Paper

NATURAL RADIATION EXPOSURE IN THE VICINITY OF SPANISH NUCLEAR POWER STATIONS

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Abstract—**Nationwide and regional surveys have been conducted to evaluate natural radiation exposure of people in the vicinity of the Spanish nuclear power stations. In these surveys, indoor radon, external gamma dose rates outdoors and indoors and radioactivity in soils were measured. Measurements of indoor radon concentrations were performed in 214 dwellings by using nuclear track-etched detectors. External exposure from terrestrial gamma rays outdoors and indoors were measured in a total of 596 points. Radioactivity in soil samples collected at 293 sampling sites are also reported in this paper. By taking into account all sources of natural radiation exposure, mean annual effective doses to the population in the surroundings of the six Spanish nuclear power stations have been estimated and compared with those coming from their normal operation.**

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Key words: nuclear power plant; radon; naturally occurring radionuclides; gamma radiation

INTRODUCTION

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

Few measurements in the field of the natural radiation environment had been made in the vicinity of the Spanish nuclear power stations. In 1999 and 2000, sponsored by the National Safety Council and the National Union of Electric Society Association (UNESA), our group carried out surveys throughout the surroundings of the six facilities working in the country and shown in Fig. 1. The population of those regions is about 200,000. In this paper we present the results achieved derived from the surveys developed.

INDOOR RADON

A total of 214 measurements were made throughout the regions proposed above using track etch detectors CR39 exposed for a 6-mo period in order to evaluate average indoor radon concentrations. Arithmetic and geometric mean radon concentrations as well as their corresponding standard deviations, ASD and GSD, and range of variation for each region are shown in Table 1. Fig. 2 gives a comparison of the values found in these surveys with the national average radon concentration (Quindós et al. 1991).

The highest average annual effective dose from the inhalation of radon is found for the population of the Almaraz region (average of 3.02 mSv) with a range of variation from 1.1 mSv to 15.7 mSv because individual values for radon concentration as high as 640 Bq m^{-3} were found in houses of this area. These values were lower for the other regions where the annual effective dose ranges from 0.08 to 4.19 mSv with average values between 0.32 mSv in the Cofrentes area and 0.85 mSv in the Trillo and Zorita surroundings. In all cases the dose conversion factor used was that proposed in the ICRP 65 Publication (ICRP 1993). Except for the Almaraz area, the evaluated annual effective doses from this source of exposure are lower than or, at most, similar to the national average of around 1.0 mSv estimated for the Spanish population (Soto et al. 1993).

EXTERNAL GAMMA DOSE RATE

A Mini-Instrument Environmental Monitor type 6-80 with an energy compensated Geiger Muller tube

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Fig. 1. Geographic locations of the Spanish nuclear power plants.

MC-70 specially designed to measure environmental levels of gamma radiation was used during the course of the surveys on external gamma radiation exposures. This instrument has a response reasonably independent of radiation energy from about 50 keV to 1.2 MeV and has been calibrated and intercompared at the National Radiological Protection Board, UK (Green et al. 1989). Each measurement point was not preselected but chosen by the investigators according to standard and normalized international criteria to avoid producing atypical results. External gamma dose rates are reported in units, nGy h^{-1}, of absorbed dose rate in air. All the values given are for 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 and ranged from 0.92 counts s^{-1} at sea level to 1.08 counts s^{-1} at 850 m height.

External gamma exposures outdoors and indoors were measured in a total of 596 points throughout the six regions studied. Random uncertainty in measurements was typically 8%, and systematic uncertainty is estimated to be of the same order. Tables 2 and 3 show a resume of the results obtained for external gamma exposures outdoors and indoors, respectively, in the six regions surveyed, which are directly related to the different underlying geological formations (IAEA 1993). Mean annual effective dose to the population from external gamma radiation has been evaluated by using a conversion coefficient from absorbed dose in air to effective dose equivalent in the human body of 0.7 Sv Gy^{-1} and considering that people in these regions on average spend about 20% of their time outdoors and 80% indoors.

Only for the Almaraz area, external gamma dose rate was higher, by about two times, than the corresponding national averages (Quindós et al. 1992). The mean annual effective dose to the population from indoor and outdoor external gamma exposure amounts to 0.76 mSv in the Almaraz area and ranges between 0.23 mSv and 0.32 mSv in the surroundings of the five other nuclear power stations.

RADIOACTIVITY IN SOILS

A specific survey of natural radioactivity in soil was also carried out by our research team to set up a map of naturally occurring radionuclides and thereby to correlate the concentration values of these natural radionuclides in soil with the external exposure rates from terrestrial gamma rays experimentally measured. The aim of this survey was focused on determining the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soils. The selection procedure used in the survey yielded a total of 293 sampling sites chosen on bare soil areas. These sites were selected on the spot by the investigators and were open, reasonably level, and not obviously prone to flooding or other natural disturbances.

