Radon, our radioactive roommate: past, present, and future

José - Luis Gutiérrez Villanueva

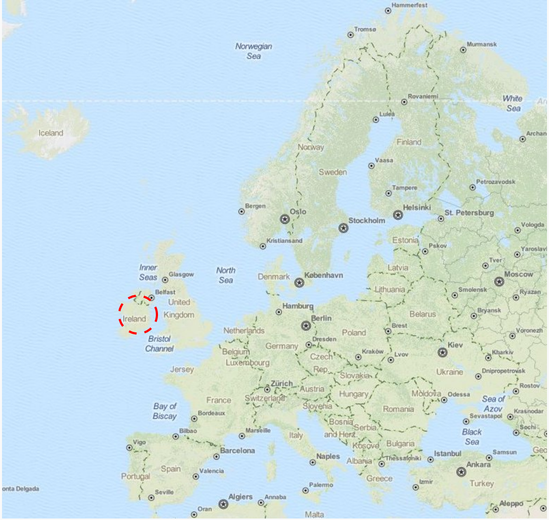
LaRUC, University of Cantabria (Spain)

27th January 2016

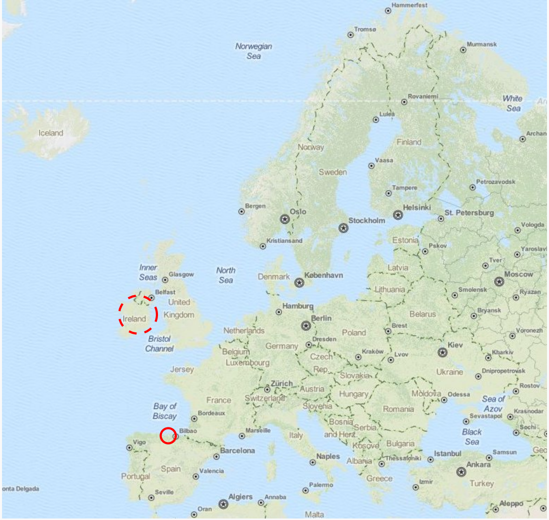
UC UNIVERSIDAD DE CANTABRIA LaRUC

Laboratorio de Radiactividad Ambiental

Location of LaRUC



Location of LaRUC



LaRUC: staff and interests

- 1 University Professor
- 1 Associated Professor
- 2 Post–doc researchers
- 2 PhD. students
- 1 MSc. student
- 5 laboratory technicians

What do we do ?

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Research: radon, gamma spec, gross alpha/beta, LSC

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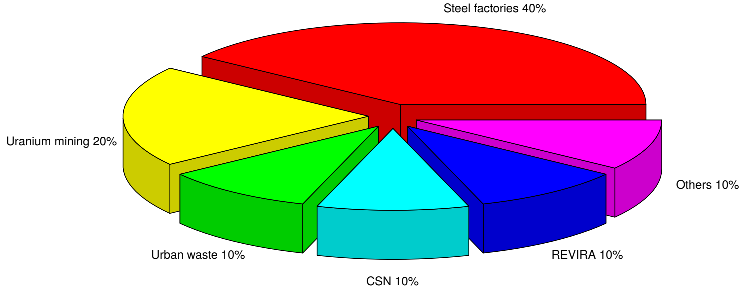
What do we do ?

Research: radon, gamma spec, gross alpha/beta, LSC
Teaching and training: university, private companies
Services: steel factories, waste treatment plant,ENUSA–ENRESA, advising

Resources


Steel factories 40%
Uranium mining 20%
Others 10%
Urban waste 10%
REVIRA 10%
CSN 10%

Quality assurance system

Public Health
England

This is to certify that

LaRUC
Departamento de Ciencias Medicas y Quirurgicas
Facultad de Medicina,
Avenida Cardenal Herrera Oria s/n
39011 Santander
SPAIN

is a validated laboratory for making measurements of radon concentrations in homes, having demonstrated that it meets the requirements given in HPA-RPD-047 for measurement accuracy and that it operates appropriate laboratory and reporting procedures.

This validation applies only to radon measurements in homes carried out using procedures that conform to the requirements of HPA-RPD-047.

This certificate is valid for twelve months from the date given below.

Date: 01 September 2014

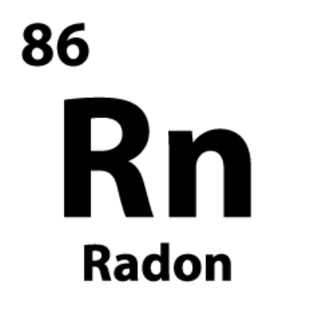
Quality assurance system

Quality assurance system

Coming soon . . . Accreditation ISO 17025

- Radon indoor measurements using SSNTD's
- Radon exhalation measurements
- Gross alpha/beta determination
- Gamma spectrometry in soil, liquid and sludge samples

Radon: a natural and radioactive gas ...



Credit: "DORN Friedrich Ernst" by Unknown - Unknown. Licensed under CC BY-SA 3.0 via Commons

Some characteristics . . .

