Radon

dangers and benefits of a radioactive gas

by

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foreword

This booklet results from a research and development project on the environmental effects of radon and other gases in volcanic areas undertaken by geoscientists of the British Geological Survey. Knowledge of the behaviour of such gases and the measurement of their natural base levels is fundamental to understanding their impact on people, animals and crops.The project was funded by the British Government's Overseas Development Administration as a contribution to the technical assistance programme to developing countries.

The booklet aims to inform the non-specialist engaged in the planning of development projects of the properties and potential hazards of natural radon and how they can be identified. Mention is also made of the benefits of radon emission, for example in mineral and geothermal energy exploration.

Technical and scientific background explanations have been kept to a minimum and are clearly differentiated from the main narrative.

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acknowledgement

The illustration on page 16 is reproduced with permission of the National Radiological Protection Board (UK).

contents

Front cover illustration:
Part of a radon distribution map of the Ashover area, Derbyshire, England. The highest radon levels, shown in red, correspond to massive sedimentary limestones of Late Palaeozoic age.

background to the problem

Over the past few years, it has been discovered that some buildings and other confined spaces such as mines and caves, contain abnormal concentrations of radioactive gas. Because of the known effects of radiation on health, this has led to considerable alarm, and much media and government attention has been focussed on the problem around the world. The gas accumulates in places far from centres of man-made radiation pollution and is of a type that points entirely to natural generation by geological processes. The gas in question is radon.

Radon has only recently been viewed as a dangerous toxin. It was once a chemical curiosity, promoted as a 'health-giving' wonder gas at various spas. Since the end of World War II, especially in the fifties and sixties, it has been used, with success, as a pathfinder element in uranium exploration. Much information on the geological behaviour of the gas stems from this period. More recently it has been employed as an aid in locating geological faults, in the assessment of hot groundwater and in the prediction of earthquakes and volcanic eruptions. The knowledge gained from all of this work is being used to address the newly discovered problems of dangerous radon levels in confined spaces and in some groundwater supplies.

what is radon ?

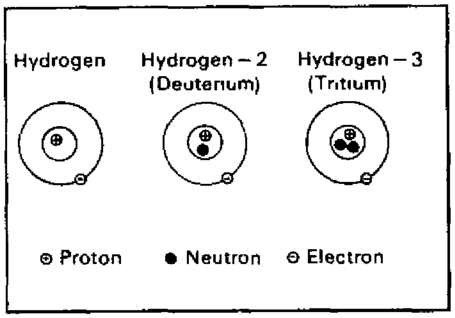
Radon (chemical symbol Rn) is an odourless, colourless gas which is produced by the natural radioactive decay of the two elements uranium (U) and thorium (Th), common constituents of many rocks. It is the only gas known to be radioactive and it decays to solid daughter products which are also radioactive. Radon exists widely and is present in all rocks and soils often in small amounts. It is frequently found at high levels in areas where there is no uranium mineralisation but, generally, more radon is produced from rocks with high uranium than from those with low concentrations. However, uranium is not uniformly distributed in rocks and soils. In some cases it is a major component in trace minerals; in other cases major minerals may contain but trace amounts of uranium.

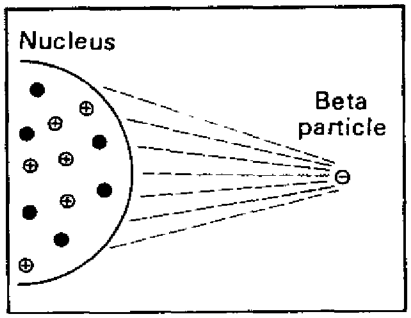
where is radon found ?

