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Current Status of Rn-220 Chamber Carrier Aerosol Modulation Research

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Abstract

Radon is the most important source of natural radiation to human beings and the second major causative agent of lung cancer other than smoking. In recent years, the hazards of human exposure to thoron (Rn-220), another isotope of radon, and its progeny have gained consensus. To accurately evaluate the dose level and hazards of Rn-220 and its progeny, a standard Rn-220 chamber with strong regulation ability for Rn-220 and its progeny needs to be established for the scale or calibration of measurement instruments. This paper describes the hazards, sources, behavioral characteristics of Rn-220 and its progeny, and some representative Rn-220 chambers established in various countries.

Keywords

Thoron, Rn-220 Chamber, Aerosol Modulation

1. Introduction

For the public, internal exposure caused by inhalation of radon and its progeny is the most important source of natural radiation to human beings. At the same time, radon is also the second leading cause of lung cancer besides smoking, and is one of the 19 environmental carcinogens announced by the World Health Organization (WHO), and the International Agency for Research on Cancer (IARC) classifies radon and its progeny as Class I carcinogenic factors. It has been widely concerned by relevant international organizations and government departments such as the International Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2009), the International Commission on Radiological Protection (ICRP, 2010) and the World Health Organization (WHO, 2009). Radon itself is a gas, but its decay product Po-218 is an electrically charged solid and is very easy to be adsorbed on particles. After radon and its progeny are inhaled into human body, they are usually deposited in the trachea and bronchial area. They continuously emit alpha particles in the lungs, and these alpha particles can harm lung cells. The injured lung cells may then mutate and become cancer cells, which will then develop into lung cancer.

Another isotope of radon, Rn-220, because of its short half-life and weak diffusion and migration ability, the hazard caused by Rn-220 and its progeny is often underestimated. However, Rn-220 and Rn-222 are both major radioactive gases in the earth's crust. According to UNSCEAR2000 (UNSCEAR, 2000), the effective dose produced by Rn-220 and its progeny accounts for 9% of the dose of radon and its progeny in the natural radiation exposure received by human beings, up from the original 6%, concentrations and doses of thoron (Rn-220) and its progeny in some countries of the world are listed in **Table 1**. Many researches also show that the hazard of Rn-220 and its progeny to human exposure has been agreed, and research on the measurement method and level investigation of Rn-220 and its progeny has made a lot of progress.

2. Sources of Rn-220 and Its Progeny

The sources of Rn-220 in the environment are mainly building materials and rocky soils.

Building materials are the main source of Rn-220 indoors, where the Rn-220 precipitation rate of masonry materials and concrete is about 4.5×10^{-2} $Bq \cdot m^{-2} \cdot s^{-1}$. In addition to building materials such as masonry and concrete, the surface coverings of building materials, such as paints, may be the main source of Rn-220 indoors.

Rocks and soils are also the main sources of Rn-220. There is a correlation between Rn-222 and Rn-220 radioactivity concentrations in the atmospheric environment and the age of geological formations, the abundance of radionuclides in strata, regional geological formations and geological fracture structures, etc. The results of Sreenath Reddy M. et al. on the levels of Rn-220 and its progeny

Table 1. Concentration and dose of thoron (Rn-220) and its progeny in some countries of the world (Hosoda et al., 2017).

Country	Concentration (Bq/m^3)		Dose (mSv)
	indoor	outdoor	
World	0.3	0.1	0.09
China	0.84	0.4	0.25
Japan	0.72		0.6 - 2.2
Korea	0.99		
America	0.3		
Sweden	0.5		0.1
Greece	0.9		0.29
Romania	1.0	0.2	0.26

radioactivity concentrations in living rooms showed that the soil under the living room is likely to be one of the causes of higher indoor Rn-220 levels (Sreenath et al., 2004).

Rn-220 is derived from the decay of Ra-224 in the thorium system, also known as thoron, the atomic structure of Rn is shown in **Figure 1**. Rn-220 is a radioactive noble gas with a half-life of 55.6 s, much smaller than Rn-222. The decay of Rn-220 produces short-lived progenies such as Po-216 (ThA), Pb-212 (ThB), Bi-212 (ThC), and finally decays to the stable nuclide Pb-208.The decay chain is shown in **Figure 2**.

The decay of Rn-220 produces Po-216 with a very short half-life, which then decays to Pb-212. The undecayed Po-216 (ThA) and the new decay of Pb-212 (ThB) can react with trace gas or water vapor in the air in a short time to form solid particles, i.e., the "unbound state", with a particle size of 0.5 - 5 nm. Because of the strong diffusivity of the unbound state, it adheres to the aerosol particles and forms aerosols with a certain particle size distribution floating in the air, at which time the Rn-220 substrates are bound. The binding process between the unbound state and the aerosol is related to the size of the unbound state, the particle size distribution and the concentration of the aerosol, while for the bound radioactive aerosol, its particle size distribution is related to both the diffusion coefficient of the unbound state and the aerosol distribution.