- Natural RADIOACTIVE GAS
- Noble gas, inert, odourless and colourless
- Half life: 3.8 days
- Alpha emitter
- Daughters: some Alpha emitters of high energy

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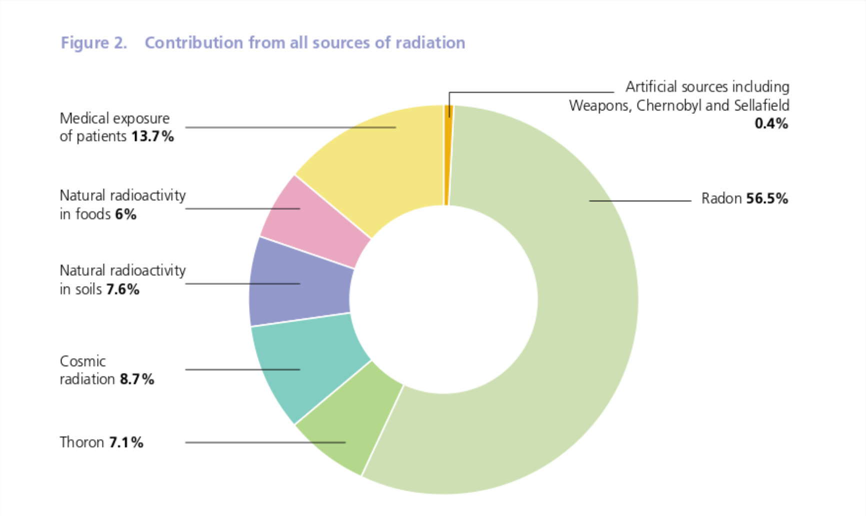
CARCINOGENIC AGENT

Some characteristics . . .

All radionuclides that emit α-particles and that have been adequately studied, including ^{222}Rn and its decay products, have been shown to cause cancer in humans (WHO (IARC): Volume 78 "Some internally deposited radionuclides")

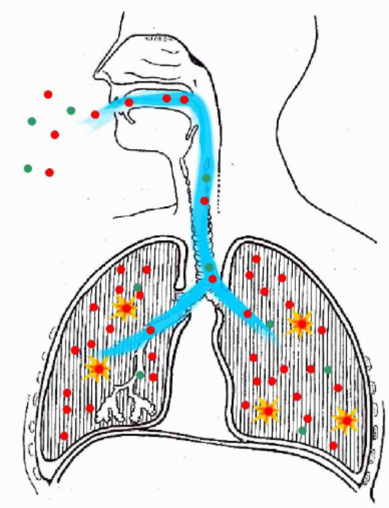
Find out if you are exposed to radiation from naturally high radon levels in your home. Take action to reduce high radon levels (European Code Against Cancer)

Sources of radiation



Credit: EPA Ireland

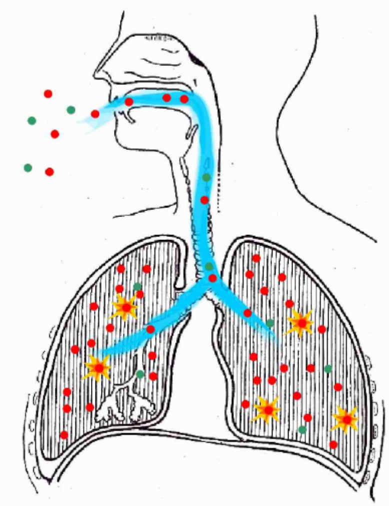
Health hazard . . .



Impact of radon daughters

- Radon daughters may be deposited on lungs
- Radioactive decay on epithelium's surface
- Emission of alpha radiation may damage the nucleus of the cell

Health hazard . . .



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Radon gas is the second leading cause of lung cancer after smoking

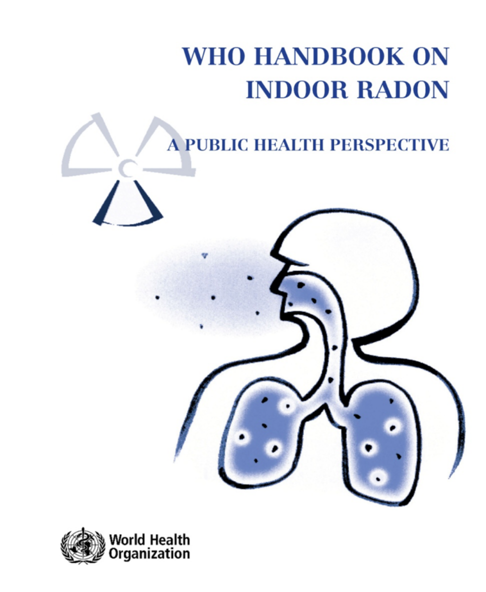
Health risk

There are two main approaches to the radon problem:

Epidemiological approach

Dosimetric approach

Epidemiological approach



Epidemiological approach

ELSEVIER

Annals of the ICRP

Effective dose from inhaled radon and its progeny

J.D. Harrison, J.W. Marsh

Health Protection Agency, Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, Oxon OX11 0RQ, UK; e-mail: john.harrison@hpa.org.uk

Dosimetric approach

- Estimation of dose per unit exposure from respiratory tract model
- Progeny retention period
- Weighting factor for alpha particles
- Sensibility of pulmonary tissue
- Weighting factors for each region
- Probability density function

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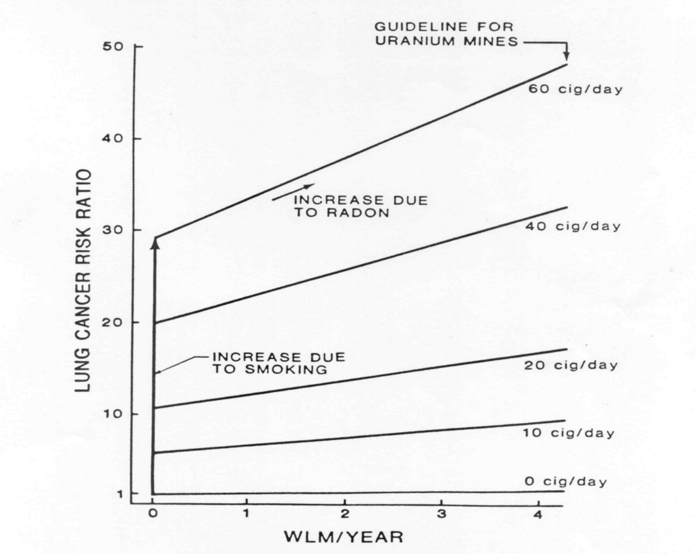
Applied to miner's conditions (Birchall 1994) 15 mSv WLM^{-1}
Applied to dwellings (Marsh 2002) 12 mSv WLM^{-1}

