Measuring radon in air, soil and water—an introduction to nuclear physics for schools

Measuring radon in air, soil and water—an introduction to nuclear physics for schools

K E Johansson[1,2], Ch Nilsson[1] and S Wachtmeister[1,2]

[1] Stockholm House of Science, AlbaNova SE-106 91 Stockholm, Sweden
[2] Department of Physics, Stockholm University, AlbaNova SE-106 91 Stockholm, Sweden

E-mail: kej@physto.se

Abstract
With the radon measurement activities at Stockholm House of Science, nuclear and experimental physics is introduced in a way that attracts the attention and interest of the students. These projects give the students the opportunity to use mobile detectors, either in their school, in the House of Science or in their homes. During 2006, 34 radon experiments were organized for school classes or groups of students. There were 21 shorter activities, ten one-day projects and three projects lasting for one or more weeks. Because of the popularity of the radon project, it will be extended with the introduction of more mobile detectors.

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Introduction

Nuclear physics is part of the physics curriculum both at elementary school and high school levels, but the schools sometimes do not have very advanced equipment for studying nuclear physics. The radon experiments and the study of radioactivity at the House of Science provide teachers with experiments in nuclear physics that go beyond the standard school experiments.

Radioactivity is a natural part of our environment. Some radiation originates from protons in the cosmic radiation colliding with the nuclei of the atmosphere, producing a variety of particles that decay into muons, electrons and photons that can be observed on the ground. Other forms of radiation emanate from radioactive decay in the crust of the Earth. This paper deals with the radiation from the inert gas radon and its decay products, the radon daughters, emanating from the rocks and material around us.

Detector equipment

Stockholm House of Science is well equipped with different kinds of nuclear detectors. Apart from the usual Geiger–Müller counters the laboratory has two gamma spectrometers with NaI detectors [1], one 'Atmos' detector [1] with which the radon content in air is measured, and one 'Markus' detector [1] with which the radon content in soil is measured. A Wilson cloud chamber with an observational area of 40 cm × 40 cm [2] is used to visualize the muons, electrons and α particles in our normal surroundings. The presence of α particles emanating from the decay of radon and polonium nuclei is clearly visible as short distinct tracks (figures 1 and 2). With the Atmos

Table 1. Normal levels of ^{222}Rn measured at a depth of 1 m [3].

Soil type	^{222}Rn (Bq m^{-3})
Moraine, normal	10 000–40 000
Moraine containing granitic materials	20 000–60 000
Moraine containing uranium-rich granitic materials	40 000–200 000
Ridge gravel	10 000–15 000
Sand, silt	4 000–50 000
Clay	10 000–120 000
Soil containing alum shale	50 000–1000 000

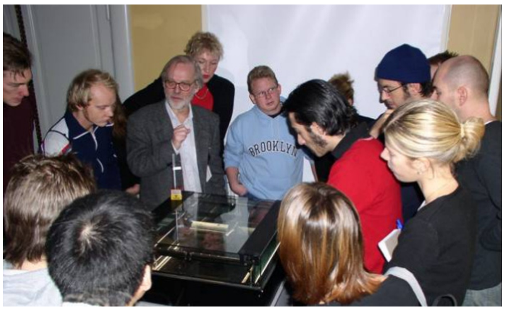

Figure 1. A group of students observing particles in the cloud chamber.

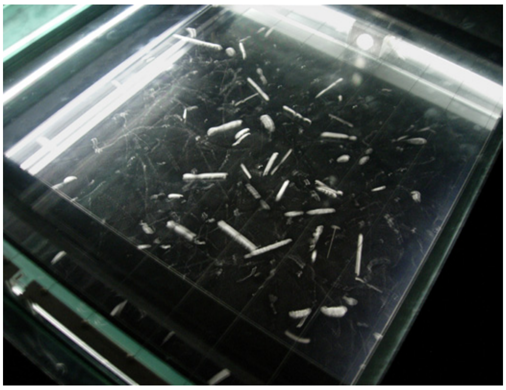

Figure 2. A photograph of the 40 × 40 cm^2 cloud chamber showing ionizing radiation including the thicker tracks from α particles emitted in the decay of the radon and polonium nuclei. The radon content in the room was measured to be around 1600 Bq m^{-3}. A short video sequence of the cloud chamber can be found in the online version of the journal at stacks.iop.org/physed/42/281and [7].

instrument the qualitative cloud chamber image is related to a quantitative measurement.

