Exposure to Ionizing Radiation and Dangerous Substances inside Buildings Related to Construction Products

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Summary: *The use of many materials of geological origin and recycled materials in the construction of buildings faces an increasing demand and stricter regulation for quality control. Construction products are requested to meet safety standards including those for radon exhalation and gamma radiation emission, amongst other dangerous substances, because if unchecked they could deteriorate the quality and safety of the indoor environment. Construction products shall pass testing for radioactivity in order to meet those standards and to maintain a high ranking position in the international markets.*

Keywords: *construction products, radon, radioactivity, quality of construction products*

1 Introduction

All populations are in general exposed to ionizing radiations. Radiation doses vary according to latitude, altitude, diet composition, and, above all, with exposure to radon. Radon (^{222}Rn) is a radioactive noble gas with a half life of 3.8 days. It originates in the disintegration of radium (^{226}Ra) (Figure 1). This element belongs to the uranium series and in Nature it is present especially in intrusive igneous rocks formed in the late stages of magmatic differentiation. Part of the radon gas escapes from the lithosphere to the atmosphere. The inhalation of radon with the air exposes humans to radiations from the radioactive decay of radon and short lived radon daughters. In Western Europe radon contributes to 50% of the total radiation exposure of population which amounts to an average of 2.4 mSv per year. However, in certain regions, this radiation dose can be 4 or 5 times higher (UNSCEAR, 2000). The exposure to internal and external sources of ionizing radiation integrating the natural radiation background is part of human life and, frequently, it is not feasible or even necessary to reduce it. However, this may be needed when additional radiation doses impinge on people due to anthropogenic changes in the natural radioactive background.

The long term exposure to radon inside buildings in radon prone areas, gives rise to accumulated high radiation doses. Studies performed in USA and in Northern and Central Europe have shown that chronic exposure to high levels of radon are related to higher rates of lung cancer (UNSCEAR, 2000). Radon concentration inside buildings depends upon local geology, typology of the buildings and high concentrations of uranium and uranium daughters in the soil under the construction. Construction products used in the buildings can also contribute to the radiation dose. In fact, the raw materials used in the construction may have a mineral composition which may vary in radionuclide concentrations. Besides radon, construction products may contribute also to the external exposure with gamma radiation from their content in radio nuclides. This concern was the basis for EU Directives to recommend maximum admissible values to radon exposure as well as to advice on the strict selection of construction products.

Products, such as cement, gypsum, tiles, and other ceramic products and, in particular ornamental rocks used in the interior of buildings, may become important sources of ionizing radiation when high concentrations of radio nuclides from uranium and thorium families are present in those materials..

2 Population exposure to ionizing radiations

The exposure of human population to ionizing radiations has been investigated with increasing attention. The populations of Western Europe, including the Portuguese population, are mainly exposed to natural sources of ionizing radiations. The exposure to artificial sources, excepting medical exposure, generally gives a low contribution to the individual effective dose. For the population in general, most of the exposure to radiation is due to inhaled radon followed by gamma rays emitted by radio nuclides in soils, construction materials, and cosmic radiation.

