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Description of the behavior of an aquifer by using continuous radon monitoring in a thermal spa

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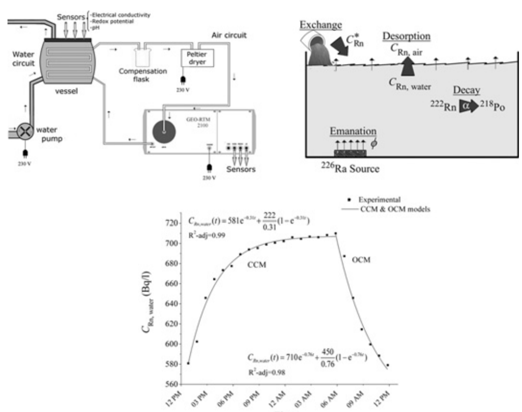
HIGHLIGHTS

- Radon in water is the major source of indoor air radon concentration in thermal facilities.
- Radon in water has been used to characterize the origin of water used for treatments in a spa.
- Preliminary dose assessment from radon exposure has been performed.

GRAPHICAL ABSTRACT



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ABSTRACT

Radon (^{222}Rn) levels in air and water have been analyzed continuously for almost a year in Las Caldas de Besaya thermal spa, north Spain. Radon is a naturally occurring noble gas from the decay of radium (^{226}Ra) both constituents of radioactive uranium 238 series. It has been recognized as a lung carcinogen by the World Health Organization (WHO) and International Agency for Research on Cancer (IARC). Furthermore the Royal Decree R.D 1439/2010 of November, 2010 establishes the obligation to study occupational activities where workers and, where appropriate, members of the public are exposed to inhalation of radon in workplaces such as spas. Together with radon measures several physico-chemical parameters were obtained such as pH, redox potential, electrical conductivity and air and water temperature. The devices used for the study of the temporal evolution of radon concentration have been the RTM 2100, the Radon Scout and gamma spectrometry was complementarily used to determine the transfer factor of the silicone tubes in the experimental device. Radon concentrations obtained in water and air of the spa are high, with an average of 660 Bq/l and 2900 Bq/m^3 respectively, where water is the main source of radon in the air. Radiation dose for workers and public was estimated from these levels of radon. The data showed that the thermal processes can control the behavior of radon which can be also influenced by various physical and chemical parameters such as pH and redox potential.

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1. Introduction

Radon (^{222}Rn) is a naturally occurring radioactive gas that has a half-life $T_{1/2}$ of 3.8 days. It is formed as the decay product of radium (^{226}Ra) with $T_{1/2} = 1600$ years, which is a member of the radioactive series of uranium (^{238}U) (Nazaroff and Nero, 1988). Uranium and radium found naturally in soil and rocks, provide a continuous source of radon. Because of its gaseous nature, radon is able to escape from the rock depending on the density and porosity thereof, being one of the most common radioactive elements in groundwater (Roba et al., 2012).

Under normal conditions, radon has a density of 9.73 kg/m^3, making it the densest gas of nature (International Agency for Research on Cancer, 1988). Of all noble gases, it is the most soluble in water. Owing to the nature of noble gas, its behavior is determined by physical processes. However its parent ^{226}Ra is highly reactive, it forms compounds as Ra^{2+}. Radium constitutes an efficient radon source when once dissolved, is absorbed by the surface of rocks and minerals of the aquifer (Surbeck, 2005), thus avoiding loss or diluting the concentration of radium in water during high flow processes or aquifer recharge.

Some hot springs have high concentrations of radium and radon. For example, studies in Spanish spas provide radon concentrations in water above 1800 Bq/l and 36 Bq/l for radium (Rodenas et al., 2008). The release of radon through water spas in the environment may be a risk to the health of workers of thermal installations as well as for patients (Welch and Mossman, 1994; International Agency for Research on Cancer, 1988).

When radon is inhaled, its disintegration products (^{218}Po and ^{214}Po) are deposited in the lungs, they emit alpha particles which could interact with biological tissues causing DNA damage (Anon., 2009). Due to its gaseous nature, which makes it possible to build up in enclosed spaces such as homes, spas, caves or mines, reaching high concentrations. In 1988 radon was classified as a human carcinogen by the International Agency for Research on Cancer (IARC), agency specializing in cancer research within WHO, from epidemiological studies of uranium miners (International Agency for Research on Cancer, 1988). Currently radon is recognized as the second cause of lung cancer in the population after tobacco (Anon., 2009). According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the average dose received by the Spanish population is 3.7 mSv/year, which 2.4 mSv are due to natural radiation (the global value) where 1.3 mSv are relevant to radon (UNSCEAR, 2000).

