OCCUPATIONAL EXPOSURE TO RADON IN WORKPLACES IN UNDERGROUND MINING OPERATIONS

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Abstract

In Chile, there is no specific regulation on matters related to occupational exposure to radon, however, multiple work activities are carried out in situations in which attention to radon levels is eventually required, and that, according to them, the need to apply a mitigation measures is determined in order to comply with either an applicable national regulation or an international recommendation.

According to the mentioned above problem it is that it has proposed a preliminary study designed to show some levels of radon in workplaces, underground mining or others, to determine the need for the establishment of a national regulation and determination a level according to the reality of the country.

1. BACKGROUND

Radon (222Rn), is a radioactive material of natural origin, is part of the decay chain of uranium (238U), which occurs in gaseous form. When undergoing radioactive decay, it originates other radioactive elements such as polonium (218Po and 214Po), which including Radon, are mainly alpha (α) emitters. These radioactive elements can be concentrated in workplaces and inside homes, when ventilation conditions are not adequate.

Radon is estimated worldwide to be the second cause of lung cancer, after smoking. Likewise, the proportion of the total number of lung cancer cases secondary to radon can vary from 3% to 14%, depending on its concentration and tobacco smoking.

2. INTRODUCTION

Radon is part of our ecosystem is a radioactive gas colorless and odorless alpha (α) and gamma (γ) emitter, comes directly from the radius (^{226}Ra), which is part of the series of natural decay of uranium (^{238}U). Its half-life is 3.2 days, their decay products are very small particles that are suspended in the air, some of which are in the order of nanometers, these being radioactive too, some of them emitting alpha radiation with half-lives of the order of minutes or less as they are those of polonium (^{218}Po and ^{214}Po) of the lead (^{214}Pb) and Bismuth (^{214}Bi).

Radon is present in the soil, water and rocks, mainly those with high quartz content, it easily emanates from the soil and passes into the air, thus, when breathing it, plus the radioactive material originated by the progeny as a result of its disintegration, can affect the DNA of cells in the airways and cause lung cancer.

In principle, there is no threshold concentration, to which one can be exposed, where the absence of risk can be assumed, therefore, the lower the concentration, the lower the risk of lung cancer.

Internationally and as a result of investigations carried out, different levels of action have been established, where, if they are exceeded, control measures should be implemented with a view to reducing their concentration, therefore, the risk. The main measure of mitigation and reduction of radon levels existing in an environment is ventilation.

Action levels established by the European Community are 1000 Bq/m^3 for workplaces and between 200 and 600 Bq/m^3 for homes. In the open air, radon is rapidly diluted to very low concentrations, so it may not represent a significant problem for the health of the population, the opposite occurs in places or closed spaces, where concentrations can be high, especially in environments such as underground mines, tunnel constructions, caves and etcetera.

First association to risk of damage to health from exposure to radon gas of occupational origin, occurred in workers in uranium mines where an unusual increase in cancers was detected, a fact that occurred in the Andujar mine in Spain, which has been in operation since 1959 to 1981. Of its 126 workers, to date, 76 have died, and of these, 70% have been due to cancers. Today, it constitutes a public health concern and problem, both due to the probable size of the exposed population, as well as the carcinogenic nature of radon, in fact, the International Agency for Research on Cancer (IARC) under the WHO (World Health Organization), classifies it as a carcinogen in humans, that is, in Group 1. Some developed countries have carried out specific evaluations and measurements that have allowed them to define the different geographic areas according to the radon concentration, therefore, according to the risk to the population, although they are mostly based on measurements made in homes. Evaluations carried out in work environments, except those in uranium mines, are not frequent, although there are some studies in countries such as Australia, Italy, United Kingdom, Spain, Mexico, among others, where, in certain environments and jobs, concentrations of radon have been found that represent a significant risk of lung cancer, which is why the application of control and mitigation measures has been required.

In Chile, despite being a country where mining is one of the main economic activities, few environmental evaluations of radon gas have been carried out, even more scarce in media and with occupational health criteria, so there is no with a baseline that reflects the magnitude of risk in the workplace. On the other hand, there is currently no specific regulation that establishes exposure limits or criteria under which to address the presence of radon in work environments. Adding to the problem is the situation that many of these activities occur at high geographical altitudes, since, in the country, many of these activities occur between 2000 and 5000 meters above sea level.