Some data to bear in mind



Relative risk

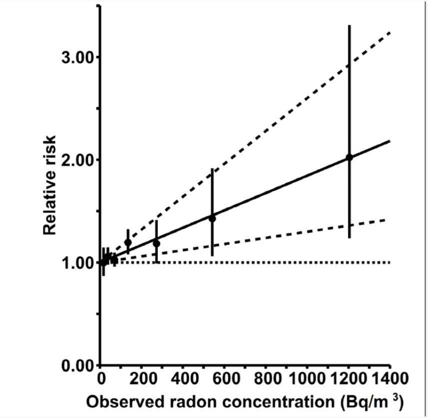
Table 16. Relative risk of lung cancer according to the categories of the time-weighted average observed residential radon concentration. (95% CI = 95% confidence interval)

Observed radon concentration[a]	Cases (N)	Controls (N)	Mean observed radon concentration	Relative risk[b]	95% CI[c]
<25 Bq/m³	566	1 474	17	1.00	0.87–1.15
25–49 Bq/m³	1999	3 905	39	1.06	0.98–1.15
50–99 Bq/m³	2618	5 033	71	1.03	0.96–1.10
100–199 Bq/m³	1296	2 247	136	1.20	1.08–1.32
200–399 Bq/m³	434	936	273	1.18	0.99–1.42
400–799 Bq/m³	169	498	542	1.43	1.06–1.92
≥800 Bq/m³	66	115	1204	2.02	1.24–3.31
Total	7148	14 208			

[a] Observed radon concentration for each address in the 30-year period ending 5 years prior to the index date weighted according to the length of time that the person lived there.
[b] Relative risks calculated after stratification by study, age, sex, region of residence, and smoking history. Risks scaled so that relative risk is 1.00 at 0 Bq/m³ on the assumption of a linear relationship, see the Statistical Methods section for details.
[c] Confidence intervals calculated using the method of floated variances.

S Darby et al. Scand J Work Environ Health 2006, vol 32, suppl 1

Relative risk



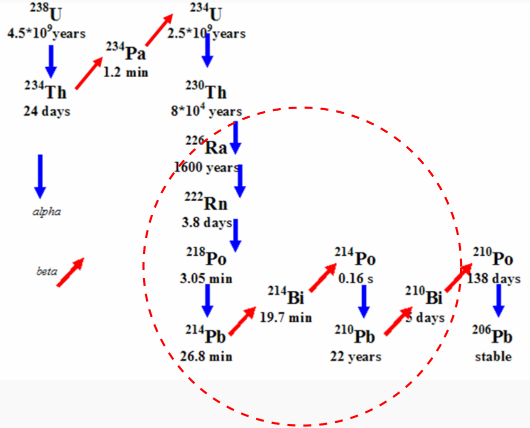
S Darby et al. Scand J Work Environ Health 2006, vol 32, suppl 1

Natural radioactive chains

Natural radioactive chains including radon isotopes

Family	Start	Gaseous isotope	End
Th	${}^{232}_{90}\text{Th}$ ($T_{1/2} = 1.4 \cdot 10^{10}$ y)	${}^{220}_{86}\text{Rn}$ ($T_{1/2} = 55.6$ s)	${}^{208}_{82}\text{Pb}$
Np	${}^{237}_{93}\text{Np}$ ($T_{1/2} = 2.1 \cdot 10^{6}$ y)	–	${}^{204}_{83}\text{Bi}$
U–Ra	${}^{238}_{92}\textbf{U}$ **(**$T_{1/2} = 4.5 \cdot 10^{9}$ **y)**	${}^{222}_{86}\textbf{Rn}$ **(**$T_{1/2} = 3.8$ **d)**	${}^{206}_{82}\textbf{Pb}$
U–Ac	${}^{235}_{92}\text{U}$ ($T_{1/2} = 7.0 \cdot 10^{8}$ y)	${}^{219}_{86}\text{Rn}$ ($T_{1/2} = 4$ s)	${}^{207}_{82}\text{Pb}$

Natural radioactive chains



Serie radiactiva natural del ^{238}U indicando el tipo de decaimiento radiactivo y la vida media

Radon daughters

- Four radon short living daughters: ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po
- Two of the radon daughters are alpha emitters (^{218}Po and ^{214}Po) and the others are beta emitters (^{214}Pb and ^{214}Bi)
- The equilibrium of the daughters is a major factor of concern when determining the dose delivered to the lung
- Equilibrium Equivalent Concentration (EEC): the radon concentration in equilibrium with its short living daughters, that would have the same potential alpha energy per unit of volume as the existing mixture

$$EEC = 0.105(C_1) + 0.516(C_2) + 0.379(C_3)$$

C_1, C_2 and C_3 are the concentrations of ^{218}Po, ^{214}Pb and ^{214}Bi respectively expressed in Bq m^{-3}

Radon daughters

Working Level (WL)

any combination of short living radon daughters in one litre of air that will result in the emission of $1.3 \cdot 10^5$ MeV, of potential alpha energy ($20.8\ \mu\mathrm{J\,m^{-3}}$)