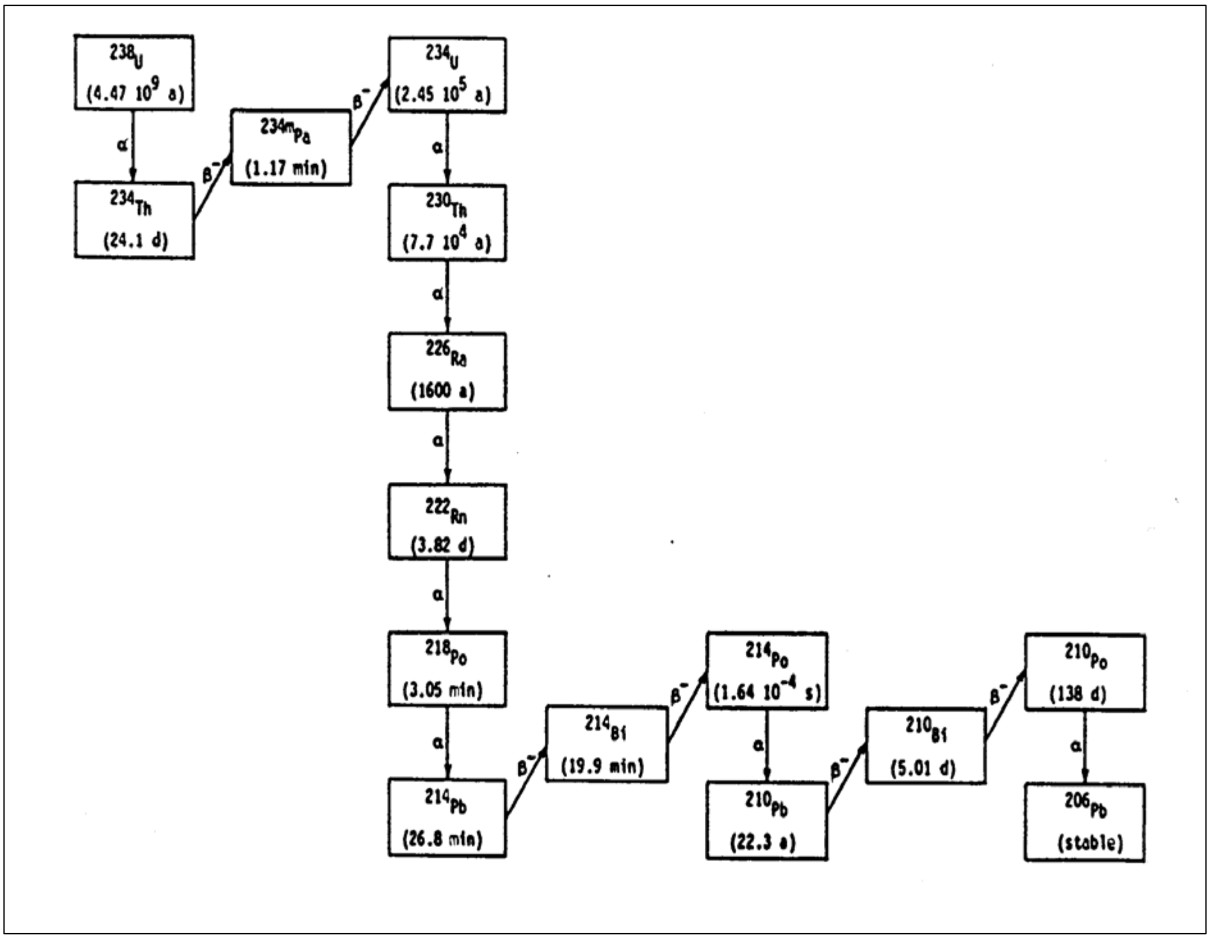


Figure 1. Uranium family (^{238}U). Decay mode and half-life of uranium and uranium daughters.

3 Ionizing radiations in buildings

The built environment may contribute significantly to additional doses of radiation above the naturally occurring radiation background. Current knowledge on the biological effects of ionizing radiation indicates that additional radiation doses may be detrimental to human health. As a consequence, recommendations have been made by the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA) and by the Radiological Basic Safety Standards (EU Directive 96/29 Euratom) to diminish the exposure of members of the public and workers to ionizing radiation. Radiation dose limits have been approved also by regulations. Therefore, it is of the utmost relevance to determine the radioactivity of the built environment and of the construction products in such a way that these products can be used without jeopardising the compliance of the EU essential requirement on hygiene, health and environment by the construction works where they are incorporated, as laid down in the corresponding regulations enforced in EU member states.

3.1 Radioactivity of construction materials

The analysis of some construction materials used in Portugal gives a preliminary account of the range of common radio nuclide concentrations (Table 1). Intrusive rocks, such as granites, have higher concentrations of U, ^{226}Ra and ^{232}Th, followed by limestone and sandstones. For comparison purposes, one may note that agricultural soils from the Tagus valley may contain 50 to 70 Bq kg^{-1} of ^{238}U and ^{226}Ra, similar to concentrations measured in many construction materials, but much lower than some specific construction products (Carvalho *et al.*, 2004).

The external radiation dose rate due to radio nuclides in soils in Portugal is 84.8 nGy h^{-1} (0.10 mSv year^{-1}). This dose varies amongst regions, from 31 nGy h^{-1} in Faro to 145 nGy h^{-1} in Braga (Amaral *et al*., 1992).