This study focuses on two objectives. Both are based on continuous measurement of dissolved radon (^{222}Rn) in water and radon concentration in air of thermal facility, as well as of physical and chemical parameters.

The main objective is based on the characterization of the source of radon in the indoor air in the thermal spa. To do this, dissolved radon in water as natural tracer was monitored to evaluate transfer dynamics to air, to determine the aquifer dynamics and find the radon sources in the thermal installation. The second objective focuses on radiological protection of the workers and patients from the risks derived of radon inhalation. In addition, the concentrations found in air are compared with reference levels detailed in Spanish legislation (IS-33 instruction): if the annual average radon concentration is lower than 600 Bq m^{-3} no specific control is needed; if it is between 600 and 1000 Bq m^{-3} it must be applied a low level of control (follow up of annual average concentration), and if it is higher than 1000 Bq m^{-3}, a high level control must be implemented, which can be related with administrative/technical interventions in order to reduce the exposure of workers (Consejo de Seguridad Nuclear, 2012).

2. Materials and methods

2.1. Site description

Las Caldas de Besaya thermal spa is located beside the river Besaya in the village Los Corrales de Buelna (43°17′53″N, 4°04′23″O) about 30 km from Santander, the capital of the autonomous community of Cantabria, Spain (Fig. 1). Thermal water of this spa is characterized by a temperature between 34 and 37 °C, a sodium-chloride composition, bicarbonated and nitrogenous (Agencia de Evaluación de Tecnologías Sanitarias (AETS) Instituto de Salud Carlos III — Ministerio de Sanidad y Consumo et al., 2006).

The rock type in this area has sedimentary origin, the most part gray limestone and dolomite (Robador et al., 2008). Although the susceptibility of Cantabrian lithologies to release radon is very low (Quindós et al., 1991), the thermal facility is located over an inverted basin geological fault called “Frente Cabalgante del Escudo de Cabuérniga”, which runs parallel to the coast. Several natural springs of thermal water are present along this fault and its relationship with the presence of high radon concentrations in water, as well as a more detailed description of the structural geology in the Cantabria region can be found in (González-Díez et al., 2009).

The period of annual opening of the resort is usually from March to December. It has many services and treatment techniques as baths, jets, circular showers, bubble baths, inhalations, sprays, sauna, underwater massage and manual massage.

In the thermal spa there are seven hot springs. The connection between them remains unknown and could be an interesting topic for future studies. To supply services, water is regularly pumped (from

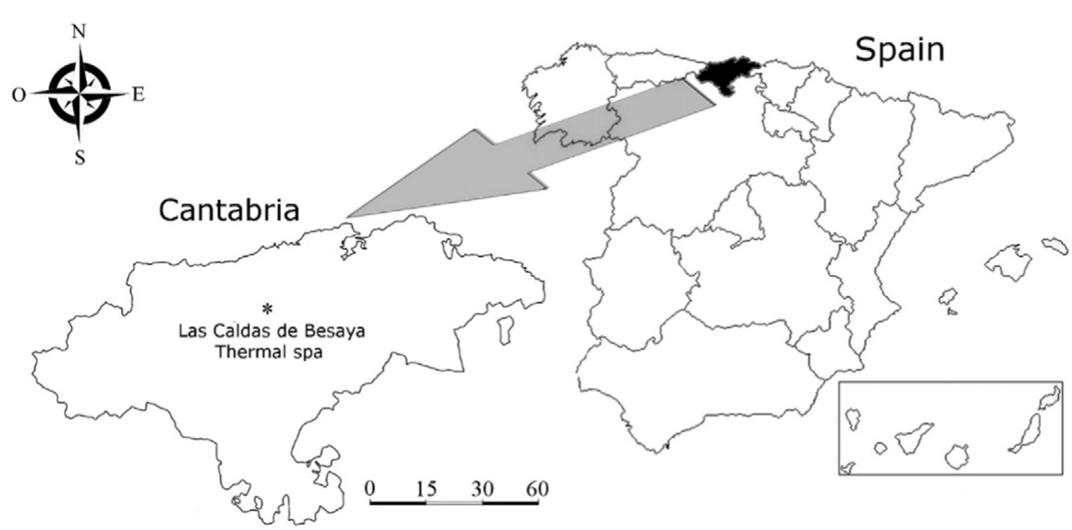

Fig. 1. Location of Las Caldas de Besaya thermal spa, Cantabria, Spain. 150 × 66 mm (300 × 300 dpi).