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one WL is equivalent to 3700 Bq m^{-3} EEC. In order to calculate the potential alpha energy concentration (PAEC) in WL units from a particular radon concentration in EEC:

$$\mathrm{WL} = \mathrm{EEC}\ (\mathrm{Bq\ m^{-3}})/3700$$
$$\mathrm{WL} = \mathrm{EEC}\ (\mathrm{pCi\,l^{-1}})/100$$
$$\mathrm{J\,m^{-3}} = \mathrm{EEC}\ (\mathrm{Bq\ m^{-3}})/1.8{\cdot}10^8$$

Radon daughters

Working level month (WLM)

Radon daughters

Working level month (WLM)

Exposure rate of 1 WL for a working month of 170 hours. Thus, while a miner exposed to 1 WL during a working year accumulates 12 WLM, a member of the population with continuous exposure to 1 WL accumulates about 50 WLM

$$WLM = WL\left(\frac{\text{Hours exposed}}{170}\right)$$

Radon risk: attached and unattached fraction

Table 2. Average dose conversion factor (DCF) for the inhalation of unattached (DCF_u) and aerosol attached (DCF_{ae}) radon decay products in air of human living places arranged accordingly to aerosol conditions, relative cancer sensitivity distribution of the bronchial (w_{BB}), bronchiolar (w_{bb}) and alveolar (w_{AI}) regions of the thoracic lung, v = inhalation rate, Z = particle concentration of the aerosol.

Place	Particle concentration Z (10^3 cm^{-3})	Nose breathing v (m^3 h^{-1})	DCF (mSv WLM^{-1}) ($DCF_u + DCF_{ae}$)	
			$w_{BB} = w_{bb} = w_{AI} = 0.33$	$w_{BB}:w_{bb}:w_{AI} = 0.8:0.15:0.05$
Outdoor air	20–40	1.2	13.2 (0.6 + 12.6)	9.7 (1.5 + 8.2)
Dwellings	5–40	0.75	8.3 (1.0 + 7.3)	7.3 (2.4 + 4.9)
	40–500	0.75	6.1 (0.1 + 6.0)	4.2 (0.2 + 4.0)
Working places	1–10	1.2	12.0 (3.0 + 9.0)	13.0 (7.0 + 6.0)
	10–50	1.2	8.6 (0.6 + 8.0)	6.7 (1.5 + 5.2)
	50–500	1.2	8.2 (0.2 + 8.0)	5.7 (0.5 + 5.2)
	50–500	1.7	10.3 (0.3 + 10.0)	7.2 (0.7 + 6.5)

Reinniking-Porstendorfer, 1997

Equilibrium factor

The short living radon daughters will come into equilibrium with radon in an effective half-life of 30 minutes

Equilibrium Factor (F)

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Equilibrium Factor (F)

The ratio to potential alpha energy concentration in the existing mixture to that which would exist if all short living radon daughters were in equilibrium with radon.

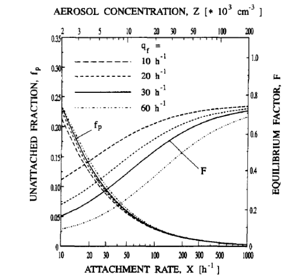
$$\mathrm{F} = \frac{\mathrm{WL} \cdot 3700}{\mathrm{Rn\,Concentration}}$$

$$\mathrm{F} = \frac{\mathrm{EEC}}{\mathrm{Rn\,Concentration}},$$

with the two concentrations expressed in the same units ($\mathrm{Bq\,m^{-3}}$)

Equilibrium factor

The removal from the atmo- sphere by deposition on surfaces is limited only to the unattached fraction
the behaviour of the attached fraction of radon short living daughters is controlled by the aerosol particles



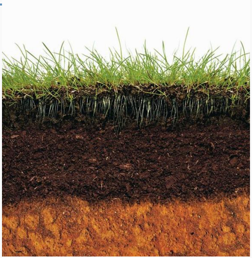
Equilibrium factor (F) and unattached fraction (f_p) for radon daughters as a function of attachment rate (X) and aerosol concentration (Z). Taken from Porstendorfer1994

Equilibrium factor

- Aerosol particles: a log-normal distribution described in terms of the activity median diameter and its geometric standard deviation
- Particle distribution can be modified by cooking, space heating, smoking or ultrasonic humidification
- Equilibrium factor can be measured and values are within a wide range
- Radon concentration has daily variations . . . equilibrium factor is more constant
- ICRP65: equilibrium factor of 0.4 and occupancy rate of 0.8 (equivalent to 7000 hours in case of dwellings and 2000 hours in case of workplaces)