The external radiation dose rate inside buildings, at home and in workplaces, is not fully known in Portugal yet. The available data indicate an average of 105 nGy h^{-1} (0.51 mSv ano^{-1}) from radio nuclides in the Earth crust and in the construction materials (Amaral *et al.*, 1992).

3.2 Radon in outside air and inside buildings

Inhalation of radon exposes lungs and other internal organs to the alpha and beta particles emitted by the radioactive decay of radon and radon short lived progeny (Figure 1).

Over the years the Department of Radiological Protection and Nuclear Safety (DPRSN) of the Nuclear and Technological Institute (ITN) performed research on atmospheric radon and on radon inside houses (Carvalho, 1995; Faísca, 1995). In the Lisbon area the average concentration of radon in outside surface air is about 1 Bq m^{-3} (0.1 – 10 Bq m^{-3}), and depends on weather conditions and origin of air masses. The average radon concentration inside the houses in Lisbon is about 10 Bq m^{-3} but may vary between <6 and 85 Bq m^{-3} with the construction products used and with other parameters.

A survey of radon concentrations around the country inside public buildings and in rural and urban houses has shown that in most regions radon concentrations are lower then 50 Bq m^{-3}. However, there are regions where average indoor radon concentrations can be above 400 Bq m^{-3} and even, in exceptional cases, above 1000 Bq m^{-3} (Figure 2).

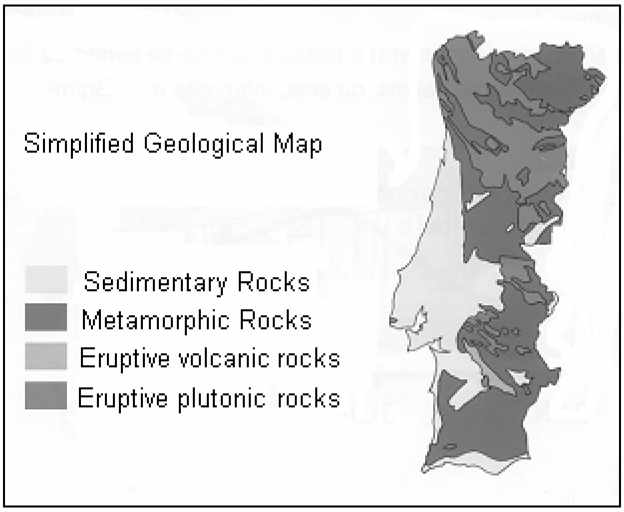
The concentration of radon inside buildings is, in some areas, 30 times higher than in the outside air. This difference is enhanced in the basements or in rooms with poor ventilation especially in winter time.

3.3. Building performance

Radon concentration inside buildings varies according to certain factors. One factor is the lithological environment under the construction, and when it is granite generally gives rise to the highest radon concentrations (Figure 2). Other important factors are the way as the building is settled in the ground, the room ventilation, the distance to soil and the construction products used.

It was observed, for instance, that in tall buildings radon concentrations decrease from the basement to the highest floor. Several studies pointed out the importance of ground level isolation in order to prevent the seepage and build up of radon in the indoor air. The levels of radon from the ground can be drastically reduced by simple constructive measures such as the ground floor isolation with a non permeable membrane, the existence of a sub-floor void and the use of mechanical ventilation (Figure 3). Radon levels inside can be decreased further by using construction products with low ^{226}Ra content (Table 1).

The knowledge of the regional radon background is relevant for planning appropriate measures to prevent and to reduce the build up of radon inside the buildings.



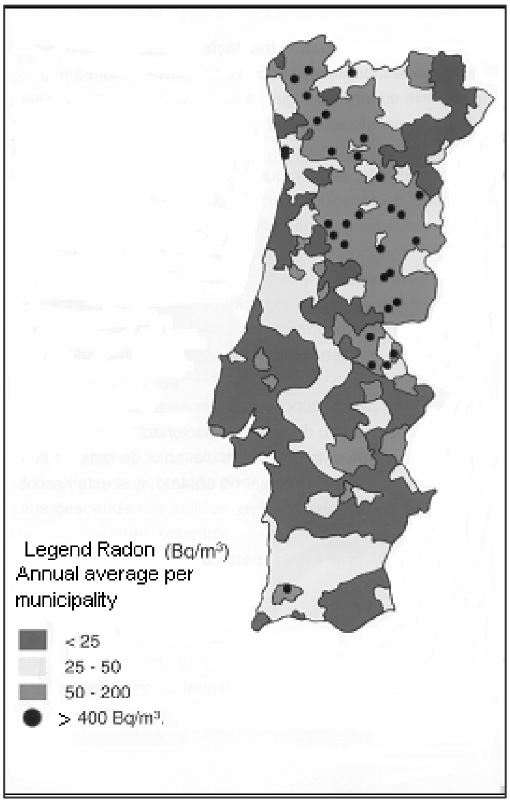


Figure 2. Geological map and distribution of radon concentrations inside houses

(Source ITN/DPRSN, 2002).

