Radon and geology in Spain: Past, present and future

Fuente Merino, I; Sainz Fernandez, C.; Gutierrez Villanueva J.L.; Quindos Lopez, L.; Quindos Poncela, L.S.

Radon Group
Universidad de Cantabria
Santander, Cantabria, Spain
Noble gas

$^{222}\text{Rn}$

Noble gas

$T_{1/2} = 3.82\text{ d}$

Emisor alfa (5.49 MeV)

Sources and transport mechanisms

Soils

Building Materials

Water

MAIN SOURCE OF RADIATION
RADON PROGENY INHALATION

LUNG CANCER RISK
Others?

Increase in risk of lung cancer:

16% por 100 Bq/m3  95% CI (5, 31)

after correction for the dilution due to random year-to-year variability in residential radon concentrations, as well stratification for study, age, sex, broad region of residence within study, and detailed smoking history.

(Darby et al. 2006)

INTERNATIONAL RADON PROJECT (WHO, 2005 - 2009)
RADON CONCENTRATION MAY PRESENT VARIATIONS

- OF 3 ORDERS OF MAGNITUDE
- FROM ONE BUILDING TO ANOTHER
- FROM ONE AREA TO ANOTHER

... SO MEASUREMENT CAMPAIGNS ARE ESSENTIAL
SPAIN: WHAT WE KNOW ..... 


- NUMBER OF DWELLINGS SURVEYED: 2,000
- ABOUT 500 CITIES AND VILLAGES
- POPULATED WEIGHTED GEOMETRIC MEAN 45 Bq/m³; G.S.D.: 2.7
- PERCENTAGE OF DWELLINGS ABOVE 400 Bq/m³: 2%
- HIGHEST VALUE: 15,400 Bq/m³

AREAS WITH HIGH RADON INDOOR VALUES HAVE BEEN IDENTIFIED, IN THE CENTER AND THE WEST OF THE COUNTRY
SPAIN: WHAT WE KNOW

> 400 Bq/m³
SPAIN: WHAT WE KNOW .....
SPAIN: WHAT WE KNOW ..... 

NATURAL RADIATION MAP (MARNA Project) (1991- )

AN ONGOING PROJECT THAT IS BEING CARRIED OUT BY THE CSN, THE URANIUM NATIONAL COMPANY, SOME UNIVERSITIES AND AUTONOMOUS COMMUNITIES.

CURRENTLY IS IN THE LAST PHASE. THIS PROJECT PROVIDES US MAPS OF THE COUNTRY WHERE THE ZONES WITH DIFFERENT GAMMA RADIATION LEVELS ARE SHOWED.

1.500.000 nationwide terrestrial gamma radiation values

1320 nationwide activity concentration data of $^{40}$K, $^{226}$Ra, $^{232}$Th in soil.
"NATURAL GAMMA RADIATION MAP (MARNA) AND INDOOR RADON LEVELS IN SPAIN"

Environment International, 29 (8), 1091-96, 2004
SPAIN: WHAT WE KNOW .....
SPAIN: WHAT WE KNOW .....  

RADON MEASUREMENTS: 

REGIONAL SURVEYS 

.- NUCLEAR POWER STATIONS  

.- OLD URANIUM MINING  

.- LOS ARRIBES DEL DUERO  

.- SIERRA DE GUADARRAMA  

.- VILLAR DE LA YEGUA
SPAIN: WHAT WE KNOW .....  

RADON MEASUREMENTS:  
REGIONAL SURVEYS

.- NUCLEAR POWER STATIONS
NATURAL RADIATION EXPOSURE IN THE VICINITY OF SPANISH NUCLEAR POWER STATIONS
Health Physics, Vol 85(5), 594-598, 2003
### Table 2. External gamma radiation (outdoors).

<table>
<thead>
<tr>
<th></th>
<th>Almaraz</th>
<th>Asco Vandellos</th>
<th>Cofrentes</th>
<th>Garoña</th>
<th>Trillo</th>
<th>Zorita</th>
</tr>
</thead>
<tbody>
<tr>
<td>External gamma radiation</td>
<td>Geometric mean</td>
<td>79.8</td>
<td>38.1</td>
<td>30.3</td>
<td>31.5</td>
<td>36.2</td>
</tr>
<tr>
<td>(outdoor) (nGy h⁻¹)</td>
<td>G.S.D.</td>
<td>1.6</td>
<td>1.5</td>
<td>1.5</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Range</td>
<td>36.0–211.0</td>
<td>18.9–83.6</td>
<td>9.2–73.2</td>
<td>16.2–66.7</td>
<td>10.8–69.4</td>
<td>8.7–62.2</td>
</tr>
<tr>
<td>Arithmetic mean</td>
<td>88.9</td>
<td>40.9</td>
<td>32.7</td>
<td>33.4</td>
<td>38.6</td>
<td>34.8</td>
</tr>
<tr>
<td>A.S.D.</td>
<td>44.6</td>
<td>16.4</td>
<td>12.9</td>
<td>11.8</td>
<td>13.3</td>
<td>12.1</td>
</tr>
</tbody>
</table>