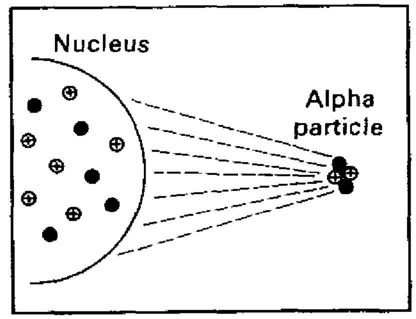
movement of radon

Most of the radon generated in a mineral remains in place but a portion may escape into voids in rocks and soils. The degree of release depends upon such factors as the surface area, shape, degree of fracturing, and other imperfections in the host mineral. The proportion of the radon that escapes is greater for soils than rocks, and for rocks than individual minerals. Once in the intergranular region, whether the radon migrates depends upon what other fluids flow through the rock and soil. Most radon is transported in carrier gases or liquids, the movements of which are in turn controlled by the permeability of the rocks. Frequently the radon concentration in soil gas relates to the amount of carbon dioxide or other carrier gases. This is particularly the case within geothermal areas and is a feature of value in surveys to assess sources of geothermal energy.

Since radon is moderately soluble in water it can be transported over considerable distances, to







atoms isotopes and decay

Everything is made up of **atoms.** Each atom has a **nucleus** containing **neutrons** and **protons**. In orbit around the nucleus, are **electrons**.

All atoms of the same chemical element have equal numbers of protons and electrons. They can, however, have different numbers of neutrons.

They are then called **isotopes** of that element and are often identified by the name of the element and the number of protons and neutrons in the nucleus.

Many elements are unstable, or **radioactive**, and will change, without external influence, into isotopes of another element by emitting **radiation** in a process known as **decay**.

Decay is most commonly caused by the emission of alpha (α) particles, beta (β) particles and gamma (γ) rays which are similar to X-rays.

α particles consist of 2 protons and 2 neutrons bound together, while β particles are electrons created when neutrons become protons in the nucleus.

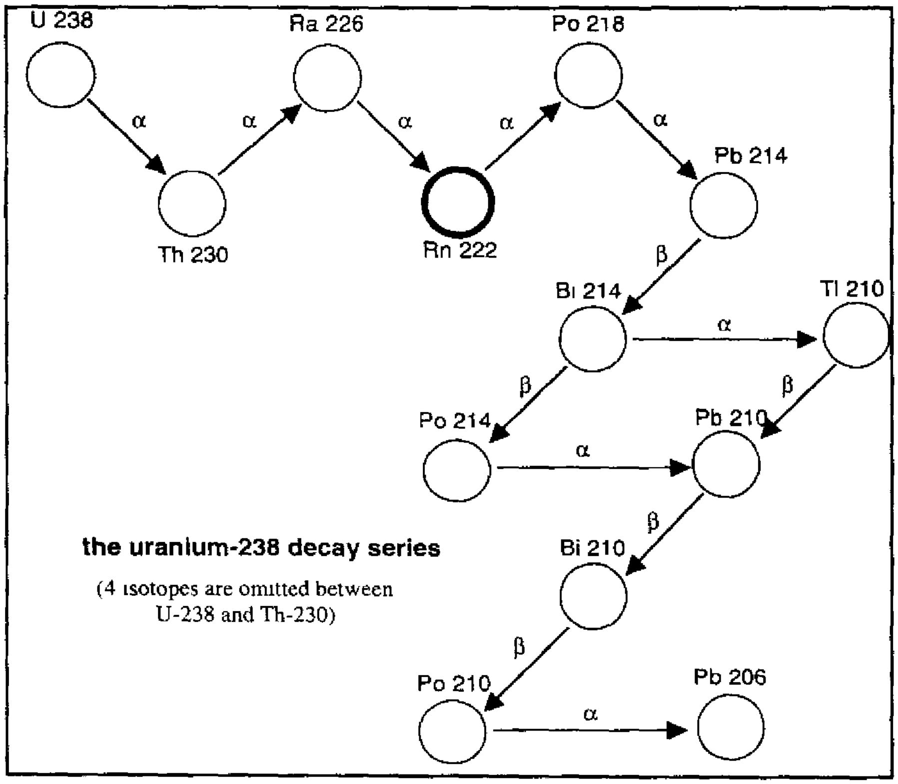
three isotopes

Uranium and thorium, in the form of three isotopes, are among the most common, naturally occurring radioactive elements. They are the parents for a whole series of radioactive daughter products which finally decay to stable lead isotopes. Three isotopes of radon are members of these series :

Rn-219 (also known as actinon) is in the decay chain of U-235. It has a very short half-life of some three seconds. This, plus the fact that U-235 makes up less than one percent of natural uranium, severely restricts its abundance in gases from most geological sources.