Geethpriya Palaniswaamy et al. elaborated that the calculation of aerosol evolution, movement and distribution involves the study of various processes such as solidification, deposition, condensation, evaporation, etc., and is affected by factors such as particle shape, charge, radioactivity, and spatial inhomogeneity (Palaniswaamy & Loyalka, 2007). The kinetic properties of aerosols include the settling, diffusion, condensation, and transfer properties of aerosols. Due to random gas collisions, aerosols in gaseous media undergo random migratory motion, i.e., Brownian motion. Diffusion drives the migration of aerosol particles from regions of high concentration to regions of low concentration in their concentration gradient field. When there is no other external influence, aerosol particles fall only by their own gravity. When they fall, they are subject to viscous forces.

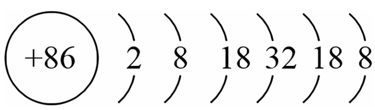

Figure 1. The atomic structure of Rn.

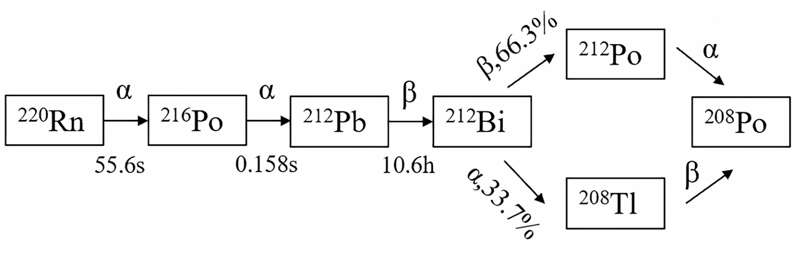

Figure 2. The decay chain of Rn-220.

Due to the dual action of gravity and viscous forces, aerosol particles in the air will settle in a uniform linear state. Aerosol particles may collide with each other and condense, thus forming large particles and gravitational settlement; it is also possible to migrate to the surface of the object and attach to the surface of the object.

3. Status of Rn-220 Chamber Research

To conduct Rn-220 chamber carrier aerosol modulation studies and accurately evaluate the dose level and hazard of 220Rn and its progeny, a standard Rn-220 chamber with strong modulation capability of Rn-220 and its progeny needs to be established for the scaling or calibration of the measurement instruments to ensure the quality of the measurements. Moreover, Rn-220 chambers need to be able to provide stable activity concentration levels of Rn-220 and its progeny, particle size distribution, equilibrium factors and other parameters. Here, activity concentration is defined as radioactive activity per unit volume. Particle size distribution refers to the proportion of the number of particles (mass or surface area) in different particle size ranges. Equilibrium factor refers to the ratio F between the equilibrium equivalent concentration of radon and the actual concentration of radon. The equilibrium equivalent concentration is the activity concentration of radon when it is in equilibrium with its short-lived daughters and has the same α potential concentration as the actual non-equilibrium mixture.

Only a few countries have established Rn-220 chambers, the earliest being the Rn-220 chamber in Canada, followed by the PTB Rn-220 chamber in Germany, the NIRS Rn-220 chamber in Japan, the Rn-220 chamber at South China University, small Rn-220 chambers at Peking University, and Rn-220 chambers in other regions, etc. Several of these representative Rn-220 chambers are described below.

3.1. Federal Institute of Physics and Technology (PTB), Germany

In 1998, radon and its progeny were measured in a radon standard chamber with different α and γ spectrophotometric systems, controlling a full set of environmental parameters such as temperature, humidity, air pressure and aerosol concentration (Honig et al., 1998). A new calibration device for measuring Rn-220 activity concentration in air was developed in 2003 (Gargioni et al., 2003). To generate and maintain a homogeneous and constant activity concentration, a flow field is established and monitored in a reference chamber. Rn-220 activity concentration is measured by a multi-line ionization chamber (MWIC) operating in pulsed mode and externally connected to the reference chamber. An Rn-220 chamber was operated in 2009, as shown in **Figure 3**, in which 220Rn, 222Rn and their progeny can be obtained under almost all environmental conditions. This allows all measurement systems to be calibrated in real climate conditions (Röttger et al., 2009). A new primary standard for Rn-220 activity concentration was established in 2010 (Röttger et al., 2010).

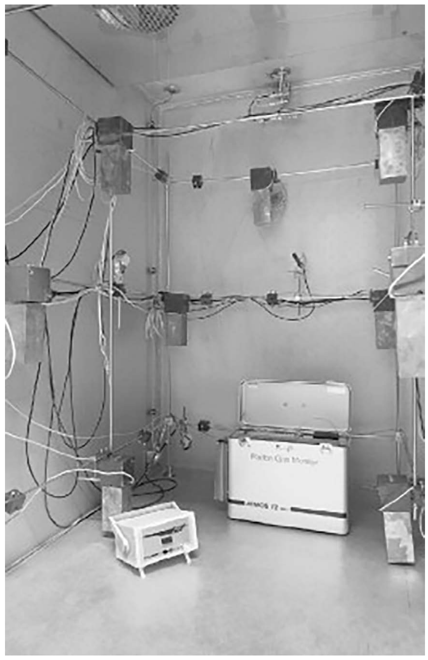

Figure 3. Thoron progeny chamber (PTB, Germany).