Radon sources

Soil



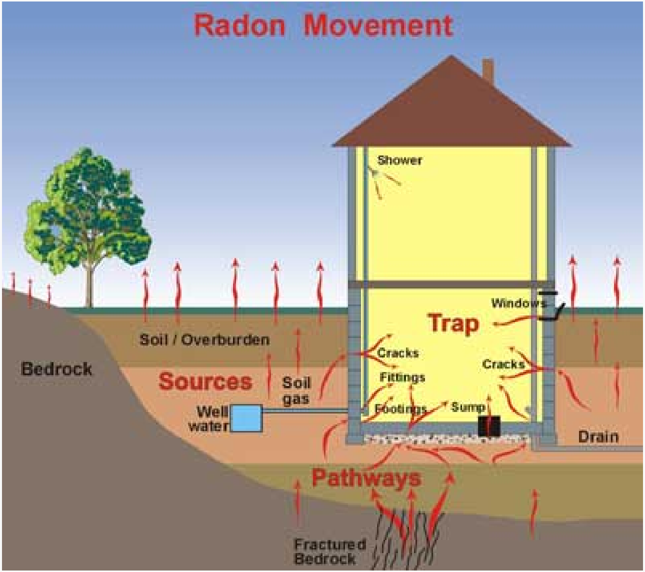
Building materials

Water

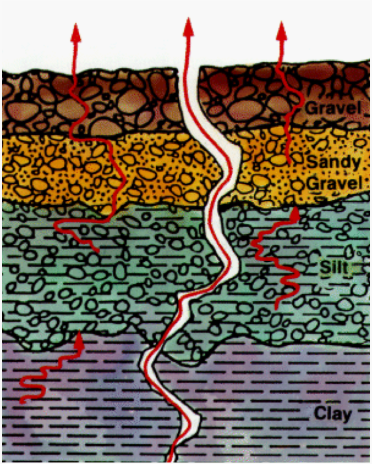
Radon transport

Diffusion	Differences on radon concentratrions
Convection	Differences on pressure between two different zones (i.e, underground soil and ground floor)

Radon transport



How does radon gas move?



Impact of radon daughters

- Radon can migrate into soil pores: EMANATION
- Radon can scape from the soil into the air: EXHALATION
- Main factors that affect radon's displacaments: porosity, permeability and soil moisture

Remedial actions

Cost and effectiveness of some remedial action used to decrease radon levels in a building

Method	Cost	Effectiveness
Soil depressurisation	Moderate	High
Floor sealing	Moderate	Moderate
Water treatment	Moderate	High
Subsoil removal	High	High
Increased ventilation	Moderate	Low
Increased air movement	Low	Low

The new Basic Safety Standards (BSS)

This document introduces radon gas into the system of radiological protection for the rst time

- The council of European Union issued the nal document in January 2014
- It aims to a better protection for both: public and workplaces
- Radon reference levels: 300 Bq m^{-3}
- Occupational exposure arrangements in workplaces
  - $>$6 mSv y^{-1} Situation to be managed as a planned exposure situation
  - $\leq$ 6 mSv y^{-1} Exposures need to be kept under review
- Establishment of a national radon action plan

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National action plans are needed for addressing long-term risks from radon exposure . . .

Where, . . . , a Member State establishes a reference level for indoor radon concentrations in workplaces that is higher than 300 Bq m^{-3}, the Member State should submit the information to the Commission . . .

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- Article 74: Member States shall establish national reference levels for indoor radon concentrations. The reference levels for the annual average activity concentration in air shall not be higher than 300 Bq m^{-3}
- Article 103: Member States shall establish a national action plan addressing long-term risks from radon exposures in dwellings, buildings with public access and workplaces for any source of radon ingress . . . The action plan shall take into account the issues set out in Annex XVIII

The new Basic Safety Standards (BSS): Annex XVIII

List of 14 items to be covered:

- Estimation of indoor radon concentrations (surveys indoor radon, radon in soil gas)
- Criteria to identify areas with high radon exposure
- Reference levels: dwellings and workplaces
- To assign responsibilities in the administration
- Strategies to reduce radon exposure: prevention, remedial actions
- Revisions and updates of the action plan
- Strategy to communicate radon risk
- Guidance on methods
- Financial support

ICRP Main Commission Meeting April 13–17 Sydney

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

ICRP ref: 4821-2831-8499
Released April 23, 2015

ICRP Main Commission Meeting
April 13-17, 2015 – Sydney, Australia

A full year had passed since the last meeting of the Main Commission. Many items of importance had been decided during the interim, including: approval to publish in the Annals of the ICRP **Radiation Dose to Patients from Radiopharmaceuticals: A Compendium of Current Information Related to Frequently Used Substances**, **Radiological Protection in Ion Beam Radiotherapy**, **Radiological Protection in Cone Beam Computed Tomography (CBCT)**, and **Stem Cell Biology in Relation to Carcinogenic Radiation Risk**; and establishing **Task Group 97 Application of the Commission's Recommendations for Surface and Near Surface Disposal of Solid Radioactive Waste**, and **Task Group 98 Application of the Commission's Recommendations to Exposures Resulting from Contaminated Sites from Past Industrial, Military and Nuclear Activities**.

Progress on the calculation of **dose coefficients** was reviewed, in particular for exposure to **radon-222** and progeny. There is a remarkable consistency between radon dose coefficients obtained by dosimetric calculations and conversion coefficients based on epidemiological comparisons. In an upcoming publication, the Commission intends to recommend a single coefficient for use in most circumstances, with a value of 12 mSv/WLM (3.4 mSv per mJ h m^{-3}). Additional data will be provided for circumstances significantly divergent from typical conditions where sufficient and reliable information is available to support an adjustment.

Task Group 99 on Reference Animals and Plants (RAP) Monographs was established to gather and update basic data and guidance on RAPs for application of the system of radiological protection.

Many aspects of **governance** were considered, including review of: the Constitution, the Strategic Plan, election procedures, arrangements for formal relations, financial matters, and the ongoing and future programme of work of all five Committees.

The Main Commission met with members of the **Minerals Council of Australia**, and the **Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)**. The half-day session, webcast live to several ARPANSA offices, focused on aspects of radon exposure, and low dose radiation management.

Plans for ICRP 2015, the **3rd International Symposium on the System of Radiological Protection**, to be held in Seoul, Korea, October 20-22, 2015, were reviewed, including the scientific programme to include sessions related to ICRP's programme or work, existing exposure situations, medicine, dose calculation, radiation effects, and ethics in radiological protection. Registration is now open, and full information is available at www.icrp2015.com.