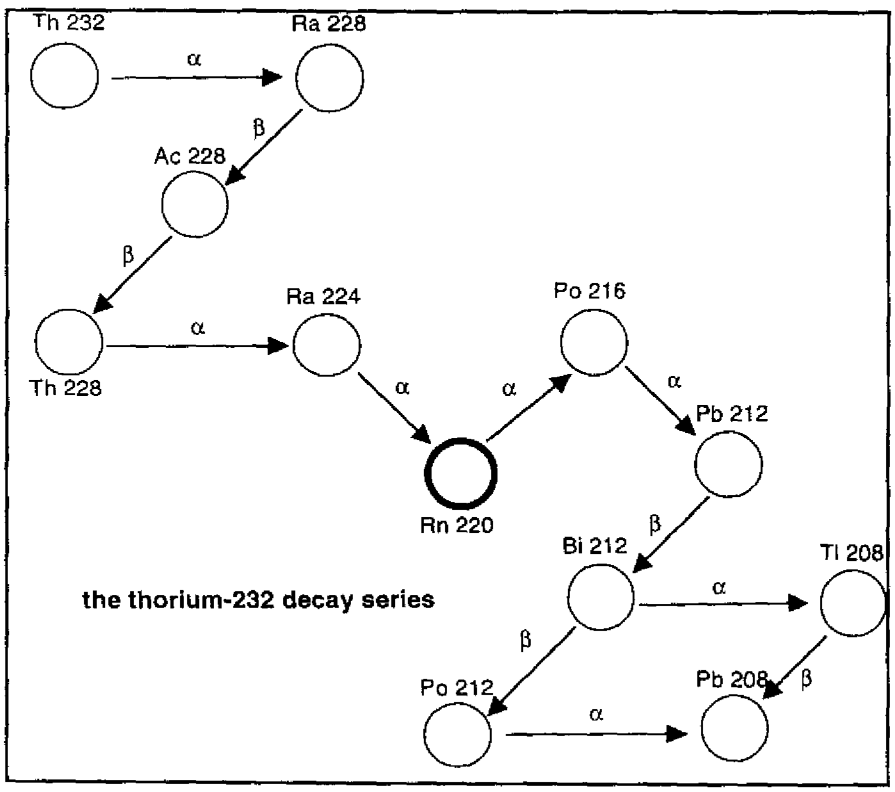
Rn-220 (thoron) has a half life of 54.7 seconds and is a member of the Th-232 decay series. Although thoron may account for 4% of the total radioactivity in houses in the UK, it does not appear to be a major threat to health.

Rn-222 (radon) is a member of the U-238 decay series and has a half-life of 3.82 days. However, its immediate parent is an isotope of radium (Ra-226) which has a half-life of 1622 years. Radium is also less mobile than uranium in the weathering environment. These two properties of radium, long half-life and stability, make Rn-222, in turn, the radon isotope of most concern. The long half life means that it can migrate over considerable distances.



the uranium-238 decay series

(4 isotopes are omitted between U-238 and Th-230)



the thorium-232 decay series

produce anomalous concentrations far from the original uranium or thorium source. Fluid transport is particularly rapid in limestones and along faults but radon levels may also be high in rocks rich in phosphate, in granites and in carbonaceous shales. Buildings sited above any such rock types, or along faults, may form ideal traps for the accumulation of radon.