At each sampling site, five cores of topsoil were taken over an area of 1,000 m^2. Each core was taken to a depth of 5 cm at a randomly chosen point within the site area; the only constraint was that no core should be taken close to a field boundary, tree, building, or other obstruction. In order to obtain a representative sample, the soil cores collected at each site were thoroughly mixed together in the laboratory.

A sample of 2 L was then weighed, air dried for several days, and placed in an oven at 100°C for 24 h. The sample was subsequently reweighed to determine the water content, sieved to remove stones and pebbles, and crushed to pass through a 1-mm mesh sieve. Finally, the prepared sample was packed in a sealable 250-mL PVC can and left for at least 4 wk before counting by gamma spectrometry in order to ensure that radioactive equilibrium between ^{226}Ra, ^{222}Rn, and short-lived radon progeny was reached. Gamma spectrometry measurements were made using a low background HPGe detector with a relative efficiency of 20% and a resolution of 1.86 keV at 1.33 MeV.

Table 4 shows the geometric means and geometric standard deviations (GSD), as well as the ranges of variation, of the concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil, expressed in Bq kg^{-1} dry weight, for the regions studied. As for indoor radon and external gamma dose rates, mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil in the Almaraz area are higher, by about 1.5

Table 1. Radon concentrations (Bq m^{-3}).

	Almaraz	Asco-Vandellos	Cofrentes	Garoña	Trillo	Zorita
Geometric mean	93.9	31.8	13.8	22.6	34.5	30.2
G.S.D.	2.4	2.1	2.1	1.6	1.8	1.7
Range	22.0–640.0	8.0–214.0	5.0–61.0	9.0–50.0	12.0–116.0	12.0–62.0
Arithmetic mean	141.9	42.5	17.9	24.9	41.3	36.2
A.S.D.	147.0	40.4	14.3	11.3	26.1	15.2

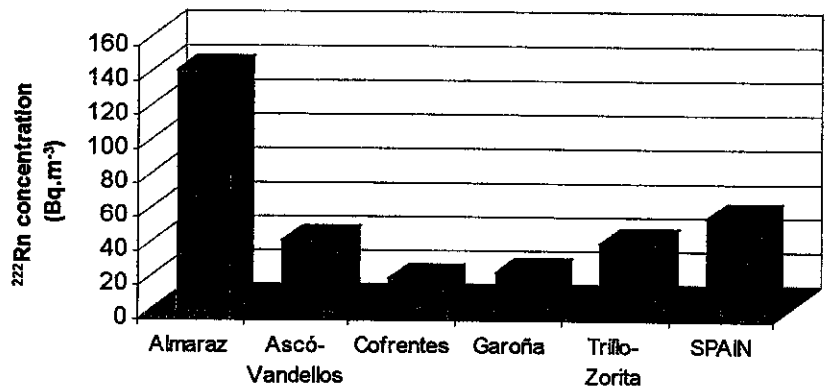

Fig. 2. Average ^{222}Rn concentrations.

Table 2. External gamma radiation (outdoors).

		Almaraz	Asco Vandellos	Cofrentes	Garoña	Trillo	Zorita
External gamma radiation (outdoor) (nGy h^{-1})	Geometric mean	79.8	38.1	30.3	31.5	36.2	32.5
	G.S.D.	1.6	1.5	1.5	1.4	1.5	1.5
	Range	36.0–211.0	18.9–83.6	9.2–73.2	16.2–66.7	10.8–69.4	8.7–62.2
	Arithmetic mean	88.9	40.9	32.7	33.4	38.6	34.8
	A.S.D.	44.6	16.4	12.9	11.8	13.3	12.1

Table 3. External gamma radiation (indoors).

		Almaraz	Asco Vandellos	Cofrentes	Garoña	Trillo	Zorita
External gamma radiation (indoor) (nGy h^{-1})	Geometric Mean	119.1	46.1	36.6	38.5	52.5	42.9
	G.S.D.	1.6	1.5	1.4	1.4	1.5	1.4
	Range	54–313.1	22.2–97.4	20.3–82.1	20.6–82.2	17.2–100.1	17.2–87.1
	Arithmetic mean	133.2	49.4	39.1	40.8	55.9	45.0
	A.S.D.	67.5	19.6	15.2	14.4	19.1	14.0

times, than the national averages (Quindós et al. 1994), while in the others regions are similar to or lower than them.

DISCUSSION

Table 5 shows the mean values and ranges of variation of the total annual effective doses coming from natural sources for the six regions studied. For all of them, excluding Almaraz plant, the values are similar to or lower than the Spanish national average of 2 mSv y^{-1} (Quindós et al. 2001). In compliance with Spanish laws, the Nuclear Safety Council submits its annual report to the two Houses of the Spanish Parliament referring to the activities carried out during the year by the different nuclear power plants. As it can be seen in Fig. 3, the total effective dose for all releases for the period 1991–2001 is less than 10 μSv y^{-1}, with the Almaraz plant showing the highest values. Nevertheless, if we compare this dose with the average value referred to above, we can conclude that the total dose coming from natural sources is 100 times higher than those from the normal activity of the Spanish nuclear power plants, and for the Almaraz station it is 400 times higher. In the light of the results of these surveys, it would be of interest to design specific studies in this last region to determine whether natural sources are affecting the health of the population in an

Table 4. Concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soils.

