Science of the Total Environment 408 (2010) 495–504

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

# Investigation of the exposure to radon and progeny in the thermal spas of Loutraki (Attica-Greece): Results from measurements and modelling

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ARTICLE INFO

*Article history:*
Received 24 June 2009
Received in revised form 24 September 2009
Accepted 25 September 2009
Available online 30 October 2009

*Keywords:*
Radon
Progeny
Model
Numerical solving
Mass-balance
Water
Effective dose

ABSTRACT

Radon and progeny ($^{218}$Po, $^{214}$Pb, $^{214}$Bi and $^{214}$Po) in thermal spas are well known radioactive pollutants identified for additional radiation burden of patients due to the activity concentration peaks which appear during bath treatment or due to drinking of waters of high radon content. This burden affects additionally the working personnel of the spas.

The present paper has focused on the thermal spas of Loutraki (Attica-Greece). The aim was the investigation of the health impact for patients and working personnel due to radon and progeny. Attention has been paid to radon and progeny transient concentration peaks (for bath treatment) and to radon of thermal waters (both for bath treatment and drinking therapy). Designed experiments have been carried out, which included radon and progeny activity concentration measurements in thermal waters and ambient air.

Additionally, published models for description of radon and progeny transient concentration peaks were employed. The models were based on physicochemical processes involved and employed non linear first order derivative mass balance differential equations which were solved numerically with the aid of specially developed computer codes. The collected measurements were analysed incorporating these models. Results were checked via non linear statistical tests. Predictions and measurements were found in close agreement. Non linear parameters were estimated.

The models were employed for dosimetric estimations of patients and working personnel. The effective doses of patients receiving bath treatment were found low but not negligible. The corresponding doses to patients receiving potable treatment were found high but below the proposed international limits. It was found that the working personnel are exposed to considerable effective doses, however well below the acceptable limits for workers. It was concluded that treatment and working in the Loutraki spas leads to intense variations of radon and progeny and consequently additional health impact both to patients and working personnel.



## 1. Introduction

Radon ($^{222}$Rn) is a naturally occurring radioactive gas formed by the decay series of $^{238}$U which disintegrates to a series of short-lived radioactive decay products (progeny) ($^{218}$Po, $^{214}$Bi, $^{214}$Pb and $^{214}$Po). Radon and progeny are recognised as the most significant natural source of human radiation exposure (UNSCEAR, 2000) and the most important cause of lung cancer incidence except for smoking (US-EPA, 2003; WHO, 2006).

Considerable high concentrations of radon and progeny have been observed in thermal spas (Steinhäusler, 1988; Lettner et al., 1996; Szerbin, 1996; Trabidou et al., 1996; Datye et al., 1997; Vogiannis et al., 2004a,b,c; Radolic et al., 2005; Song et al., 2005; Manic et al., 2006; Bonotto and Santos, 2007; Somlai et al., 2007; Gnoni et al., 2008) causing significant additional radiation burden to patients and working personnel. The EU has identified this fact in the directive 96/29/EURATOM, proposing spa therapy as a professional activity of enhanced natural radiation exposure (CEC, 1996).

In Greece, thermal spa therapy is well accepted by the Greek National Health System. Therefore, it is frequently recommended by medical doctors. This fact leads many individuals to visit such centres for treatment through baths (bath treatment) or drinking of thermal water. On account of the related health risk and the recent tendency of introducing spa centres as recreation sites or as health resorts, the reporting team investigates the radiation exposure of patients and working personnel due to radon and progeny (Geranios et al., 2004; Vogiannis et al., 2004a,b,c; Vogiannis 2005; Nikolopoulos and Vogiannis, 2007; Vogiannis and Nikolopoulos, 2008). Recently (2007), the generation of radon progeny transient concentration peaks in thermal spas in Greece has been modelled (Nikolopoulos and

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doi:10.1016/j.scitotenv.2009.09.057

Vogiannis, 2007). Modelling was achieved through simulation of the involved physical procedures through a set of first order time-varying differential equations (dynamical approach) and a set of parameters of physical interest (semi-empirical modelling). In addition, the generation of the concentration peaks of radon and the corresponding temporal variations, were modelled on the basis of physicochemical processes involved, by employing non linear first order derivative mass balance differential equations and specially developed computer codes (Vogiannis and Nikolopoulos, 2008).

The present paper has been focused on radon and progeny of the thermal spas of Loutraki (Attica-Greece) (Fig. 1). The aim was the investigation of the radiation burden to patients and working personnel through measurements and modelling. Towards this, radon and progeny activity concentrations were determined and analysed incorporating the abovementioned models.

## 2. Materials and methods

### 2.1. Area of study

Loutraki (Fig. 1) is located northwest of Athens on the Gulf of Corinth coast (latitude 37.58° N and longitude 22.58° E). Loutraki is considered as the most ancient bathing resort of Greece. It is distinguished as a principal therapeutic spot. It is famous for its spas which are recommended for disorders of the urinary tract, gravel, stones in kidney, gallstones and gout.

The main spa centres of Loutraki are two; the building of the municipal thermal spas (BMTS) and the building of the spring (BS). The BMTS includes 25 treatment rooms (TRs) for bath treatment of patients and a large reception room (RR) which serves for management and administration. The TRs contain bathtubs of 8 $m^{-3}$ equipped with taps providing spring (thermal) and non-spring water, places for dressing and sanitary purposes, windows for natural ventilation, a small mechanical system which may be utilised for forced ventilation and a door. Spring water is periodically pumped from its source by means of a mechanical drainage system located a few meters outside the BMTS. The pumped water may be used instantly, but for most of the cases, it is stored in a water tank until drained. The water in the tank may be used at the tank's temperature (cold water) or after heat supply (hot water); however the latter is not advisable. Under regular conditions, the spa personnel is responsible for bath filling, managing of the mechanical and natural ventilation system, bath emptying and cleaning and overall functioning of the TR. The BS, named after its position, is built around a physical spot from which spring water enters straight from two different sources named after their spring content; the Heavy Source (HS) and the Light Source (LS). Both sources are different from the one located outside the BMTS and are utilised for drinking therapy of patients. The working personnel reside in the building and are responsible for the services related to the drinking therapy, i.e., cleaning of glasses, filling of ewers, opening and closing of the centre.

The regular recommendations are 30 sequential days of bath treatment or 15 sequential days of drinking therapy. The advised bath treatment programme requires the stay of the patient into the bathtub for 30 min/day. However, according to the practice followed by the majority of the patients receiving a bath, the advised 30 min programme includes additional time for the filling of the bathtub. The advised drinking therapy programme entails the sequential consumption of three 350 mL glasses (total 1050 mL) of spring water.

### 2.2. Methods and measurement instrumentation

Radon and progeny measurements were collected during spring–summer (working period) of 2007 from the BMTS and the BS. Designed experiments were carried out in a manner that would allow dose estimations, as well as, modelling of radon and progeny peaks according to the models (Nikolopoulos and Vogiannis, 2007; Vogiannis and Nikolopoulos, 2008). The experience gained from previous relevant works (Geranios et al., 2004; Vogiannis et al., 2004a,b,c; Vogiannis 2005) was taken into consideration. The measurements involved the determination of the radon content of spring waters, the collection of transient radon and progeny peak concentrations in TRs


**Fig. 1.** Map of Loutraki (Attica-Greece).