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www.icrp.org

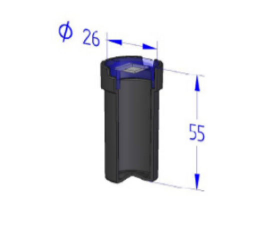
How can we measure our roommate?

- Passive systems

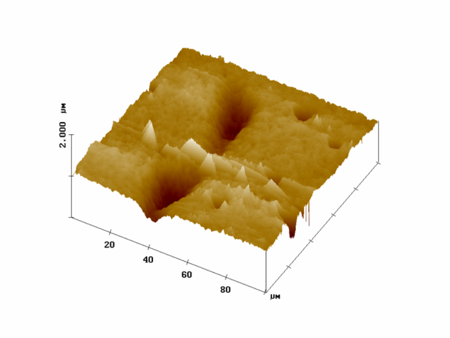
  SSNTD's (Solid State Nuclear Track Detectors)
  Charcoal canisters
  Liquid Scintillation counting
  Electret ion chamber
  Lucas cells

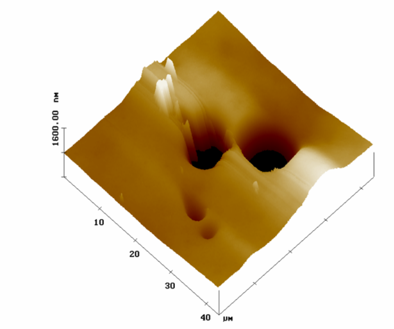
- Active devices

SSNTD's



SSNTD's





Charcoal canisters

LSC

Electrets


E-PERM®
"ELECTRET RADON MONITOR"
SYSTE
6
4.853.536. 4.926.053. 4.992.658. 5.008.540
5.126.567. 5.128.540

Lucas cells

Active devices

Active devices

Active devices

Active devices

Active devices

Active devices

Active devices

Radon can be use as a tracer

- ATMOSPHERIC PROCESS: TRANSPORT AND DIFUSSION
- SEISMIC ACTIVITY AND ACTIVE FAULTS
- CONTAMINATION OF SOILS: L-DNAPLs
- AQUIFERS
- VENTILATION OF CAVES

Atmospheric process

J. Aerosol Sci., Vol. 14, No. 4, pp. 495–498, 1983.
Printed in Great Britain.
0021–8502/83 \$3.00 + 0.00

DETERMINATION OF RADON DAUGHTER PRODUCTS NEAR LAND–SEA DISCONTINUITIES BY GAMMA SPECTROMETRY

L. S. QUINDOS, J. SOTO and E. VILLAR

Fundamental Physics Department, Science Faculty, University of Santander, Spain

(*Received* 25 *October* 1982)

Abstract—The low number of experimental measurements of the levels of radon daughter products in the air near exhalation source discontinuities has led us to carry out a long series of measurements of these levels. The correlations between these levels and different meteorological parameters have been studied.

1. INTRODUCTION

Determination of the concentrations in the air of short-life radon (Rn-222) daughter products is important in as much as it has a bearing on a wide variety of problems relating to the environment. Problems such as the irradiation of mineworkers' lungs, the origin and trajectory of air masses or the washing of atmospheric aerosols by rainfall (Wilkenning *et al.*, 1976; Stranden, 1979) may be studied by determining the concentrations in the environment of short-life radon daughter products (Bouville *et al*, 1971; Subba *et al.*, 1969). Therefore, in view of the low number of experimental works to be found in the bibliography with respect to the measurements of these elements close to land–sea discontinuities, we have carried out a series of measurements of the concentrations in the air close to the ground of short-life gamma emitting radon daughter products.

2. EXPERIMENTAL METHOD

The measurements were carried out close to the Science Faculty of the University of Santander (Spain), located some 500 m from the sea in a semi-built-up area, with an undulating layer of lawn cover. Radon daughter products were captured by filtration, an airflow being directed through a Whatman 41 filter with a surface area of 440 cm^2. A suction pump produces a flow through the filter of 100 m^3/hr which, given the area of the filter, generates a through flow speed sufficient to ensure a 100% retention in the filter of those aerosols of the size in which radon daughter products become fixed (Dueñas, 1976). The filtration time was 30 min. Samples were taken in the early morning, the air intake being placed at a height of 1.5 m above ground level.

To measure the activity of the radon daughter products trapped in the filter, we used gamma spectrometry. For this purpose, we used a 3×3 in. NaI (Tl) scintillation detector connected to an amplifier, this in turn being coupled up to an Intertechnique Histomat multichannel analyzer which analyzes the activity found in the samples, the results being shown either directly on an oscilloscope screen or through a teleprinter. The detector was placed within a lead sheath, the internal dimensions of which were $60 \times 60 \times 60$ cm, the walls being 10 cm thick and internally lined with sheets of zinc and cadmium to reduce background noise and the X-ray contribution of the lead. The filters were cut to a fixed geometry and placed on the upper face of the detector. The spectrometry chain was calibrated by means of an Ra-226 sample in equilibrium with its daughter products, with a known activity and possessing the same geometry as the filters.

