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The exposure of United Kingdom miners to radon

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Duggan, M. J., Soilleux, P. J., Strong, J. C., and Howell, D. M. (1970). *Brit. J. industr. Med.*, **27**, 106-109. **The exposure of United Kingdom miners to radon.** Airborne radon has been recognized as a probable cause of lung cancer since the epidemiological studies made in the mining communities of Schneeberg and Jachymov during the 1920s and 1930s. Uranium miners are generally exposed to high concentrations of radon, and the growth of the uranium mining industry in the past 20 years has therefore stimulated a great amount of work on the risk from inhalation of radon and its daughters. However, there is still no general agreement on either the physical measurements in which the maximum permissible concentration in air should be expressed or the numerical value of this concentration.

There are no uranium mines being worked in the United Kingdom but there are considerable numbers of coal and other mines. It was therefore decided to make some radon measurements in a selection of mines in the UK to see if there was any prospect of obtaining useful dose-risk data. Measurements were made in 22 mines in all – 12 coal mines and 10 other mines – and the highest concentrations were found in three haematite mines in West Cumberland and in the two tin mines which were visited. The concentrations in these five mines were, in general, greater than 0·3 of a working level (WL) and in many locations were greater than 1 WL.

Because of these findings and also because an excess incidence of lung cancer among West Cumberland haematite miners has been previously reported, a further study of the mortality experience of West Cumberland miners has been carried out by Boyd, Doll, Faulds, and Leiper (1970). Their findings are reported in this Journal (p. 97).

The hazard from radon

Airborne radon (^{222}Rn) was first recognized as a probable cause of lung cancer during the epidemiological studies made in the mining communities of Schneeberg and Jachymov during the 1920s and 1930s (Lorenz, 1944). Evans and Goodman (1940; Evans, 1943) made one of the first proposals for a maximum permissible concentration in air (MPC_a) of ^{222}Rn; they summarized the available data on the concentrations of ^{222}Rn in air in the Schneeberg and Jachymov mines and concluded that prolonged breathing of air containing 1 000 pCi of ^{222}Rn per litre could lead to a 30-fold increase in the incidence of lung cancer. Evans and Goodman decided to apply a safety factor of 100 to this and so arrived at 10 pCi/litre as a 'safe working concentration'.

Since that time there has been a great amount of work and discussion on the risk from inhalation of ^{222}Rn and its daughters. Much of this has been concerned with the way in which the daughters deliver a radiation dose to the lung and with the calculation of this dose. There have been few attempts to relate risk directly to radon concentration by epidemiological studies.

It is now generally agreed that the daughters formed in the atmosphere, rather than the ^{222}Rn itself, are responsible for the major part of the radiation dose received by the lung, but there is still uncertainty about many aspects of the way in which this dose is delivered. There is in consequence no general agreement on either the physical measurements in which the MPC_a of ^{222}Rn daughters should be expressed or the numerical value of this MPC_a.

In 1955 the International Commission on Radiological Protection (ICRP) recommended a value of 10^{-7} μCi of ^{222}Rn plus its daughters per cubic centimetre of air as the MPC_a for continuous exposure (168-hour week); this is equivalent to 300 pCi per litre of air for a 40-hour working week. In 1959 the Commission decided, largely as a result of the work of Chamberlain and Dyson (1956), to reduce the MPC_a. Chamberlain and Dyson's work had indicated that, when ^{222}Rn and its daughters are present in ordinary air, only about one tenth of the total number of RaA atoms present at equilibrium remain unattached to nuclei, but that almost all the dose to the trachea and main bronchi is due to these free atoms. The Commission gave the general expression,

$$MPC_a = \frac{3 \times 10^{-6}}{1 + 1000f} \ \mu\text{Ci/cm}^3$$

for exposure to ^{222}Rn and its daughters during a 40-hour working week, f being the fraction of the equilibrium number of RaA atoms unattached to nuclei. When $f = 0{\cdot}1$, the MPC_a is 30 pCi of radon per litre of air for a 40-hour week. These remain the current views of the Commission.