Table 1. Concentrations of naturally occurring radio nuclides (Bq kg^{-1} dry weight) in construction products marketed and used in Portugal.

Material	U total [a]	^{232}Th	^{226}Ra	^{40}K
Sandstone	41 ± 3	49 ± 1	26 ± 0.5	298 ± 16
Limestone	20 ±1	2.8 ± 0.3	10 ± 0.5	< 33
Marble	28 ± 2	4.7 ± 0.3	16.6 ± 0.5	67 ± 6
Granite	65 ± 7	106 ± 3	68 ± 2	1205 ± 25

[a] Sum of ^{238}U, ^{235}U, ^{234}U concentrations

Table 2. Concentrations of naturally occurring radio nuclides (Bq kg^{-1} dry weight) in industrial by-products that occasionally may be incorporated in or used as construction materials.

Material	U total [a]	^{232}Th	^{226}Ra	^{40}K
Phosphogypsum	2006 ± 100	30 ± 9	1400 ± 26	< 33
Coal ashes	*na*	144 ± 6	107 ± 5	272 ± 13
Sand from mining residues	2573 ± 300	< 98	15700	1480 ± 60

[a] Sum of ^{238}U, ^{235}U, ^{234}U. *na*, not analyzed

3.4 Other dangerous materials

In the construction sector market, materials with high radioactivity content such as phosphogypsum, a by-product obtained during the production of phosphoric acid and phosphate fertilizers, may appear. Besides the high acidity, this material contains also high uranium and radium concentrations which were already present in the original raw material (Table 2). Radionuclide concentrations in phosphogypsum may reach values as high as 1000 Bq kg^{-1} of ^{238}U (Carvalho, 1995). If used as wall renders, for instance, this gypsum with high uranium content would be an important radon source. Therefore, it is not an acceptable raw material on the grounds of radiological protection.

The use of old uranium mine dump materials, including sand and gravels, has been sometimes problematic in the North-centre region of Portugal. Due to the lack of surveillance of those abandoned mining sites, some contractors and even individual people have repeatedly used this dump material in public and private works ignoring the inherent risks for public health. This happened recently in some towns such as Cubos (Mangualde) and Gouveia, where mining residues were used in public sanitation works. This kind of materials may contain variable radionuclide concentrations, ranging from low values equivalent to the radioactive background up to very high concentration values (Table 2) (Carvalho *et al.*, 2004b)

In present days much of the iron and steel used in construction comes from recycling processes and, therefore, the metallic off scouring market is presently an international profitable business. However, some of these metallic wastes may be contaminated if they come from recuperation of the disassembly of old nuclear submarines, from nuclear reactors maintenance works or even from foundry cinders. Some radiological accidents have also occurred by the use of iron contaminated during the production process with melted radioactive sources mixed with scrap metal. This kind of accidents can disenable all the metal batch produced.

Portugal is a coal importer to the electricity production and industrial furnaces. Fly ashes are residues of this process and frequently are intended to be valorised through incorporation in cement. However, this may incorporate some radioactive elements also in the construction materials which will be reflected in increased radiation doses in the built environment.