### Table 3. External gamma radiation (indoors).

<table>
<thead>
<tr>
<th></th>
<th>Almaraz</th>
<th>Asco Vandellos</th>
<th>Cofrentes</th>
<th>Garoña</th>
<th>Trillo</th>
<th>Zorita</th>
</tr>
</thead>
<tbody>
<tr>
<td>External gamma radiation</td>
<td>Geometric Mean</td>
<td>119.1</td>
<td>46.1</td>
<td>36.6</td>
<td>38.5</td>
<td>52.5</td>
</tr>
<tr>
<td>(indoor) (nGy h⁻¹)</td>
<td>G.S.D.</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Range</td>
<td>54–313.1</td>
<td>22.2–97.4</td>
<td>20.3–82.1</td>
<td>20.6–82.2</td>
<td>17.2–100.1</td>
<td>17.2–87.1</td>
</tr>
<tr>
<td>Arithmetic mean</td>
<td>133.2</td>
<td>49.4</td>
<td>39.1</td>
<td>40.8</td>
<td>55.9</td>
<td>45.0</td>
</tr>
<tr>
<td>A.S.D.</td>
<td>67.5</td>
<td>19.6</td>
<td>15.2</td>
<td>14.4</td>
<td>19.1</td>
<td>14.0</td>
</tr>
</tbody>
</table>
NATURAL RADIATION EXPOSURE IN THE VICINITY OF SPANISH NUCLEAR POWER STATIONS
Health Physics, Vol 85(5), 594-598, 2003

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

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

3% of houses > 400 Bq/m$^3$
"NATURAL RADIATION EXPOSURE IN THE VICINITY OF THE SPANISH NUCLEAR POWER STATIONS. SPECIFIC STUDY OF CAMPO ARAÑUELO (CÁCERES, SPAIN)"

Journal of Environmental Radioactivity, Vol 79, 347-54, 2005
“NATURAL RADIATION EXPOSURE IN THE VICINITY OF THE SPANISH NUCLEAR POWER STATIONS. SPECIFIC STUDY OF CAMPO ARAÑUELO (CÁCERES, SPAIN)”


<table>
<thead>
<tr>
<th>STUDY</th>
<th>A.M. (Bq/m³)</th>
<th>G.M. (Bq/m³)</th>
<th>PERCENTAGE &gt;200 Bq/m³</th>
<th>PERCENTAGE &gt;400 Bq/m³</th>
<th>NO. OF MEAS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CAMPO ARAÑUELO</td>
<td>168.6</td>
<td>113.9</td>
<td>23.6</td>
<td>9.0</td>
<td>55</td>
</tr>
<tr>
<td>NORTHERN ZONE</td>
<td>87.6</td>
<td>65.7</td>
<td>7.2</td>
<td>2.7</td>
<td>549</td>
</tr>
</tbody>
</table>

La Vera: 6 mSv/y

La Vera, 9 % of houses > 400 Bq/m³.

Jarandilla: 25 mSv/y

30 % of houses > 400 Bq/m³.
SPAIN: WHAT WE KNOW ..... 

RADON MEASUREMENTS: 
REGIONAL SURVEYS 

.- OLD URANIUM MINING
POPULATION DOSE IN THE VICINITY OF OLD SPANISH URANIUM MINES

[Map of Spain highlighting areas mentioned in the text]
POPULATION DOSE IN THE VICINITY
OF OLD SPANISH URANIUM MINES
### POPULATION DOSE IN THE VICINITY OF OLD SPANISH URANIUM MINES


