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Short communication

Population dose in the vicinity of old Spanish uranium mines

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Abstract

Regional surveys were conducted to determine exposure to natural sources of radiation for people in the vicinity of old Spanish uranium mines. The surveys evaluated indoor radon concentrations and outdoor and indoor external gamma dose rates. Indoor radon concentrations were measured in 222 dwellings by means of nuclear track-etched detectors. The terrestrial gamma ray dose rate was measured outdoors and indoors at a total of 256 points and 115 points, respectively. Estimates mean annual effective doses for the six areas studied ranged from 3.2 to 5.1 mSv per year, which is between 1.2 and 2 times higher than the average national value.

Keywords: Survey; Radiation; Dose; Radioactivity

1. Introduction

Human exposure to ionizing radiation is a scientific subject that, by its very nature, attracts enormous public attention and arouses considerable controversy. Since radiation of natural origin is responsible for most of the total radiation exposure to the general population, knowledge of the dose received from natural sources is crucial in the discussion, not only because of its effects on health, but also because of the incidence of other radiation from man-made sources (UNSCEAR, 2000).

Few measurements of natural radiation have been made in the vicinity of the old Spanish uranium mines. Under the sponsorship of the Spanish Nuclear Safety Council, our group carried out surveys in the six uranium-mining areas in the country during 2000 and 2001. The mines, which are mainly located in the western part of Spain, are shown in a geological map of the country (Fig. 1). The rock types, which compose the largest fraction of the surface area of the mines, are calcite carbonatite (Peñarroya, Andujar), biotitic and muscovitic granodiorite (Vitigudino, Alburquerque), two micas granodiorites (Albala) and methamorphic slate, near granitite contact (La Haba).

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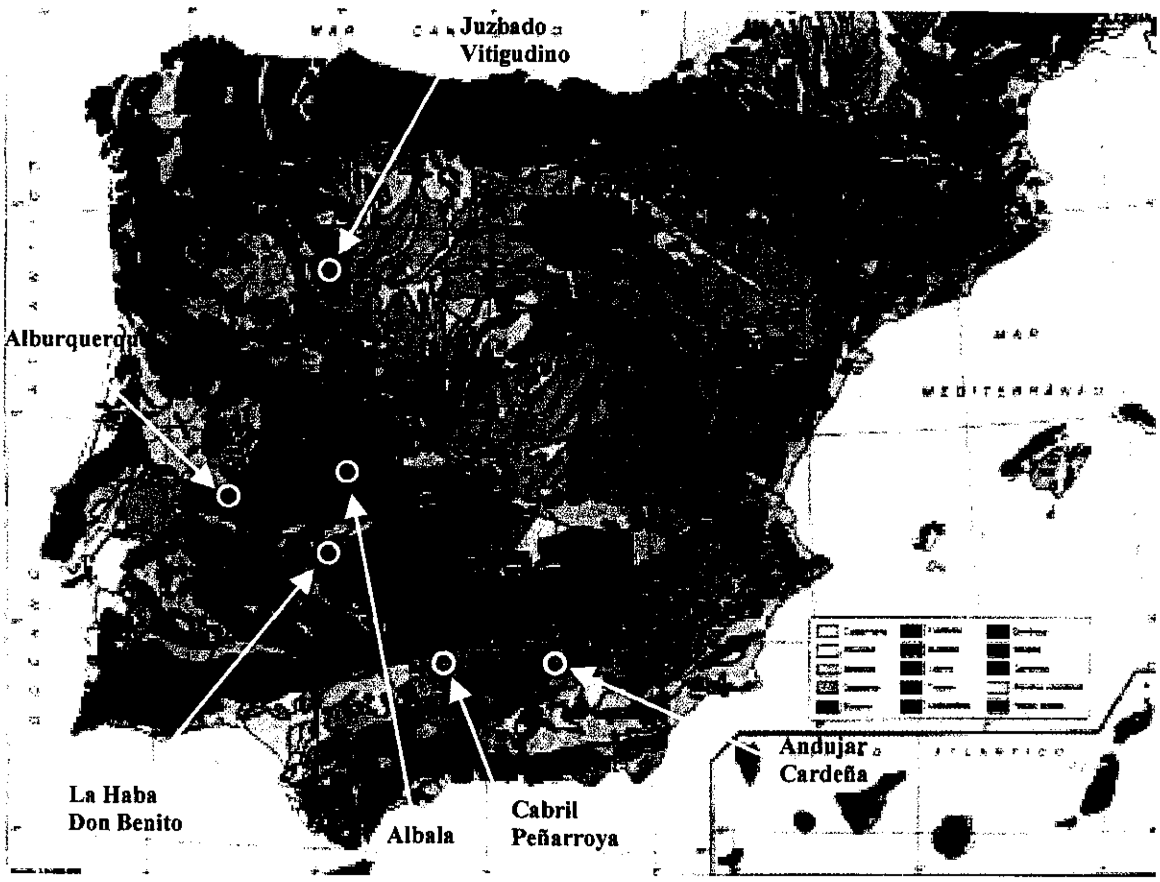

Fig. 1. Location of old uranium mines in the country.