3.2. National Institute of Radiology (NIRS), Japan

A radon aerosol chamber with an internal volume of about 25 m^3 was developed in 2004 (Ichitsubo et al., 2003). The chamber is designed to control the temperature, relative humidity, aerosol concentration, radon concentration and pressure difference between inside and outside. The temperature and relative humidity can be controlled at 278 - 303 K and 30% - 90% respectively, and the pressure difference between indoor and outdoor can be kept at negative value. The temperature and relative humidity fluctuate very little. The indoor particle concentration can be controlled in the range of 10^8 - 10^{10} m^{-3}. Particle concentration and distribution are very stable. Particle concentration fluctuations are within the statistical error of the TSI-CPC3010 particle counter. Variations in temperature and relative humidity have little effect on the particle concentration and its distribution. Rn-220 chamber system was established in 2008, as shown in **Figure 4**, consisting of four components: exposure, monitoring, calibration, and humidity control system (Sorimachi et al., 2008). An aerosol chamber system that can be used for Rn-220 passive progeny detector calibration and performance experiments was established in 2014 (Sorimachi et al., 2014). The properties of the equilibrium factor F of Rn-220 and the unbound fraction fp of Rn-220 progeny are related to the aerosol conditions (particle size and particle number concentration).

3.3. University of South China

The solid Rn-220 source with high and stable injection coefficient was developed in the Radon Laboratory of University of South China, and an Rn-220 chamber with a volume of about 2.7 cm^{-3} was established. The structure of Rn-220 chamber

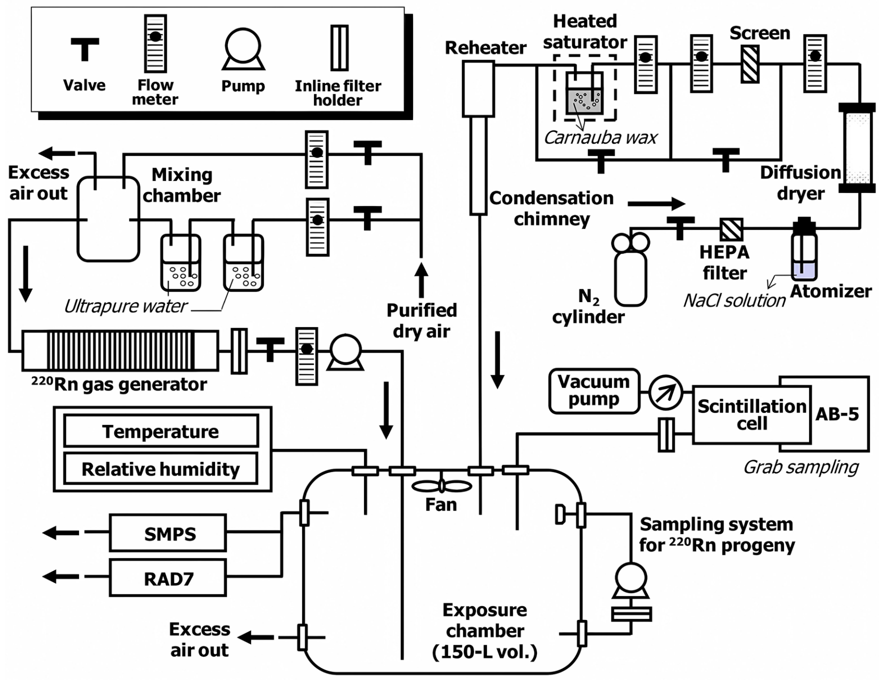

Figure 4. A block diagram of NIRS thoron chamber system.

mainly includes: aerosol source and its injection system, Rn-220 source and its injection system, main body box and circulation fan. A wide range of continuous adjustment of 220Rn concentration in the Rn-220 chamber can be achieved by adding a time delay, changing the source activity of the Rn-220 and regulating the gas flow.

4. Conclusion and Outlook

In this paper, we present the current status of research on aerosol regulation of Rn-220 chambers and its progeny in terms of their hazards, sources, behavioral characteristics, and some representative Rn-220 chambers established in various countries. At present, the representative Rn-220 chambers have basically achieved stable control of Rn-220, and their research mainly focuses on controlling parameters such as Rn-220 activity, ambient temperature, humidity, air pressure and aerosol concentration to provide stable Rn-220 measurement conditions. Rn-220 is an inert gas, and the regulation of Rn-220 is not complicated compared with the regulation of Rn-220 progeny. Therefore, the current problem for Rn-220 progeny regulation is still the focus and difficulty of Rn-220 chamber operation and the key problem in the Rn-220 sub-body metering system.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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