Nuclear Instruments and Methods in Physics Research B 362 (2015) 187–193

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

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

Experimental setup for radon exposure and first diffusion studies using gamma spectroscopy

Andreas Maier [a,*], Patrick van Beek [a,b], Johannes Hellmund [a], Marco Durante [a,b], Dieter Schardt [a], Gerhard Kraft [a], Claudia Fournier [a]

[a] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany
[b] Technical University Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany

ARTICLE INFO

Article history:
Received 19 June 2015
Received in revised form 4 September 2015
Accepted 15 September 2015

Keywords:
Radon
Gamma spectroscopy
Diffusion
Biokinetics

ABSTRACT

In order to measure the uptake and diffusion of ^{222}Rn in biological material, an exposure chamber was constructed where cell cultures, biological tissues and mice can be exposed to ^{222}Rn-activities similar to therapy conditions. After exposure, the material is transferred to a gamma spectrometer and the decay of ^{214}Pb and ^{214}Bi is analyzed. From the time kinetics of these decays the total amount of the initial ^{222}Rn concentration can be calculated. In this paper the design and construction as well as first test measurements are reported.

1. Introduction

The exposure to ^{222}Rn is very likely because of two reasons: in areas of elevated uranium concentration, ^{222}Rn gas emanates from the soil into living areas and is inhaled continuously. As a consequence, about one out of seven deaths from lung cancer is caused by ^{222}Rn and not by smoking [6]. In contrast to this impact, ^{222}Rn is used in medicine as a therapeutic agent in the treatment of inflammatory diseases. Patients suffering mainly from rheumatic diseases like ankylosing spondylitis (Morbus Bechterew) undergo ^{222}Rn treatment such as bathing in ^{222}Rn containing water or visiting ^{222}Rn galleries. For these patients a temporary release or reduction of pain, starting some weeks after the treatment and lasting for several months is reported [5].

Although a very large number of people using this treatment the exact dose-relations are not known nor the underlying molecular mechanisms of the action of ^{222}Rn [15].

Concerning a potential tumor induction, epidemiological studies suffer mostly from the influence of other lifestyle factors like smoking as well as from the insufficient knowledge of the actual dose received by the individuals. Therefore, the effects for low ^{222}Rn concentrations are not significant, even for very large cohorts of test persons [4].

For the understanding of anti-inflammatory effects, the general situation is even more complex because of the widely unknown physical and biological mechanisms of uptake, diffusion and exhalation of the primary ^{222}Rn as well as the biokinetic of its radioactive progeny [10]. In addition, the dose delivered by the radioactive decay of a few μGy per session [12] is very low and the risk as well as the observed clinical reaction is still under investigation.

The very scarce literature refers to ^{222}Rn accumulation in animals [14] and in activated charcoal [1]. Human studies examined the exhalation of ^{222}Rn [8,9,7,11]. Most of these references found a rather short half-life of 10 to 30 min for the removal of the primary ^{222}Rn.

In contrast, Harley et al. report much longer ^{222}Rn exhalation up to 56 h after exposure. This is based on experiments where an exponential function consisting of 5 components was fitted to the activity concentration of exhaled radon over time. Afterwards these components were attributed to different parts of the human body like lung, blood, body liquids and fat. In all these publications there is no general agreement on the storing capacity of the various tissues or on exhalation and diffusion velocity.

In order to obtain more information about the physical processes of ^{222}Rn in the human body, a ^{222}Rn exposure chamber was constructed in which cell cultures, tissues, and small animals can be exposed under therapy like conditions, but also at higher ^{222}Rn gas concentrations than in ^{222}Rn galleries. One objective is to measure the distribution of ^{222}Rn in different types of tissue

* Corresponding author.
E-mail address: a.maier@gsi.de (A. Maier).

http://dx.doi.org/10.1016/j.nimb.2015.09.042
0168-583X/

with gamma spectroscopy to better understand the effects of the ^{222}Rn therapy.

In Sections 2 and 3 the chamber design, first test measurements and the detector setup used for quantitative analysis of the activities of ^{222}Rn and its decay daughters ^{214}Bi and ^{214}Pb are presented. In Sections 4–6 first diffusion studies with activated coal and tendon samples will be reported and discussed.

2. Radon exposure chamber

2.1. Methodology and design

In order to be independent from an external supply, a ^{226}Ra source with a half-life of 1600 years produces the wanted ^{222}Rn gas at sufficient concentrations. After passing through the exposure chamber the ^{222}Rn is sampled quantitatively in activated coal where it decays. The exposure chamber located between the ^{222}Rn source and the coal filter has to have a size that allows to expose up to 15 mice simultaneously, but small enough to be filled and cleaned within a few minutes. Therefore, a stainless steel container with a volume of 50 l was found to meet to meet these requests best.