<table>
<thead>
<tr>
<th>Location</th>
<th>Arithmetic Mean (Bq m⁻³)</th>
<th>Arithmetic S.D. (Bq m⁻³)</th>
<th>Geometric Mean (Bq m⁻³)</th>
<th>Geometric S.D.</th>
<th>Range (Bq m⁻³)</th>
<th>Percentage &gt;200 (Bq m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albala (26)</td>
<td>164.4</td>
<td>159.0</td>
<td>111.2</td>
<td>2.5</td>
<td>31–679</td>
<td>26.9</td>
</tr>
<tr>
<td>La Haba-Dón</td>
<td>94.3</td>
<td>75.7</td>
<td>66.9</td>
<td>2.4</td>
<td>13–273</td>
<td>11.1</td>
</tr>
<tr>
<td>Benito (27)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alburquerque (31)</td>
<td>101.5</td>
<td>84.3</td>
<td>77.9</td>
<td>2.1</td>
<td>18–358</td>
<td>16.1</td>
</tr>
<tr>
<td>Juzbado</td>
<td>116.3</td>
<td>124.9</td>
<td>78.3</td>
<td>2.4</td>
<td>11–627</td>
<td>17.0</td>
</tr>
<tr>
<td>-Vitigudino (58)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andujar</td>
<td>100.9</td>
<td>99.2</td>
<td>69.6</td>
<td>2.3</td>
<td>14–355</td>
<td>16.7</td>
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<tr>
<td>-Cardeña (48)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cabril</td>
<td>81.3</td>
<td>61.3</td>
<td>62.0</td>
<td>2.1</td>
<td>12–218</td>
<td>7.4</td>
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<tr>
<td>-Peñarroya (32)</td>
<td></td>
<td></td>
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</tbody>
</table>
### POPULATION DOSE IN THE VICINITY OF OLD SPANISH URANIUM MINES


<table>
<thead>
<tr>
<th>ZONE</th>
<th>PERCENTAGE &gt; 400 Bq/m³</th>
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</thead>
<tbody>
<tr>
<td>ALBALA</td>
<td>14</td>
</tr>
<tr>
<td>LA HABA-DON BENITO</td>
<td>6</td>
</tr>
<tr>
<td>ALBURQUERQUE</td>
<td>8</td>
</tr>
<tr>
<td>JUZBADO-VITIGUDINO</td>
<td>9</td>
</tr>
<tr>
<td>ANDUJAR-CARDEÑA</td>
<td>8</td>
</tr>
<tr>
<td>CABRIL-PEÑARROYA</td>
<td>5</td>
</tr>
</tbody>
</table>

All the areas are included in the ICRP 65 criteria for radon prone area.
SPAIN: WHAT WE KNOW

RADON MEASUREMENTS:
REGIONAL SURVEYS

.- SIERRA DE GUADARRAMA
SIERRA DE GUADARRAMA

First survey (1988-1990)

- 7% OF HOUSES > 400 Bq/m³
- 28% OF HOUSES > 200 Bq/m³
- GEOMETRIC MEAN: 122 Bq/m³ G.S.D.: 2.1
- HIGHEST VALUE: 1,706 Bq/m³

Actual survey (2002-)

- 14% OF HOUSES > 400 Bq/m³.
- 30% OF HOUSES > 200 Bq/m³
- GEOMETRIC MEAN: 180 Bq/m³ G.S.D.: 1.9
- HIGHEST VALUE: 2,600 Bq/m³

"Lung cancer risk estimations: A comparison between radon prone areas Stei (Romania) and Sierra de Guadarrama (Spain)"

Proceedings of the IRPA Regional Congress for Central and Eastern Europe, Romania, 2007
VILLAR DE LA YEGUA

"The Spanish experience on HBRA"
International Congress Series, Vol 1276, 50-53, 2005
THE VILLAR DE LA YEGUA TOWN

RADON SURVEYS:
Nº OF MEASUREMENTS: 500
200 POPULATION

MAIN RESULTS:
- GEOMETRIC MEAN: 818 Bq/m³  G.S.D.: 1.7
- HIGHEST VALUE: 25,160 Bq/m³
- 75% OF HOUSES > 400 Bq/m³
- 25% OF HOUSES > 1,000 Bq/m³
- AVERAGE EXTERNAL GAMMA DOSE RATE: 300 nGy/h
- RADON IN WATER: 1,500 Bq/l

DOSES AS HIGH AS 40 mSv per year

High background radiation areas: The case of Villar de la Yegua village (Spain); Radiation Protection Dosimetry 125,pp. 565 – 567, 2007.
EFFECTIVENESS OF REMEDIATION TECHNIQUES
Location of the experimental pilot house

POTENTIAL RADON MAPPING
Source: Spanish Nuclear Safety Council
PREVIOUS SOIL STUDY

