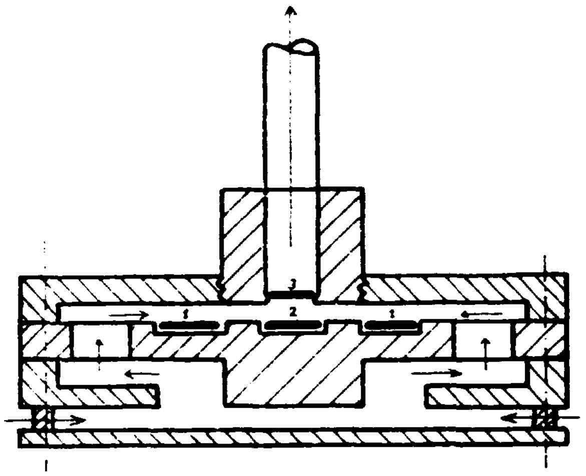

Fig. 2. Radon daughter dosimeter.
1 = TLD-pellet for background
2 = TLD-Pellet for radon daughters
3 = Fiber-glass filter
Arrows indicate the air-stream

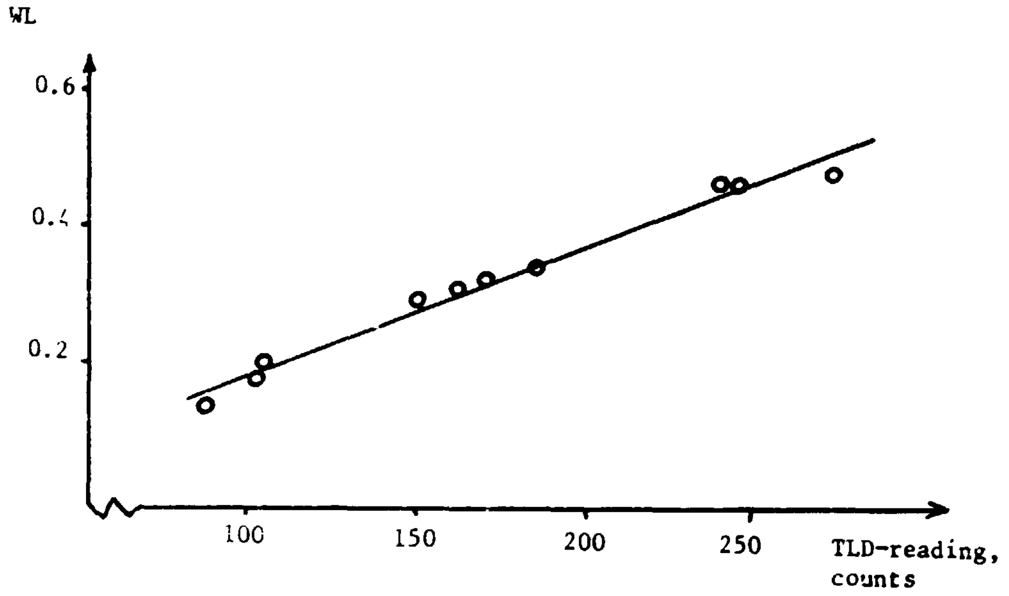

Fig. 3. Net TLD-reading as function of radon daughter concentration. Average background 30 counts/day

Continuously running radon measurements are made with a device based on the ionization chamber principle [7]. The air flows at a constant rate through the chamber and the ionization caused by radon in the air is registered by a pen recorder. This equipment is occasionally used in mines when there are special problems relating to ventilation or extension of the mining area. Special equipment intended for dwellings is under construction. It works on the principle of self-diffusion of radon into a chamber, radon daughters build up and are collected by an electric field on a TLD pellet. The same principle is used e.g. by the EML (Environmental Measurement Laboratory) in New York [8].

In the mines the radon sources and modifying factors are now fairly well known. However, there is a permanent need of checking the radon levels because of the potential risk of high levels. Changes in ventilation, opening of new mining areas and ground water leakage into the mine may suddenly change the radon (radon daughter) situation drastically.

Normally, the radon (radon daughter) concentration is relatively constant in mines and it is possible to divide a mine into one or several "radon daughter zones". These zones are defined as follows, where C is the radon daughter concentration:

I: $C < 0.1$ WL (working level)
II: $0.1 \text{ WL} \leqslant C < 0.3$ WL
III: $0.3 \text{ WL} \leqslant C < 1$ WL
IV: $1 \text{ WL} \leqslant C < 3$ WL

According to the Swedish radon regulations which were issued in 1972 [9], the maximum permissible annual radon daughter exposure corresponds to a full working-time stay in a radon daughter concentration of 0.3 WL (in the regulations expressed as an equilibrium equivalent radon concentration of 30 pCi/l). This implies an annual exposure of 3.6 WLM (expressed in the regulations as 60,000 pCi·h/l).

To check the compliance with the radon regulations, the radon daughter exposure is calculated for each miner using a special computerized record-keeping system. This system is used for about 70 % of the miners. Every day each miner fills in a "timecard" giving his working location in the mine and times.

Since it is known to which zone each work place belongs, the total exposure expressed in pCi·h/l can be calculated for each month, quarter and year. The same system also uses information on other air pollutants and this system thus makes it possible in the future to make systematic studies on possible health effects resulting from these pollutants, as well as from radon daughters.

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