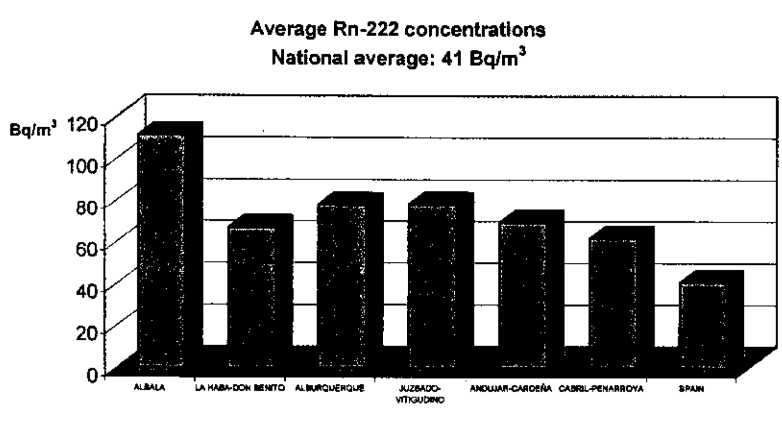

Fig. 2. Average indoor radon concentrations.

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Table 1
Radon concentration in the different areas studied

	Arithmetic mean ($Bq\ m^{-3}$)	Arithmetic S.D. ($Bq\ m^{-3}$)	Geometric mean ($Bq\ m^{-3}$)	Geometric S.D.	Range ($Bq\ m^{-3}$)	Percentage >200 ($Bq\ m^{-3}$)
Albala (26)	164.4	159.0	111.2	2.5	31–679	26.9
La Haba-Don Benito (27)	94.3	75.7	66.9	2.4	13–273	11.1
Alburquerque (31)	101.5	84.3	77.9	2.1	18–358	16.1
Juzbado -Vitigudino (58)	116.3	124.9	78.3	2.4	11–627	17.0
Andujar -Cardeña (48)	100.9	99.2	69.6	2.3	14–355	16.7
Cabril -Peñarroya (32)	81.3	61.3	62.0	2.1	12–218	7.4

The figures in brackets represent the number of measurements.

The sites were mined for uranium from 1950 to 1980. From 1987 to 1996, a general decommissioning plan was carried out based on the following general criteria: to avoid risk to people and the environment, to prevent the dispersion of pollutants, to reduce and control radon flow and contamination of water, to ensure long-term stability of the mines (1000 years) and minimize maintenance requirements. The population of these areas is over 400 000 inhabitants. This paper summarises the main results obtained in these surveys.

2. Methods and results

Exposure to natural sources of radiation to people living in the areas described was determined from 222 indoor radon measurements and 371 external gamma dose rate measurements (256 outdoors and 115 indoors). The following sections present the procedure employed, the main results and doses from these three sources.

2.1. Indoor radon

A total of 222 measurements were made throughout the areas using CR-39 track-etched detectors in order to evaluate average values for exposure to indoor radon over a 6 month period. The individual error of radon measurements was estimated at less than 10%. Table 1 gives the arithmetic and geometric mean radon concentrations and their corresponding standard deviations together with the range of variation and percentage of measurements over the recommended action level of 200 $Bq\ m^{-3}$ (UE, 1990) for each area. Except for the Cabril-Peñarroya area, the percentage of houses with indoor radon concentrations over 200 $Bq\ m^{-3}$ was between 1.3 and 3 times higher than the 9% measured for the whole country (Quindós et al., 1992a). Fig. 2 compares the values obtained from the measurements mentioned above with the average national radon concentration (Quindós et al., 1991). The radon concentration was significantly different ($P<0.001$ by Student's t-test) from the national average for all mines considered together. This is basically due to the high radium content measured in the bedrock predominant in the studied areas.

The highest values were found in the Albala area, where indoor radon concentrations were as high as 679 $Bq\ m^{-3}$. This area was showed the highest significance compared with the average national radon concentration ($P<0.02$ by Student's t-test). Using the dose conversion factor proposed in the ICRP65 Publication (ICRP, 1994), annual average doses from indoor radon were between 1.5 and 2.7 times higher than the annual national average to the Spanish population for this source, which was evaluated as 1.6 mSv (Soto et al., 1993).