- Determination of radioactive isotopes in soil ► High radium concentration
- Determination of radon in soil at 1 m depth ► AM = 250000 Bq m$^{-3}$ (70000-500000)
- Granulometry and permeability determination ► AM = 10$^{-12}$ m$^2$ (medium)

HIGH RADON RISK AREA
Design of the experimental pilot house
MATERIAL AND METHODS

• COUNTER LUDLUM
• 8 TEMPERATURE SENSORS (T1 ... T8)
• 4 PRESSURE DIFFERENCE SENSORS (P1... P4)

CONTINUOUS RADON MONITORING:

• 2 DoseMan SARAD
• 2 Radon Scout SARAD
LABORATORY INSTALLED AT THE MODEL HOUSE
METEOROLOGICAL PARAMETERS PROVIDED BY A NEARBY STATION

Data were recorded every 10 minutes

- Mean wind velocity (m/s)
- Maximum wind velocity (m/s)
- Mean wind direction (°)
- Mean air temperature (°C)
- Maximum air temperature (°C)
- Mean relative humidity (%)
- Mean pressure (mb)
- Mean solar radiation (W/m²)
- Maximum solar radiation (W/m²)
- Accumulated fall (mm)
- Evaporation (mm)
- Battery state (V)

Mean wind speed varied from January 2006 until June 2007 between 0 y 11.6 m/s whereas air temperature between –5.3 °C y +36.1 °C.
Initial measurements (4 months)

CLOSED MODULE

Mean indoor radon concentrations:

- 42,000 Bq/m³ in CELLAR (MAX VALUE 120,000 Bq/m³)
- 7,000 Bq/m³ in FIRST FLOOR (MAX VALUE 40,000 Bq/m³)

- Increased indoor radon concentrations after heavy rain
- No significant influence of wind and temperature
- Inverse correlation with atmospheric pressure variations. Main factor
Remedial actions tested

Natural/Forced air extraction from soil with lateral and central pipe

Pressurization/depressurization of air within the soil with central pipe

Crossed ventilation in cellar

Insulation barrier
CENTRAL PIPE UNDER SOIL
Radon barrier
EFFECTIVENESS

Considerable radon reduction with all actions

MEAN RADON CONCENTRATION REACHED
1.700 Bq/m³ CELLAR
500 Bq/m³ FIRST FLOOR
**EFFECTIVENESS** (mean lowest level reached in Bq m$^{-3}$)

<table>
<thead>
<tr>
<th>Action</th>
<th>First floor</th>
<th>Cellar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central natural ventilation</td>
<td>600</td>
<td>1700</td>
</tr>
<tr>
<td>Lateral natural ventilation</td>
<td>2300</td>
<td>16000</td>
</tr>
<tr>
<td>Central forced extraction</td>
<td>250</td>
<td>400</td>
</tr>
<tr>
<td>Lateral forced extraction</td>
<td>700</td>
<td>1300</td>
</tr>
<tr>
<td>Central pressurization</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>Crossed ventilation</td>
<td>500</td>
<td>7200</td>
</tr>
<tr>
<td>Radon barrier</td>
<td>300</td>
<td>1700</td>
</tr>
</tbody>
</table>
WHOLE STUDIED PERIOD. 2006 AND FIRST SIX MONTHS OF 2007
CONCLUSIONS

.- THE RISK COMING FROM NATURAL RADIATION IS VERY DIFFICULT TO ACCEPT FOR THE AUTHORITIES WHICH FINALLY ARE SUPPORTING THE RESEARCH ACTIVITIES.

.- THE INCLUSION OF RADON AS ANOTHER INDOOR AIR POLLUTANT, IS VERY IMPORTANT BECAUSE THIS MEANS TO BE IN LAW AS A NATURAL WAY.
There is a lack of requirements concerning radon protection in the Spanish legislation for radon in houses BECAUSE in this case only exist a Recommendation 90/143/EURATOM with a design level value of 200 Bq/m$^3$. 
We kindly invite you to take part in

INTERNATIONAL INTERCOMPARISON EXERCISE ON NATURAL RADIATION MEASUREMENTS UNDER FIELD CONDITIONS

Organized by the Radon Group (University of Cantabria, SPAIN)

SUMMER 2011

Saelices el Chico
(Salamanca, Spain)

GRUPO RADÓN
Facultad de Medicina
Avda. Cardenal Herrera Oria s/n
39011 Santander
Cantabria (SPAIN)
Phone: +34 942 20 22 07
e-mail: laruc@unican.es
SINCERE THANKS FOR YOUR ATTENTION!