In 1962 the International Atomic Energy Agency decided that, because in certain industrial applications it had been found impracticable to apply the ICRP's 1959 value of 30 pCi/litre, the ICRP's 1955 value of 300 pCi/litre would be adopted provisionally.

In 1967 the results of an epidemiological study carried out on a large group of uranium miners by the United States Public Health Service (USPHS) began to appear (Federal Radiation Council, 1967; Joint Committee on Atomic Energy, 1968). The USPHS used the method of Kusnetz (1956) for measuring the concentration of ^{222}Rn daughter products and expressed the result in terms of the 'working level' (WL). One working level is defined as any combination of ^{222}Rn daughters in 1 litre of air that will result in the ultimate emission of $1{\cdot}3 \times 10^5$ MeV of potential alpha energy. One working level corresponds to a concentration of 100 pCi/litre of ^{222}Rn in air if it is assumed that the ^{222}Rn is in equilibrium with its short-lived daughters. In July 1967, The Federal Radiation Council recommended that occupational exposure to ^{222}Rn daughters must be so controlled that a miner should receive no more than 6 WLM[1] in any consecutive 3-month period and no more than 12 WLM in any consecutive 12-month period. However, as a result of much subsequent discussion in the United States, the US Department of Labour, in December 1968, issued regulations on 'radiation standards for mining' which require that no individual shall receive an exposure of more than 2 WLM in any consecutive 3-month period and no more than 4 WLM in any consecutive 12-month period. The latter is equivalent to an average concentration of ^{222}Rn daughters of 0·3 WL throughout the working year. If the daughters are in radioactive equilibrium with the parent ^{222}Rn, 0·3 WL corresponds to a ^{222}Rn concentration of 30 pCi/litre.

Some of the latest attempts (Jacobi, 1964; Altshuler, Nelson, and Kuschner, 1964; Haque and Collinson, 1967) at calculating the lung doses arising from the inhalation of ^{222}Rn daughters suggest an MPC_a of around 10 pCi/litre if a quality factor of 10 is assumed for the effect of α-rays in producing lung cancer and if the annual dose limit is set at 15 rems for any tissue in lung where the dose is considered.

The ICRP has a task group which is considering the MPC_a of ^{222}Rn and which will presumably take account of all the available epidemiological data and lung dose calculations in its recommendations to the Commission.

^{222}Rn concentrations in UK mines

There are no uranium mines being worked in the UK but there are considerable numbers of coal and other mines. It was, therefore, decided to make some ^{222}Rn measurements in a selection of mines in the UK to see if there was any prospect of obtaining useful dose-risk data. No report of any previous measurements of concentrations of ^{222}Rn in the air of mines in the UK could be found.

Measurements were made by two methods:

(1) A sample of mine air is taken and subsequently transferred to a chamber containing a zinc sulphide screen. The decay of a ^{222}Rn atom results in a charged daughter product atom of RaA which is collected onto the screen by means of an electric field. The α-rays emitted by the subsequent decay of RaA and RaC′ are measured and the ^{222}Rn content of the sample is calculated (Vennart, Maycock, Godfrey, and Davies, 1964).

(2) A known volume of mine air is drawn through a filter paper (for, say, 10 minutes) and the alpha activity on the filter is measured one or two hours later. Although this alpha activity cannot be directly related to the ^{222}Rn concentration unless the relative concentrations of radon, RaA, RaB and RaC in the sampled atmosphere are known, Kusnetz (1956) has shown that the alpha activity on the filter at a given time after sampling is nearly proportional to the total alpha energy which would result from the

[1]An exposure of 1 WLM results from the inhalation for one working month (170 hours) of air containing a ^{222}Rn daughter concentration of 1 WL, or from two months' exposure at a concentration of 0·5 WL, etc.

complete decay of the daughter products in the sample.