The physics of radon

Radon is an invisible, colourless and odourless inert gas. It occurs naturally in rocks and soil and is produced in the radioactive decay of uranium and thorium. The ground is the most important source for radon in buildings. The other source is construction materials, foremost 'blue concrete' containing alum shale. The levels found in soil depend strongly on the constituents and the underlying rock (table 1).

Particularly, three radon isotopes are of interest: ^{219}Rn, ^{220}Rn and ^{222}Rn, which appear in the decay chains starting with ^{235}U (actinium series), ^{232}Th (thorium series) and ^{238}U (uranium series) respectively. Radium nuclei decay into radon by emission of an α particle (figure 3). Being an inert gas, radon can migrate from the radioactive minerals and travel through sand and the tiny cracks in the rocks to enter houses through cracks in foundation plates and basement walls. Due to the relatively long half-life of ^{222}Rn (3.8 days as compared to 3.9 s for ^{219}Rn and 51.5 s for ^{220}Rn) it can migrate long distances to reach the indoor atmosphere where it can cause health hazards. The other isotopes of radon have normally decayed into radon daughters that are quickly absorbed before reaching houses.

Medical hazards

Breathing air with high levels of radon gas and radon daughters increases the risk of lung cancer. Smoking increases the risk dramatically. This is due to the fact that the radon daughters like Po and Pb are metallic and stick easily to dust or smoke particles in the air. These particles can stick to the lung tissues thereby increasing the risk of radiation damage. The radon gas itself is less dangerous than the radon daughters. Being an inert gas, most of it is ventilated out. Radon in indoor air can be

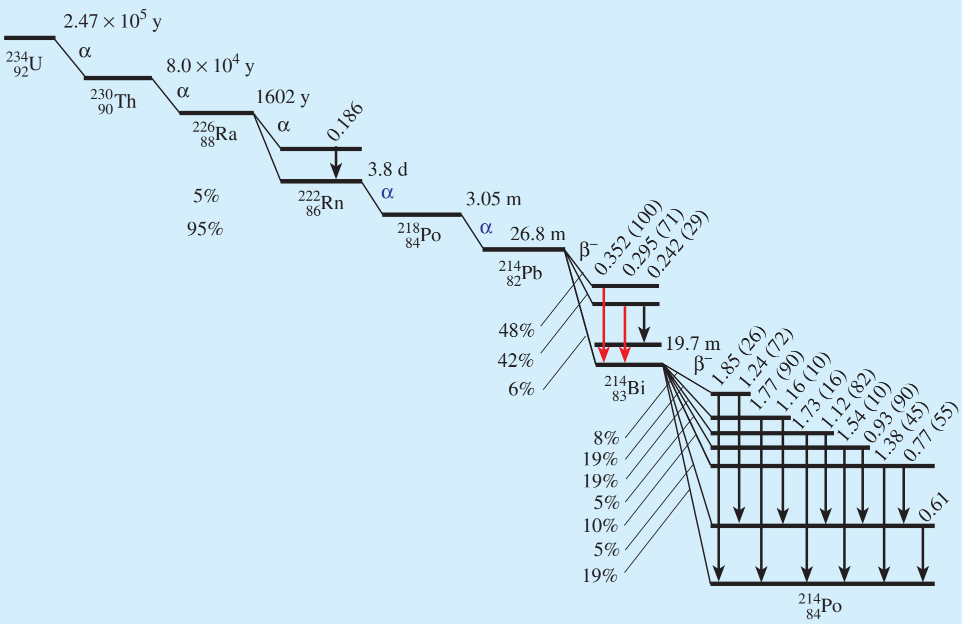

Figure 3. Part of the uranium decay series. In the coal container method, γ radiation from the decay ^{214}Pb → ^{214}Bi ('radon daughters') is analysed to determine the radon concentration. Atmos measures the radiation emitted from the ^{222}Rn and ^{218}Po decays while Markus uses the decay from ^{218}Po alone to determine the radon content.

a problem. In Europe, the average radiation levels are around 70–90 Bq m^{-3} [4].