The main objective of this study is to carry out some measurements and evaluations of radon of occupational origin in the mining sector, in order to have evidence that allows us to make an estimate of the risk in our environment, to later extend these evaluations to others economic sectors and other work environments, such as the construction of tunnels, in the subway train, among others, for the establishment of criteria appropriate to national conditions for both the work environment and the environment, as well as the establishment of policies specific public authorities in this matter, likewise, the identification of the necessary control and surveillance measures for each case.

3. OBJECTIVES

- Carry out radon measurements in work environments in the mining sector, in order to have evidence that allows a preliminary assessment of the magnitude of the risk from radon exposure.

- To have results of radon exposure levels in work environments, which define the need to extend the measurements to other economic sectors and work areas, in order to establish appropriate health policies for this purpose and the establishment of criteria for managing the risk, appropriate national conditions.

4. METODOLOGY

4.1 Sample size and type.

So far, measurements have been made in a series of places in two underground mines of what could be classified as large mining, located in central and northern Chile, both with the particularity of being at a considerable geographical altitude. The samples were environmental samples, carried out with sampling periods of one hour, obtaining a mean concentration value within one hour, and at each point, a variable number of readings.

An **Airthings Corentium Pro** detector was used, which was located at respiratory level of workers.

4.2 Workplace variables.

Environmental variables such as: temperature (° C), relative humidity (RH%) and barometric pressure (Pa) were measured. In addition, data related to ventilation (type and flow) of the areas to be evaluated will be recorded.

Complementarily, workplace variables such as: exposure time and schedules, geographic altitude, type and use of respiratory protection, type of fortification or other sealing of walls or workplace environments, accumulation were observed and notes were taken. and water leaks, the type of task that is carried out, also including places where food is consumed.

4.3 Concentration and dose criteria.

In Chile there is no limit for radon and its decay products. For this, the level established as a recommendation by the International Atomic Energy Agency (IAEA)[1] for radon and its decay products will be used as a limit, for reference only, which is set at a value that does not exceed an annual average concentration. of radon activity and its decay products of 1000 Bq/m^3 in workplaces. This concentration corresponds to an effective annual dose of the order of 10 mSv. In addition, dose conversion factors established in Publication N°65 of the International Commission on Radiological Protection (ICRP) will be used.

4.4 Dose calculations derived from radon concentrations and its decay products.

To determine the effective dose resulting from the incorporation (inhalation of radon and its decay products) of radioactive material in air, some calculations must be made to convert the concentration of radioactive material in air (Bq/m^3) to an effective dose (annual mSv), to evaluate (compare with limits) the magnitude of risk of the evaluated agent. The types of calculations to be performed are detailed below.

- **Radon concentration:** Radon gas activity expressed as decays per unit time in a given volume of air in Bq/m^3.

- **Working level (WL):** It is the historical unit for the potential progeny, of short period, of radon in 1 m^3 of air that will result in the emission of 1.3 x 10^5 MeV/m^3 of potential alpha energy, which is approximately equal to 2.08 x 10^{-5} J/m^3. 1 WL = 3700 Bq/m^3 of progeny.

- **Working Level Month (WLM):** The cumulative exposure from breathing an atmosphere at a concentration of one WL during 170 hours work month (2000 hours per year).

- **Equilibrium Equivalent Concentration (EEC):** The activity concentration of radon gas, in equilibrium with its short-lived progeny, that would have the same potential alpha energy concentration as the existing non-equilibrium mixture.

- **Concentración equivalente de equilibrio (EEC):** La concentración de actividad del gas radón, en equilibrio con su progenie de corta duración, que tendría la misma concentración potencial de energía alfa que la mezcla de no equilibrio existente.

- **Equilibrium factor (F):** The relationship between the equilibrium equivalent concentration and the radon gas concentration.

The factors to be used to calculate the effective dose (Bq/m^3 at annual mSv), for this study, will be carried out as established in the ICRP, Publication N°65; equilibrium factor of 0.4 (factor used for closed environments) and an annual occupancy rate of 2000 hours, a dose conversion coefficient of 5 mSv/ WLM (dosimetric factor derived from the dose conversion convention).

