RADON

1. Chemical and Physical Data

1.1 Introduction

Radon is a noble gas that occurs in several isotopic forms. Only two of these are found in significant concentrations in the human environment: radon-222, which is a member of the radioactive decay chain of uranium-238, and radon-220 (thoron), which is formed in the decay chain of thorium-232.

The contribution of radon-220 and its decay products to the exposure of workers and of the general population is usually small (less than 20%) compared with that of radon-222 and its decay products (United Nations Scientific Committee on the Effects of Atomic Radiation, 1982). Therefore, in this monograph, the sources of and levels of exposure to radon-220 are not discussed, and 'radon' is used to mean radon-222.

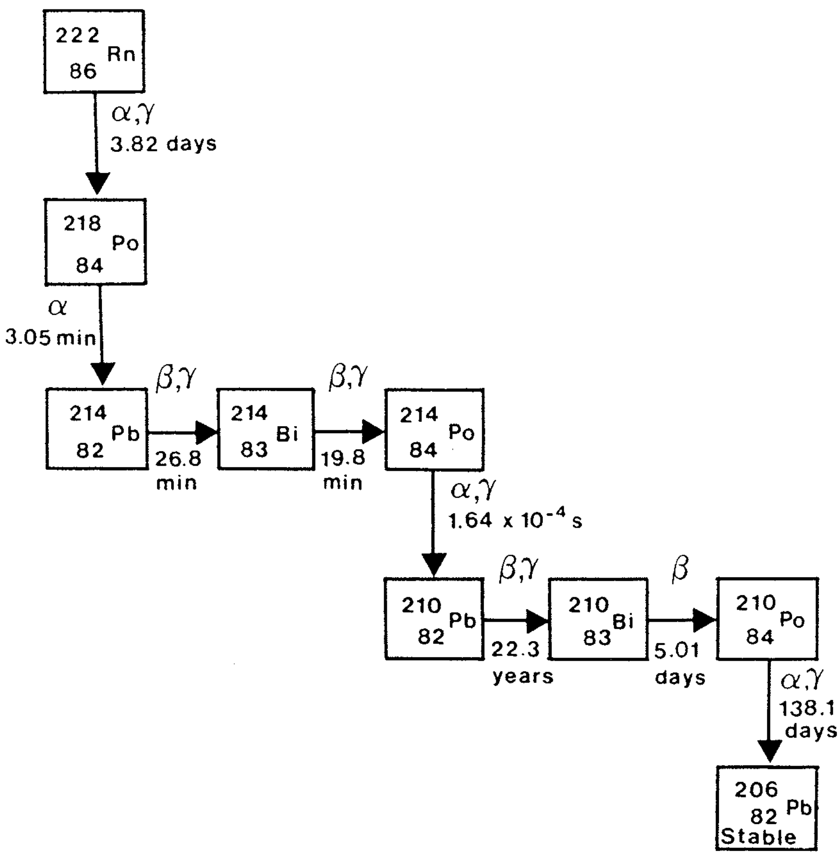
Radon-222 decays in a sequence of short-lived radionuclides, called radon decay products, radon daughters or radon progeny. In this monograph, they are generally referred to as radon decay products. Figure 1 shows the radioactive decay chain of radon-222, with the type of decay (α, β, γ) and the radioactive half-life of the radionuclides involved.

Radon is a colourless, odourless, inert gas (boiling-point, −61.8°C), denser than air (density, 9.73 g/l at 0°C and 760 mm Hg) and fairly soluble in water (51.0 cm^3 radon/100 cm^3 water at 0°C; 22.4 cm^3/100 cm^3 at 25°C; 13.0 cm^3 at 50°C) (Weast, 1985).

The decay products of radon-222 are radioisotopes of heavy metals (polonium, lead, bismuth), and the release of radon into air leads also to formation of these decay products, which attach rapidly to particles. The major human exposure is inhalation of the short-lived decay products, polonium-218 to polonium-214, since the long-lived decay products, lead-210 and polonium-210, are removed from outdoor and indoor air by various mechanisms. In this monograph, only exposures to radon-222 and to its short-lived decay products are considered.

Although radon is a gas, its decay products are not, and they occur either as unattached ions or atoms, condensation nuclei (~0.002 μm) (Duport *et al.*, 1977) or attached to particles. The probability of attachment is high and depends strongly on the concentration of dust in the air. In very clean air, under experimental conditions, radon decay products exist mainly as nuclei or in the unattached form. Radon decay products can be removed

Fig. 1. Radon-222 decay series[a]



[a]From US Environmental Protection Agency (1986a)

from contaminated air by filtration, but there is subsequently progressive build-up of short-lived decay products, so that steady-state equilibrium is achieved within a few hours (Jonassen, 1984).

1.2 Synonyms

Chem. Abstr. Serv. Reg. No.: 10043-92-2
Chem. Abstr. Name: Radon
Synonyms: Alphatron, niton, radium emanation

Chem. Abstr. Serv. Reg. No.: 14859-67-7
Chem. Abstr. Name: Radon-222

Chem. Abstr. Serv. Reg. No.: 15422-74-9
Chem. Abstr. Name: Polonium-218
Synonym: Radium A

Chem. Abstr. Serv. Reg. No.: 15735-67-8
Chem. Abstr. Name: Polonium-214
Synonym: Radium C′

Chem. Abstr. Serv. Reg. No.: 13981-52-7
Chem. Abstr. Name: Polonium-210
Synonym: Radium F

Chem. Abstr. Serv. Reg. No.: 14733-03-0
Chem. Abstr. Name: Bismuth-214
Synonym: Radium C

Chem. Abstr. Serv. Reg. No.: 14331-79-4
Chem. Abstr. Name: Bismuth-210
Synonym: Radium E

Chem. Abstr. Serv. Reg. No.: 15067-28-4
Chem. Abstr. Name: Lead-214
Synonym: Radium B

Chem. Abstr. Serv. Reg. No.: 14255-04-0
Chem. Abstr. Name: Lead-210
Synonym: Radium D

1.3 Quantities and units

(*a*) *Terms used*

The quantity *activity* defines the number of radioactive transformations of a radionuclide over unit time in a specified material (e.g., air, water, soil, tissue). The SI unit is the becquerel (Bq); 1 Bq = 1 disintegration per second; the unit used previously was the curie (Ci); 1 Ci = 3.7×10^{10} Bq. Consequently, the *activity concentration* of radon in air is expressed in Bq/m^3 air.