To calculate the activity in the air of radon daughter products, we worked on the hypothesis that the radiactive equilibrium between the first, Po-218 or Ra A, and the second, Pb-214 or Ra B, daughter products is checked in the place of measurement. This hypothesis, a reasonable one by virtue of the different half-lives of the two elements, adds a condition to the

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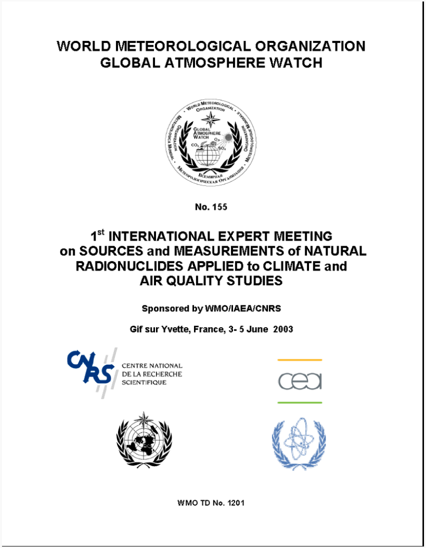
Atmospheric process


WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH

No. 155

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Seismic activity

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

April 16, 2009

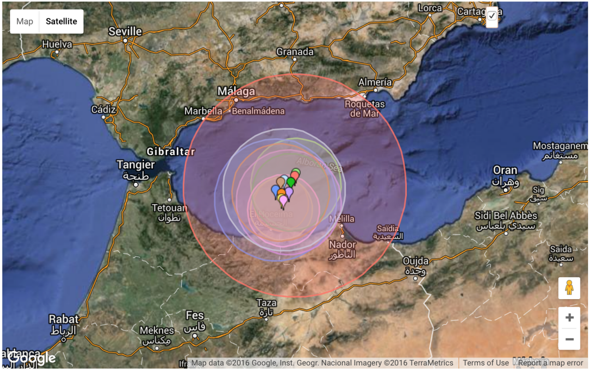
Can radon gas measurements be used to predict earthquakes?

After the tragic earthquake of April 6th 2009 in Aquila (Abruzzo), a debate has begun in Italy regarding the alleged prediction of this earthquake by a scientist working in the Gran Sasso National Laboratory, based on radon content measurements. Radon is a radioactive gas originating from the decay of natural radioactive elements present in the soil.

IRSN specialists are actively involved in ongoing research projects on the impact of mechanical stresses on radon emissions from underground structures[1], and some of their results dating from several years ago are being brought up in this debate[2]. These specialists are therefore currently presenting their perspective on the relationships between radon emissions and seismic activity, based on publications on the subject.

Seismic activity

We are always late . . .



- about 5 hours ago 4.2 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 8 hours ago 4.4 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 9 hours ago 4.9 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 15 hours ago 4.7 magnitude, 2 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 17 hours ago 5.3 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 18 hours ago 5.1 magnitude, 12 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 19 hours ago 4.6 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 19 hours ago 5.3 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 19 hours ago 5.0 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco
- about 19 hours ago 6.1 magnitude, 10 km depth
  Al Hoceïma, Taza-Al Hoceima-Taounate, Morocco

From http://earthquaketrack.com/p/spain/recent

L-DNAPLs

Characteristics

- Non-Aqueous Phase Liquids
- They can stay in the soil in non-aqueous phase due to their low solubility
- It is a multiphase problem
- Organic compounds: Low density (i.e, petrol, L-NAPLs) or high density (i.e, solvents, D-NAPLs)

L-DNAPLs

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Field validation of radon monitoring as a screening methodology for NAPL-contaminated sites

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ABSTRACT

Screening methodologies aim at improving knowledge about subsurface contamination processes before expensive intrusive operations, i.e. drilling and core-sampling, well installation and development, sampling of groundwater and free-phase product, are implemented. Blind field tests carried out at a hydrocarbon storage and distribution center in NE Spain suggest that Rn monitoring can be effectively used to locate the boundaries of subsurface accumulations of NAPLs. Sixty seven measurements of Rn in soil air were performed with a SARAD RTM 2100 current-ionization alpha-particle spectrometer following a 10 m square grid. Reductions of ^{222}Rn concentration above a pool of LNAPL due to the preferential partition of Rn into the organic phase were spatially analyzed and resolved to yield the surface contour of the NAPL source zone. This surface trace of the source zone agreed well with the extent and situation inferred from measurements of free-phase thickness taken at eight monitoring wells at the site. Moreover, the good repeatability (as measured by replicate measurements at the same sampling point) and spatial resolution of the technique suggest that the boundaries of the plume can be delineated at the sub-decametre level.

Aquifers

Journal of Hydrology 406 (2011) 148–157

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Radon and CO_2 as natural tracers to investigate the recharge dynamics of karst aquifers

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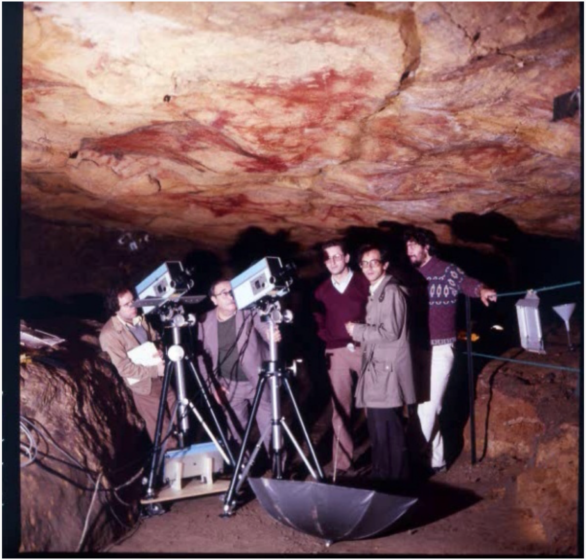
Ventilation of caves



Ventilation of caves

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Natural ventilation of the Paintings Room in the Altamira cave

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The Altamira cave (Santillana del Mar, Santander, Spain) is famous for the ceiling of one of its chambers, the Paintings Room, which is decorated with palaeolithic paintings. However, the massive influx of visitors resulted in deterioration of these rupestrian paintings and the cave was closed in 1977 to determine both the causes and the maximum number of visitors that could visit the cave without putting the paintings at risk[1–3]. The natural ventilation of the Paintings Room is one of the most important factors in formulating the maximum occupational index for visitors to the cave. The emission of carbon dioxide and water vapour by visitors inside the chamber is directly proportional to the number of visitors and the time spent in the room. By ventilating the room, these components should be removed from the air within a short period of time, thus returning the chamber to the prevailing conditions before visitors were allowed in. We report here variations in the ^{222}Rn concentration in the air of the Paintings Room which we use as a quantitative index of the natural ventilation existing in this chamber. We carried out parallel studies of the temperature at different points in the cave and the evolution of the carbon dioxide concentration in the air of the Paintings Room, and hence established the maximum number of people per hour that should be allowed to visit this chamber.