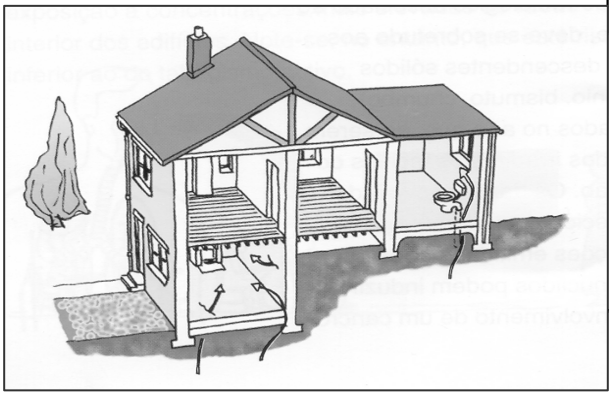
Several non-radioactive materials are also potentially harmful for the health of people in public buildings and for the environment. The Interpretative Document No. 3, Hygiene, Health and Environment, derived from the European Construction Products Directive (Directive 89/106/EEC of 21 December 1988) include in this group, materials such as toxic volatile organic compounds, asbestos, micro organisms, etc. They will not be treated here but the approach taken in the essential requirements laid down in the mentioned Directive applies to all dangerous materials the same principles as for radioactive substances.

4 Characterization and certification of construction products

Following the Construction Products Directive publication, the EU is developing other regulatory tools, such as the harmonization of test methods of construction products related to the compliance of construction works with the essential requirement on Hygiene, Health and Environment. It should be highlighted in this context an EC mandate to CEN – European Committee on Standardisation, under execution, in order to prepare horizontal European standards, establishing harmonized methods for characterization and evaluation of construction products on three aspects: content of dangerous substances in products and raw materials; release of dangerous substances from products into indoor air; and release of dangerous substances into soil, groundwater and surface water.

Amongst recommendations for the work concerning the second aspect are: the analysis of products suspect of emitting radio nuclides and toxic gases to inhabitants and to the environment, including the analysis of gamma rays and radon emanation; and methods for determining the radioactivity index of construction materials.

At the same time, the manufacturing industry is encouraged to characterise their products and to make them comply with the CE marking requirements, in order to allow their free circulation in the Economic European Space.



5 Final Considerations

The demand for qualification and certification of construction products and raw materials as well as for certification of the buildings' performance from the radioactivity point of view, especially in regions of high radioactivity, will continue to raise interest and may lead to minimizing radon exposure. Eventually, regulations on radioactivity may limit the international trade and the use of inadequate construction products.

The question of ionizing emissions and release of radon from construction products is a particular case amongst dangerous substances that can be released in the various phases of the construction process. S*ensu lato*, the construction process includes: exploitation of raw materials; manufacture of products from raw materials; incorporation of these products in buildings; use of the buildings during their life-time period, and the demolition with possible recycling of materials or use of construction waste in new works.

This is a matter that tends to be increasingly regulated in the European Union and that should, therefore, deserve special attention in Portugal. It seems advisable in this context that the Portuguese industry should take steps in advance to avoid future constraints, qualifying and certifying the Portuguese construction products and raw materials and providing reliable information on their composition, in order to improve their competitiveness in the international market.

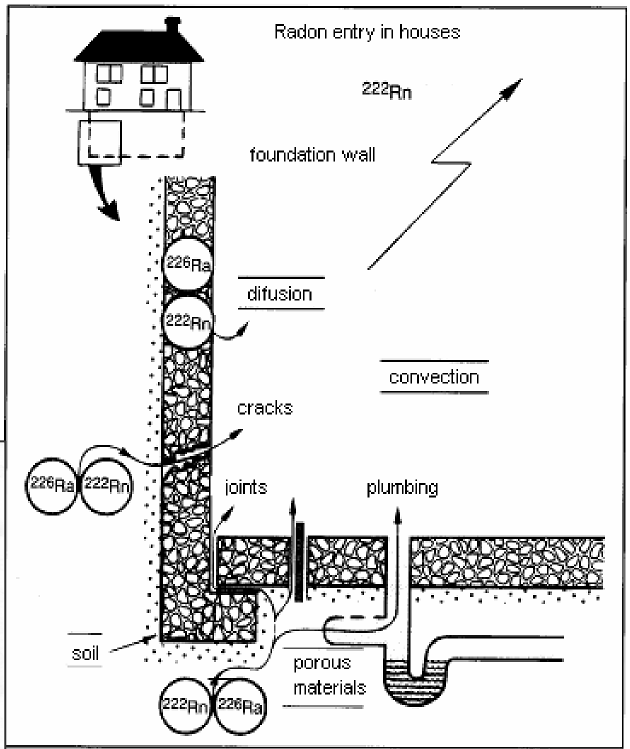


Figura 3. Radon infiltration from soil in the inhabited environment (ITN/DPRSN, 2002).

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