radon and health

Radon is a health hazard because it emits alpha particles (page 6). Outside the body these present no problems because, being large and relatively highly charged, they cannot pass through skin or clothing. However, once ingested or inhaled in air or water, alpha particles can damage tissue *because* they are not penetrative, and thus give up their energy to a relatively small volume of tissue. Although radon is the major pathway by which alpha activity enters the human body, most is breathed out again. Its solid daughter products however, which are also alpha particle emitters, are more dangerous because they often remain in the respiratory tract where they increase the risk of lung cancer. Some radon may be dissolved in body fats and its daughter products transferred to the bone marrow. The accumulated dose in older people can be high and may give rise to leukemia. In contrast, beta and gamma emitters, for the same level of activity, when ingested, present less of a problem since the effect of their radiation is more widespread. The National Radiological Protection Board has shown that, in the UK, about half of the total dose for the average person results from combined radon and daughter products.

radon detection and measurement

The same alpha particles that can cause so much damage to health are of much benefit in the detection and measurement of radon, the only alpha-emitting gas. This can be done with relatively simple equipment.

applications of radon surveys

Many strategies for radon surveys, especially the field procedures, were developed for prospecting for nuclear raw materials. However, radon exists widely and frequently is found at high levels in areas where there is no uranium mineralisation. Studies have also shown that radon measurements can be important in other geological investigations. Measurements of radon in soil gas have been used to locate naturally heated groundwater, which can often be a source of energy. Other applications include the location of faults, and the possible prediction of earthquakes and volcanic eruptions.

radon in confined spaces

Currently the major use for radon geochemical measurements is in the assessment of areas for their potential to generate radon which may get into buildings.

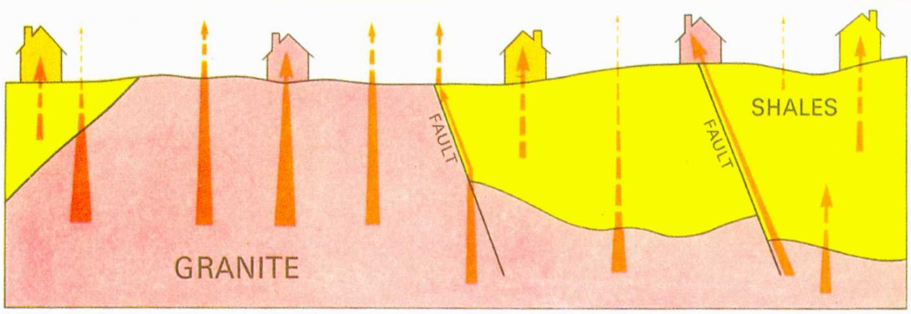
Radon is easily dispersed to very low levels in the atmosphere. However, in confined spaces in contact with soil or rock, such as caves, mines and buildings, radon and its daughters can accumulate. Soil gas is drawn into a building by a slight underpressure indoors which results from the warmer air rising. Hence radon problems in houses are due to bulk flow of ground gas carrying radon, with a relatively small contribution from building materials.

measurement in soil

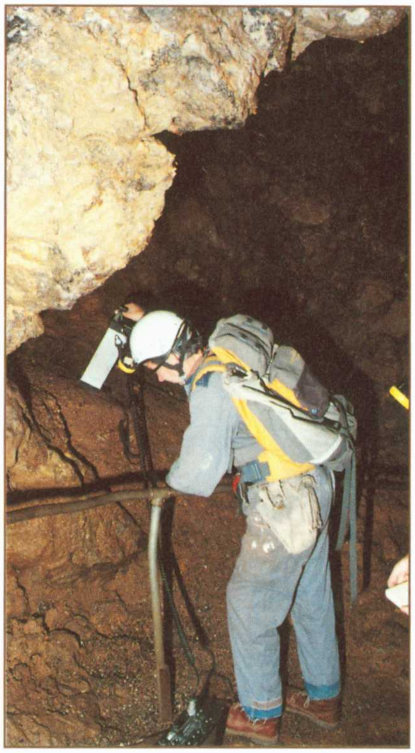
In soil, radon is measured in a matter of minutes by means of a hollow spike hammered into the ground and linked to a gas pump and detection unit. An augered hole serves just as well. Up to 50 readings per day are possible. The technique has the advantage of minimal soil disturbance if the sampling probe is narrow, and is usually used for rapid surveys. Detection of radon is usually based upon the zinc sulphide scintillation method (page 14). However, in interpreting the results, account must be taken of the prevailing weather conditions and of the permeability of the soil. Both can have profound effect on radon levels in soil gas.