For the measurement of the ^{222}Rn uptake and its diffusion, the radioactivity of the ^{222}Rn progeny can be used as a monitor. Sufficient counting rates can be expected for the radionuclides ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po before reaching the long-lived ^{210}Pb (see Fig. 1). Its long half-life of 22.3 years reduces the counting rates of the following decay daughters to values below the detection limit. Reasonable counting rates can be expected for the α-emitters ^{218}Po and ^{214}Po as well as for the β/γ-emitters ^{214}Pb and ^{214}Bi. Due to the short range of α-particles, their detection is less favorable: In order to obtain sharp α-energies an elaborate sample preparation is necessary, in which the biological samples have to be incinerated and processed because only thin films of the radioisotopes would yield α-lines with the necessary energy resolution. The process of sample preparation requires several days [13]. In this time period all ^{222}Rn has diffused out of the probe and the disintegration of the daughter nuclides ends in the quasi-stable ^{210}Pb (see Section 4.2).

In contrast, the detection of γ-rays is experimentally rather simple and fast. Because of their high energies, the γ-decays can be measured without large preparations: the corrections for the attenuation inside the samples are minor and the counting efficiency in a high purity Ge-detector is sufficient for measurements at low counting rates.

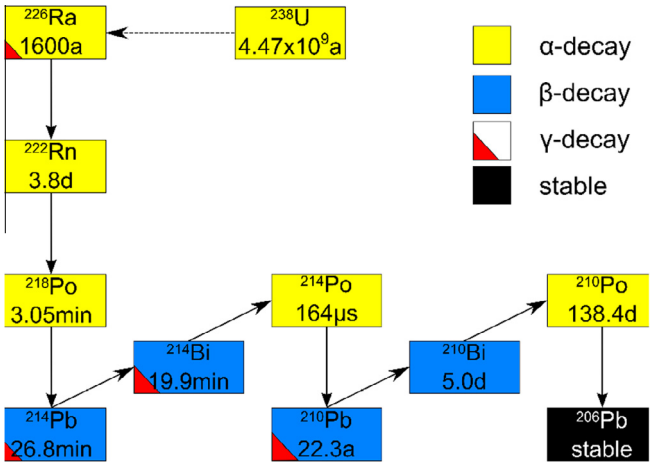

Fig. 1. Section of the uranium series [3].

2.2. Construction of the exposure setup

There are several radon exposure chambers in laboratories all over the world. The range of the different parameters like radon concentration, temperature or humidity is similar to our setup. But the main objectives of those chambers are calibration purposes [2]. To perform experiments with cell cultures and small animals, we use a stainless steel chamber with a volume of 50 l that has ^{222}Rn inlets and outlets at opposite sites. In this way changes of the parameters can be induced quickly. The profile is a round barrel allowing to avoid edges, where pollution and contamination can accumulate. For animal experiments a special cage with a floor covering made of cork was used as housing for up to 15 mice simultaneously.

Access to the chamber is possible by a removable lid which is sealed during experiment. Inside the lid a small window is integrated to have visible control of the animals or samples during experiment. There are several grommets integrated in the wall for the different media or cables. Inside, a small ventilator is fixed to circulate the air. A video camera is integrated to have permanently visible control of the animals during experiment.

The chamber is connected to the ^{226}Ra source, a humidity generator, pressurized air and CO_2 inlets and exhaustion to the coal dump (see Fig. 2).

With this device, we can provide physical conditions comparable to galleries in Germany or Austria which are used for therapy. The parameters and their range are shown in Table 1 in comparison to conditions in the galleries. Experiments with higher ^{222}Rn concentrations can be performed. In addition, we can add CO_2 during cell culture experiments. All parameters can be reproducibly regulated and monitored. They will be explained in more detail in the following sections.

2.3. Activity concentration

The ^{222}Rn concentration inside the chamber can be adjusted by varying the accumulation time of ^{222}Rn in the source and then flushing the ^{222}Rn into the chamber with pressurized air. We use a commercial available source (RN-1025, Pylon Electronics, Canada). Inside a cylinder of stainless steel, ^{226}Ra is deposited to a lattice texture and decays with a half-life of 1600 years to ^{222}Rn, which accumulates inside the source. Due to the long half-life of ^{226}Ra, we can assume the production rate to be constant during the time of observation.

During the time periods between experiments the source is sealed from environment and ^{222}Rn can accumulate inside the source. In Fig. 3, we show the theoretical ^{222}Rn concentration in the ^{222}Rn chamber over different accumulation intervals and the measured values. The deviation is due to the fact that it is not possible flush ^{222}Rn out of the source completely.

By guiding a regulated flow of pressurized air through the source the activity concentration inside the chamber can be adjusted, which is sealed against environment during experiments. In parallel, the ^{222}Rn concentration inside the chamber is permanently monitored (RTM 1688-2, Sarad GmbH, Dresden, Germany).

2.4. Temperature

The temperature is regulated by a water bath containing 70 l, in which the chamber is bolt down. The ^{222}Rn chamber is immersed in a way that 2/3 are surrounded by circulating water at the sides and the bottom. All transfer wires for sensors or electrical components into the chamber are above the water line. The setup is isolated against environment at the top side via air bubble film and foam.