2.2. External gamma dose rate

During the surveys, external gamma radiation was measured with a Mini-Instrument Environmental Monitor type 6-80 with an energy compen-

Table 2
External gamma dose rate outdoors for the areas studied

	Arithmetic mean (nGy h^{-1})	S.D. (nGy h^{-1})	Range (nGy h^{-1})
Albala (40)	68.7	17.2	45.6–126.2
La Haba-Don Benito (41)	57.0	23.1	12.6–113.9
Alburquerque (41)	62.1	23.6	25.2–117.3
Juzbado -Vitigudino (53)	75.2	30.3	31.5–179.5
Andujar -Cardeña (45)	52.3	25.7	12.1–117.1
Cabril -Peñarroya (36)	65.8	29.0	19.9–126.5

The figures in brackets represent the number of measurements.

sated Geiger Muller tube MC-70, specially designed to measure environmental levels of gamma radiation with a response reasonably independent of radiation energy from approximately 50 keV to 1.2 MeV (Green et al., 1989). The instrument was calibrated and intercompared at the National Radiological Protection Board, Didcot, UK. Measurement points were not preselected, but were chosen by the investigators according to standard and normalised international criteria to avoid producing atypical results (UE, 1999). Results are reported in units of absorbed dose rate in air in nGy h^{-1}. All the values given are of dose rates from terrestrial gamma rays 1 m above the ground and exclude any contribution from either cosmic rays or instrument background, which has been experimentally evaluated to range from 0.92 counts s^{-1} at sea level to 1.08 counts s^{-1} at a height of 850 m. The uncertainty in the measurements was typically 8%. A total of 371 individual measurements including outdoor and indoor measurements were made to cover the areas under study.

Tables 2 and 3 summarise the results obtained for the areas studied. The results were directly related to the different underlying geological formations (IAEA, 1993). The mean annual effective dose from external exposure to terrestrial gamma rays to the population, was evaluated by using a conversion coefficient from absorbed dose in air to effective dose in the human body of 0.7 Sv per Gy (UNSCEAR, 2000) and considering that people in these areas spend, on average, approximately 20% of their time outdoors.

For this source of radiation, the annual average dose to the population calculated from the values shown in Tables 2 and 3 was in the range of 0.4–0.6 mSv y^{-1}. Significant differences were found for Albala, La Haba-D.Benito, Juzbado-Vitigudino and Cabril-Peñarroya, when the dose from this source was compared with the average dose evaluated for the country ($P<0.0001$ by Student's t-test) (Quindós et al., 1992b).

3. Risk assessment

Table 4 shows the average value of the annual effective doses from natural sources for the six areas studied. The assessment of risk to the population living in the vicinity of the old Spanish uranium mines must be focused on the exposure to radon and its decay products. Basically, there are five models for evaluating the risk of lung cancer from radon exposure: the NCRP and ICRP models (NCRP, 1984; ICRP, 1987) and the more recent ones developed by the fourth US National Research Council, (BEIR IV, 1988), the US National Cancer Institute, NCI model (Lubin et al., 1994) and the sixth National Research Council, (BEIR VI, 1999).

The BEIR VI model was applied to the areas studied, for a population of 400 000 inhabitants, a derived arithmetic mean indoor radon concentra-

Table 3
External gamma dose rate indoors for the areas studied

	Arithmetic mean (nGy h^{-1})	S.D. (nGy h^{-1})	Range (nGy h^{-1})
Albala (15)	87.2	17.6	58.9–112.2
La Haba-Don Benito (15)	83.9	20.0	48.8–125.6
Alburquerque (18)	71.0	25.4	35.6–135.6
Juzbado -Vitigudino (27)	102.9	34.6	65.3–212.5
Andujar -Cardeña (24)	64.5	24.1	25.0–125.6
Cabril -Peñarroya (16)	81.3	22.1	45.0–136.5

The figures in brackets represent the number of measurements.

tion of 110 Bq m^{-3} and the population-weighted average lifetime risk of lung cancer 1.6×10^{-4}. This yielded a lifetime risk of lung cancer of 1.76%, which means an annual number of lung cancer deaths due to radon in these areas of approximately 80. This represents a percentage value that is twice as high as that for the whole Spanish population (Colgan, 1995).

4. Discussion and conclusion

As can be seen in Table 4, the total average annual effective doses for these regions are between 1.2 and 2 times higher than the Spanish national average of 2.6 mSv y^{-1} (Quindós et al., 2003). However, taking into account the highest radon concentrations found for each area, as shown in Table 1, doses as high as 30 mSv per year can be reached in some places. From a general point of view, this information is very important in assessing the incidence of natural radiation exposure on the health of the population living near these sites. In this regard, cancer incidence and mortality studies have been conducted in these areas to eliminate doubts about possible adverse effects on the population attributable to old routine operations (Lopez et al., 2001). Nevertheless, these studies revealed a pattern of solid tumour mortality mainly characterized by an excess of lung cancer (relative risk RR 1.12, 95% confidence interval: 1.02–1.25) and very similar for all the areas studied. In light of this increase and the results of surveys and risk assessment described in this paper, it would be of interest to design-specific

Table 4
Annual average doses rates from natural sources of radiation (mSv y^{-1})

	Cosmic dose	External gamma dose Indoors and outdoors	Radon	Total
Albala	0.3	0.5	4.3	5.1
La Haba-Don Benito	0.3	0.5	2.6	3.4
Alburquerque	0.3	0.4	3.0	3.7
Juzbado -Vitigudino	0.3	0.6	3.0	3.9
Andujar -Cardeña	0.3	0.4	2.7	3.4
Cabril -Peñarroya	0.3	0.5	2.4	3.2

studies in these areas to determine whether natural sources of radiation, especially radon, are responsible for the observed excess lung cancer incidence.

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