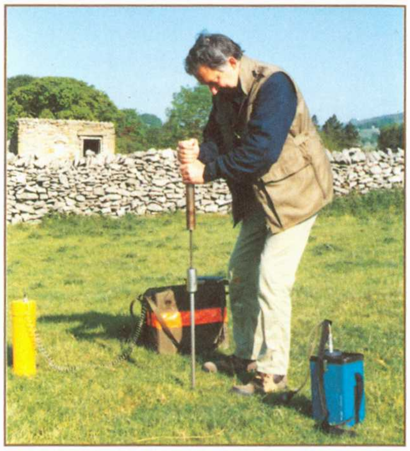
Alternative, passive, methods are based upon detectors being buried in the ground and recovered some time later, often up to a month. The long exposure is necessary to ensure that the soil gas re-equilibriates with the gas in the hole after the considerable disturbance to the soil that the method causes. This procedure is used when long term monitoring is to be employed to overcome the problems of variation in concentration of radon caused by changing weather conditions.

Etched track methods are the most popular and are generally used for long term monitoring of soil radon. Occasionally semiconductor or absorber methods are employed (page 15). The detectors are normally taped to the bottom of a plastic cup, which is inverted before burial. Although they overcome many of the problems associated with temporal variation in radon fluxes the detectors are time consuming to emplace. Two visits to each site followed by laboratory processing are necessary. In practice they are generally not favoured for primary survey, although they do have an important role to play at later stages.



Radon may be abundant in granites. Shales impede its progress except where faulted





Above:
Radon gas and gamma spectrometry survey.

Top right:
Gamma spectrometry survey in a radon-rich cave.

Right:
Driving the gas-collector tube.

measurement in water

There is a high partition coefficient (gas to water) for radon so that the passage of fine gas bubbles through water provides an efficient means of extraction. The gas may be drawn into an evacuated zinc sulphide counting chamber. Alternatively a sealed recirculating system may be set up. Very careful attention must be paid to the timing of both degassing and counting and careful calibration of the procedure with standard radium solutions is required.

Other methods show promise but require expensive equipment and laboratory processing such as the use of immiscible liquid scintillators. An alternative method makes use of the radon daughter Bi-214 photopeak emission at 1.76 MeV, measured using either a sodium iodide scintillation crystal or a high resolution lithium drifted germanium semiconductor detector. The Bi-214 is allowed to 'grow-in' for several weeks prior to measurement.

measurement in solid materials

One of the solid daughter products of radon is Bi-214 (page 7). This emits high energy gamma radiation at 1.76 MeV. Gamma spectrometric determinations of uranium in field and laboratory often make use of this photopeak on the assumption, reasonable in most cases, that the decay chain is in equilibrium and therefore this measurement provides an effective total radon determination. If the parent uranium mineral is resistant to weathering (thorium - and REE-rich uranium oxides and silicates, monazites, zircons etc.) then generally the radium will tend to be in secular equilibrium with the uranium. In such minerals the radon loss is generally low and gamma spectrometric measurements give a good indication of the uranium contents.

The measurement of radon release from samples requires an alternative method. This measurement is useful for assessing the likely release of radon from solid samples and is usually expressed as a proportion of the radon capable of being emitted from the sample (the Emanation Coefficient). Because of the large diffusion distances in air, most measurements are carried out under water. Samples such as disaggregated soil, or rock core, are placed in water for a period of about 30 days. The radon which has passed into the aqueous phase is measured by one of the analytical procedures for water described above.