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, General Safety Requirements No. GSR Part 3, IAEA, Vienna (2016).

5. RESULTS

Evaluations have been carried out in two underground mines that carry out their activities at high geographical altitude with different combinations of activities carried out underground and on the surface. The following table shows some details of the evaluated tasks:

Table 1: Evaluated mining operations and some details of the measurements.

Mine site	Geographical altitude (MAMSL)	Number of measurements	Measurement distribution
A	Between 3000 and 4000.	50	Transport level. Subsidence level. Production level and crushing plants. Grinding.
B	Between 2000 and 3000.	48	Production level. Dump. Foundry.

Some of the values found are the following:

Table 2: Some of the highest values found in each of the sites.

Mine Site	Measurement site	Concentration Average (Bq/m^3)	WL *	WLM *	Dose* (mSv/year)
A	Subsidence level. Sector 1.	63,60	0,01	0,11	0,56
A	Subsidence level. Sector 2.	980,80	0,14	0,40	1,98
A	Transport level.	19,50	>0,0001	>0,0001	>0,01
A	Crushing plant.	253,00	0,05	0,07	0,35
A	Grinding plant.	50,00	0,01	0,01	0,07
B	Production level. Sector 1.	27,00	<0,0001	<0,0001	<0,01
B	Production level. Sector 2.	9,00	<0,0001	<0,0001	<0,01
B	Office workshops without ventilation.	182,00	0,02	0,23	1,13
B	Office workshops with ventilation.	85,00	0,01	0,11	0,56

*** Note:** Correspond to the maximum values obtained at each sampling point.

6. DISCUSSIONS

Concentrations found at Mining Site A fluctuate between 9 and 1304 Bq/m^3 of radon, while at Site B concentrations between 9 and 163 Bq/m^3.

According to calculations developed with the factors provided in Publication N°65 of ICRP, the annual effective dose values found in Site A range from 0.07 mSv to 1.98 mSv per year, while for Site B they range between <0.01 mSv to 1.13 mSv per year.

All the previous values were obtained in normal ventilation conditions and in the warmer times of the year. Presumably, in the colder times of the year, due to the technical difficulties imposed by the low temperatures that occur at these geographical heights, for ventilation systems, presumably some of these values could increase. Likewise, due to rain or snowfall, the greater presence of water percolated through the mining substrate, added to the solubility of radon gas in water, could be a factor that can increase the concentration of radon gas in the air. The latter could have been a factor in some of the results obtained, since some of the highest readings obtained actually occurred in places with a large presence of water that filters through the structures of the caves built.

An exception to the above, are the last two readings of Site B, in which there was the opportunity to take measurements under conditions with normal ventilation and another with several hours in which, due to a scheduled maintenance activity, the evaluated area did not had normal ventilation, where an increase in radon concentrations could be verified, yielding the highest values found in the entire site, which also reinforces the relevance of ventilation as a mechanism for mitigating radon levels at which workers can be found subjected in this type of environment.

Water exists deposited in some places, which runs naturally through the rock of the mine, can be a determining factor in the concentration of radon and its decay products, due to the fact that radon dissolves in water and can be concentrated in its transit through the rock, where it is naturally contained, and later, when it is in an open space, it comes out of the solution in the water to find itself dissolved in the air of workplace.

7. CONCLUSIONS

With this set of measurements, it can be concluded that there is indeed a presence of radon gas in the work environment of underground mining operations. The dose levels found so far may not imply the implementation of mitigation measures, nor, according to international criteria, to consider jobs with occupational exposure to ionizing radiation, however, the doses involved, compared with those that are usually found for the practices authorized in the country, they are not negligible, therefore, it is convenient to continue assessments for more robust information regarding the real magnitude of the problem and likewise, promote that in the country a treatment of this type of exposures is approached from a policy or regulatory point of view.

On the other hand, it can be observed, as described in all the bibliography and international recommendations, that factors such as ventilation are fundamental for the control of this agent, factors that in large underground mining are already present for the control of levels of other pollutants present such as dust, silica, combustion gases, among others, likewise, other factors such as ambient temperatures, geographical altitude and the natural presence of water in the substrate being exploited could be important.

8. FIGURES