Because of National Coal Board safety regulations it was not possible to use our electrically operated air sampler in coal mines and only the first method of measurement was used. Kusnetz's method, in some cases supplemented by the first method, was used in the other mines visited. Where both methods were used at the same location in a mine, the results indicated that the daughters were usually in or close to radioactive equilibrium with each other and with the parent ^{222}Rn. The thoron (^{220}Rn) concentration was measured in only two mines, but method (1) for measuring ^{222}Rn is not influenced by the presence of ^{220}Rn, and measurements of the decay of activity on the filter paper indicated that, only in a few cases (and those where the ^{222}Rn concentration was low – about 1 or 2 pCi/litre), was the ^{220}Rn:^{222}Rn ratio large enough to interfere with Kusnetz's method. A correction for the activity due to ^{220}Rn was made in these cases. The errors associated with the measurements were small, especially when compared with the variation in ^{222}Rn concentration usually found within a mine.

Results

Coal mines

Measurements were made in 12 mines chosen from the East Midlands, Kent and Scottish coalfields. These measurements have been reported elsewhere (Duggan, Howell, and Soilleux, 1968) but, for the sake of completeness, they are briefly mentioned here.

The concentrations found ranged from 0·6 pCi/litre to 14 pCi/litre and the median concentration for the 12 mines was found to be about 2 pCi/litre, a value very close to that found by Lucas and Gabrysh (1966) for Pennsylvanian coal mines.

The death rate of coal miners in the UK from cancer of the lung has been shown to be appreciably lower than the national rate for men of comparable age (Doll, 1958; Goldman, 1965). Goldman has considered the possibilities that miners are exposed to less air pollution and smoke less than the general population and has come to the conclusion that neither of these can account for the low incidence.

Other mines

Coal mines are very well ventilated in comparison with other types of mines in the UK, some of which rely solely on natural ventilation. It is probably for this reason that we often found greater variations in the concentration of ^{222}Rn in these other mines than in coal mines.

Measurements were made in six haematite mines, two tin mines, one fluorspar and one anhydrite mine. The results expressed in working levels are given in the Table. The first four mines listed, A to D, are the four haematite mines in the Egremont area of West Cumberland.

Nearly all the measurements referred to in the Table were made in those parts of the mines which were continuously occupied throughout the working

TABLE

Mine	*Type of mine*	*^{222}Rn daughter product concentrations (WL)*	
		Range[1]	*Median*
A	Haematite	0·35 -3·2 (10)	2·0
B	Haematite	0·3 -1·0 (6)	0·5
C	Haematite	0·3 -0·8 (6)	0·6
D	Haematite	0·15 -0·2 (3)	0·15
E	Haematite	0·15 (2)	0·15
F	Haematite	0·005-0·6 (25)	0·03
G	Tin	0·1 -11 (15)	3·7
H	Tin	0·9 -1·4 (7)	1·1
I	Fluorspar	0·15 (2)	0·15
J	Anhydrite	0·003-0·008(3)	0·005

[1]The number of measurements per mine is given in parentheses.

week. It can be seen that the highest concentrations were found in three of the haematite mines in West Cumberland and in the two tin mines which were visited. The concentrations in these five mines were, in general, greater than 0·3 WL and in many locations exceeded 1·0 WL. In a few of the mines, sufficient measurements were made to obtain a good idea of the annual exposure of the miners concerned. For example, in mine G it was estimated that the average annual exposure for all the underground workers was about 50 WLM.

Most of the mines have been in operation for many years. There are about 350 underground workers in the tin mines and there were about 500 in the Cumberland haematite mines until the closure of mine A last year. Mine A employed about 180 underground workers. New tin mines are being developed in Cornwall but are not expected to be in production until the early 1970s.

An excess incidence of lung cancer among West Cumberland haematite miners has been reported by Faulds and Stewart (1956). These workers concluded that radioactivity was not a contributory factor in the production of the lung cancers which they found. However, this conclusion was based on their failure to find any unusual amounts of long-lived activity in the mine ores or in lungs obtained *post mortem*. They made no measurements of radon or its short-lived daughters. Faulds and Stewart considered that sidero-silicosis predisposed the haematite miners to lung cancer.

In view of the suggestion by Faulds and Stewart that the miners concerned suffer from an incidence of lung cancer in excess of that expected in an unexposed population, and of the high concentrations of ^{222}Rn daughter products found in the Cumberland haematite mines, Dr. J. T. Boyd and his colleagues have carried out an epidemiological study in West Cumberland and their findings are reported in this Journal (p. 97).

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