		Almaraz	Asco Vandellos	Cofrentes	Garoña	Trillo	Zorita
^{226}Ra (Bq Kg^{-1})	Geometric mean	41.9	22.6	17.9	22.0	19.6	17.5
	G.S.D.	1.8	1.4	1.4	1.4	1.4	1.6
	Range	14.4–128.3	9.5–51.5	8.7–32.3	11.9–71.6	6.2–44.2	5.4–63.5
^{232}Th (Bq Kg^{-1})	Geometric mean	43.0	27.2	27.5	27.2	26.2	14.1
	G.S.D.	1.8	1.5	1.4	1.4	1.8	2.2
	Range	14.0–179.0	5.6–56.6	12.0–47.7	7.6–45.4	2.5–90.4	2.0–57.4
^{40}K (Bq Kg^{-1})	Geometric mean	620.1	325.7	320.1	263.1	385.4	268.0
	Range	1.8	1.7	1.6	1.4	1.5	1.6
	G.S.D.	138.8–1698.0	69.8–949.6	90.1–1166.3	101.7–475.9	111.1–672.1	73.3–669.2

Table 5. Annual doses and ranges of variation for the regions studied.

	Annual cosmic dose (mSv)	Annual external gamma dose (outdoors) (mSv)	Annual external gamma dose (indoors) (mSv)	Annual radon dose (mSv)	Total Annual dose (mSv)
C.N Garoña	0.30 (0.28–0.32)	0.04 (0.02–0.08)	0.20 (0.10–0.40)	0.46 (0.21–0.94)	1.00 (0.62–1.73)
C.N Cofrentes	0.31 (0.27–0.36)	0.04 (0.01–0.09)	0.19 (0.10–0.40)	0.32 (0.08–1.09)	0.86 (0.46–1.94)
C.N Almaraz	0.29 (0.28–0.32)	0.11 (0.04–0.17)	0.65 (0.26–1.52)	3.02 (0.50–13.70)	4.07 (1.08–15.71)
C.N Asco-Van	0.28 (0.27–0.30)	0.05 (0.02–0.10)	0.24 (0.11–0.47)	0.84 (0.15–4.19)	1.41 (0.55–5.06)
C.N Zorita	0.32 (0.30–0.33)	0.04 (0.01–0.07)	0.22 (0.08–0.42)	0.85 (0.23–2.41)	1.43 (0.62–3.23)
C.N Trillo	0.33 (0.31–0.36)	0.05 (0.01–0.08)	0.27 (0.08–0.49)	0.85 (0.23–2.41)	1.50 (0.63–3.34)

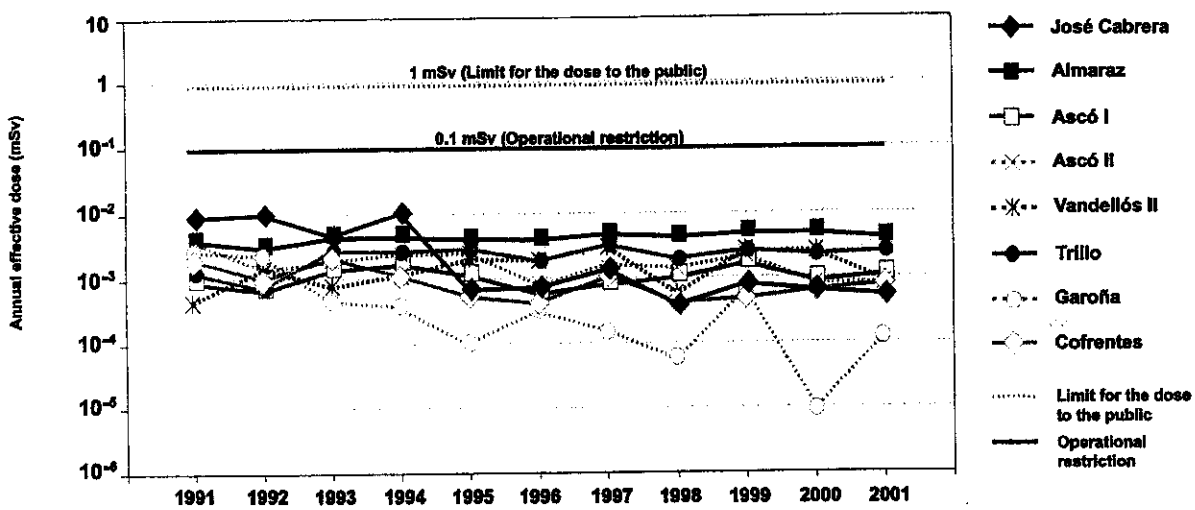

Fig. 3. Total effective equivalent dose per release for the Spanish nuclear power plants.

area where people could think the nuclear power plant is absolutely responsible.

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