Radon-222 is a noble gas of the radioactive series of ^{238}U, an element that occurs in rocks in the Earth's crust with a concentration between 2 and 5 p.p.m. (parts per 10^6). Because of its gaseous nature and its greater concentration within the Earth, radon escapes through the interstices of the soil to the atmosphere, with an exhalation rate of ~ 1 atom $c^{-2}\,s^{-1}$. When this exhalation occurs in places with little ventilation, the radon concentration of the air may be high.

The ^{222}Rn concentration of the air of the Altamira cave was measured by scintillation cells with a capacity of 500 cm^3, in which a vacuum had been created down to a pressure of 50 torr. These scintillation cells were made of transparent plastic and their internal walls were covered with a film of SZn(Ag). The emission of α radiation by the radon ($t_{1/2} = 3.8$ days) contained in the air filling the cell leads to this radiation falling onto the film of SZn(Ag), where it produces fluorescence. The light thus emitted can be detected using a photomultiplier tube and the pulses produced can be recorded.

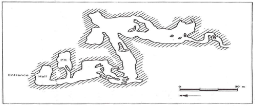

Fig. 1 Map of Altamira cave. PR, Paintings Room.

Because two of the short-lived radon daughters, ^{218}Po and ^{214}Po, are also α emitters, their contribution to the total counting supplied by an air sample increases with time until a radioactive equilibrium is reached between the radon and the two daughters. This equilibrium is reached 3 h after the sample is taken only if, initially, radon gas was present in the air sample. Therefore, to calculate the radon concentration, we carried out a 10-min counting 3 h after the collection of the air sample assuming that there was a radioactive equilibrium between the radon and its daughters. The number of counts obtained from the scintillation cell when empty was subtracted from each measurement resulting from fluorescence of the SZn(Ag).

The ^{222}Rn concentration was measured in two chambers within the cave: the Hall chamber, located at the entrance to the cave; and the Paintings Room (see Fig. 1). Measurements were made three times per week over a period of 1 yr between February 1983 and January 1984. From these results, we calculated the monthly average radon concentrations (Table 1).

To calculate the natural ventilation in the Paintings Room from the radon concentrations, we used the simplified model proposed by Wilkening[4], which is based on the fact that the temporal variation in the radon concentration (C) in the air of this chamber can be expressed as the sum of the production caused by radon exhalation from the rock surfaces, the radioactive decay and the radon loses resulting from the natural ventilation:

$$\frac{dC}{dt} = E\frac{S}{V} - \lambda C - \frac{Q}{V}(C - C_h) \qquad (1)$$

where E is the radon exhalation rate, S and V the surface and volume of the Paintings Room, respectively, Q the ventilation rate in this chamber, λ the radon decay constant and C_h the radon concentration in the Hall chamber.

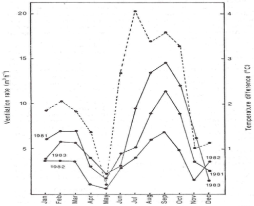

Fig. 2 Variations in the ventilation rate (dashed line) and the temperature differences (solid lines) between the Paintings Room and the Hall chamber.

ERA

European Radon Association

- When did it all start? INTERNATIONAL INTERCOMPARISON ON NATURAL RADIATION UNDER FIELD CONDITIONS (Ciudad Rodrigo, Salamanca – Spain, May 2011) and ROOMS 2008.
- ERA was launched in May, 2013: founding assembly (Bouillon, Belgium) May 28 2013. 48 participants in the assembly
- I ERA WORKSHOP: May 29 2013 "International and national radon regulations and strategies" (Bouillon, Belgium)
- So far: Seven meetings ERA executive Committee: Prague, Brussels, Stockholm, Dublin

Key objectives of ERA

1. To assist in reducing the health burden from radon in Europe
2. To promote public awareness about radon
3. To encourage the development of quality standards in indoor radon metrology, remediation, prevention and control technologies
4. To provide a communication network for all radon professionals and other relevant groups
5. To serve as a consultative body to national and international agencies in all matters relating to the reduction of the risk from exposure to radon
6. To assist in the organization of radon conferences and workshops and to contribute to education and training in all aspects of the radon field

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European Radon Association

ERA
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Improving Awareness and Reducing Risk of Radon Exposure Across Europe

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There is a large and growing community in Europe of professionals such as scientists, technologists, public health officials and decision makers working in the radon field. Their areas of interest range from epidemiology, radiation dosimetry, instrument development and measurement protocols, remediation and prevention construction technologies to control strategies and regulation.

In recognition of this the European Radon Association (ERA) has been formed aimed at serving the interests of the European radon community and to assist in reducing the health burden of Radon Exposure in Europe.

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and

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25th - 29th April 2016
Ciudad Rodrigo (Salamanca, Spain)

Thank you – go raibh maith agat