The *concentration* of radon decay products in air is expressed as the total *potential* α energy concentration of the radon decay product mixture present, being the sum of the α energies of all the short-lived radon decay product atoms present per unit volume of air. The potential α energy of a decay product atom is defined as the total α energy emitted during the decay of the atom to lead-210.

The SI unit for the potential α energy concentration of radon decay products in air is joules (J)/m^3; 1 J/m^3 = 6.24×10^9 million electron volts (MeV)/l of air. A special unit often used for this quantity is the *working level* (WL). A WL is defined as any combination of short-lived radon decay products that will result in the emission of 1.3×10^5 MeV of α energy per litre of air. Thus,

$$1 \text{ WL} = 1.3 \times 10^5 \text{ MeV/l} = 2.08 \times 10^{-5} \text{ J/m}^3$$

(United Nations Scientific Committee on the Effects of Atomic Radiation, 1982). One WL corresponds approximately to the potential α energy concentration of short-lived radon decay products that are in radioactive equilibrium with a concentration of 3.7×10^3 Bq radon/m^3 of air (100 pCi/l of air). Radioactive equilibrium occurs when every short-lived radon decay product is present at the same activity as radon.

In confined air spaces, as in mines and houses, and in outdoor air near ground level, the activity concentration of the decay product radionuclides never reaches radioactive equilibrium with radon, due mainly to ventilation and the deposition of radon decay products on surfaces. In order to account for this, an *equilibrium factor* (F) is used, defined as the ratio of the potential α energy concentration of the decay product mixture to the corresponding concentration if they were in radioactive equilibrium with radon.

The concentration of radon decay products in indoor air is often expressed in terms of the *equilibrium equivalent concentration* of radon or activity concentration of radon at equilibrium (EEC_{Rn}). It corresponds to the activity concentration of radon for which the decay products in equilibrium with radon have the same potential α energy as the actual concentration of decay products. It is thus expressed in units of Bq/m^3 (EEC_{Rn}) as:

$$EEC_{Rn} = F \times a_{Rn},$$

where a_{Rn} is the activity concentration of radon.

Cumulative exposure to inhaled *radon decay products* is the potential α concentration of the short-lived radon decay product mixture in inhaled air, integrated over the residence time in the air space (e.g., mine, house), expressed as:

$$1\ \text{Jh/m}^3 = 6.24 \times 10^{12}\ \text{MeVh/m}^3$$
$$= 4.8 \times 10^4\ \text{WLh}$$

for radon decay products (1 WLh = 2.08×10^{-5} Jh/m^3). In terms of the equilibrium equivalent concentration of radon, the corresponding cumulative exposure is expressed as Bqh/m^3.

The potential α energy exposure of miners is often expressed as *working level months* (WLM). This unit is generally used to estimate exposure to radon decay products in epidemiological studies of miners and for establishing radiation limits in mines. One WLM corresponds to exposure to a concentration of 1 WL for a reference period of 170 h:

$$1\ \text{WLM} = 170\ \text{WLh} = 3.5 \times 10^{-3}\ \text{Jh/m}^3$$
$$1\ \text{Jh/m}^3 = 285\ \text{WLM}$$

Thus,

1 WL corresponds to 3.7×10^3 Bq/m^3 (EEC_{Rn}) = 100 pCi/l (activity concentration of radon at equilibrium)

$$\text{WL} = (a_{Rn} \times F)/3.7 \times 10^3$$
$$\text{WLM} = (\text{WL} \times \text{length of exposure (h)})/170.$$

(*b*) *Evaluation of cumulative exposure*

The cumulative potential energy exposure E to the short-lived radon-222 decay products in air follows from the relationship:

$$E = k \times T \times F \times a_{Rn},$$

where $k = 5.6 \times 10^{-9}$ J/Bq = 1.6×10^{-6} WLM m^3/Bqh, the conversion factor between potential α energy and the equilibrium equivalent activity in air; T is the residence time in the considered area (in hours); F is the equilibrium factor for the decay product mixture; and a_{Rn} is the activity concentration of radon-222 in air.

Measurements of indoor air indicate an equilibrium factor in the range of 0.3–0.6. The long-term residence probability of individuals at home covers a range of 0.5–0.8 or a residence time in the range of 4380-7000 h per year. Assuming a mean equilibrium factor of 0.45 and a mean residence time of 5700 h per year (corresponding to a residence probability of 0.65), cumulative annual exposure to radon decay products in indoor air at home is calculated as

$$E = 1.4 \times 10^{-5} \times a_{Rn} \text{ (in Jh/m}^3\text{)} = 4.1 \times 10^{-3} \times a_{Rn} \text{ (in WLM).}$$

For a typical mean value of $a_{Rn} = 50$ Bq/m^3, cumulative annual exposure to radon decay products is about 0.0007 Jh/m^3 = 0.2 WLM per year.

1.4 Technical products

Radon is not produced as a commercial product, although it has been used in some spas for presumed medical effects.