Regulations in Sweden

Radon levels in schools and day-care centres must not exceed 200 Bq m^{-3} after 2010 and radon in dwellings must not exceed 200 Bq m^{-3} after 2020. Today, these are recommended maximum levels. For most working places the limit is 400 Bq m^{-3}.

Measuring radon content in air, soil and water

Radon content in air

Two methods, both developed by Gammadata [1] for measuring the radon content in air, are used. The first method, the 'coal container method', uses containers with a filter and activated charcoal inside. Thanks to the filter, only air and radon gas, but not radon daughters, enter the container through diffusion. The radon gas is adsorbed to the surface of the activated charcoal. Equilibrium with the surrounding air and radon gas is reached after an exposure time of around 3 days. The radon content is determined by measuring the γ radiation from the container using a gamma spectrometer. This measurement is done in the House of Science physics laboratory. To correctly estimate the radon content, it is important to compensate for the elapsed time after the exposure and also the activated charcoal's ability to adsorb radon atoms, which depends on the humidity and the average temperature during the exposure. The computer program is then able to determine the radon content by utilizing the measured γ radiation from ^{214}Pb and the known probabilities for decay (figures 3 and 4). The obtained result is the average radon content during the 3 days of exposure. The coal containers can be reused an unlimited number of times by placing them in an oven for 12 h at 140 °C.

To determine the radon content in air, the Atmos 12 instrument [1], a high performance continuous radon measurement instrument, is also used. Air is pumped into the instrument through filters that remove the radon daughters. The radon content of the air is then measured in an ionization chamber that counts the α particles emitted in the decay of the ^{222}Rn and ^{218}Po nuclei. The instrument can determine the average radon

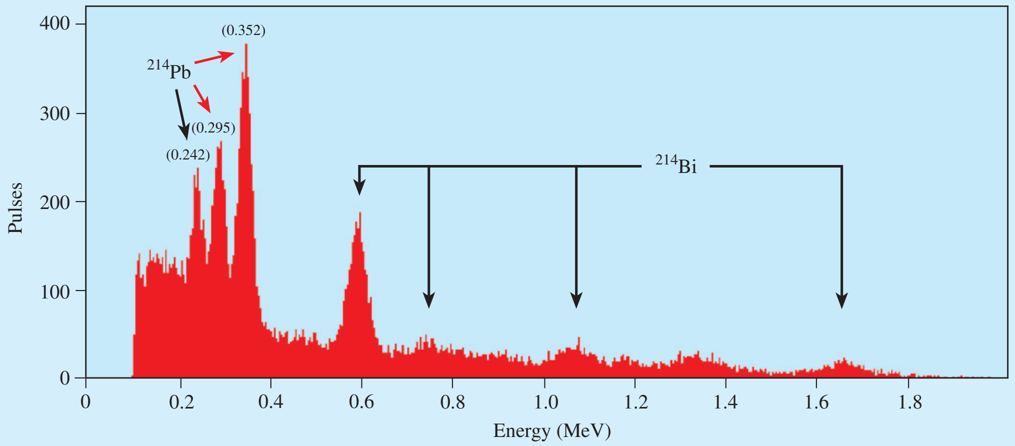

Figure 4. A gamma spectrum from a coal container that has been exposed to air and radon gas for three days. The computer program winDAS subtracts the background spectrum and counts the number of pulses within the interval 0.26 to 0.39 MeV before converting the result to measured radon content, in this case 1500 Bq m^{-3}.

content every 1, 5, 10 or 30 min and every 1, 8 or 24 h. The Atmos instrument already gives reliable results at the 10 min setting. The collected data can be transferred to a computer for further analysis. Due to the quick response of the instrument it is possible to study how the radon content changes during the time of the measurement. It is also possible to detect where radon gas may be leaking into a house by attaching a tube to the 'air in' connection and then 'sniffing' for increased activities. With the Atmos instrument, it is also possible to quickly investigate the radon content in several different locations by allowing for the air in the measuring chamber to be completely changed and then completing a new integration. In this way the current radon content can be determined fairly well in a new location every 10–20 min.

Radon content in soil

For measuring the radon content in ground air, the portable, battery-powered Markus 10 instrument developed by Gammadata [1] is used. After hammering the probe pipe down to a depth of about 70 cm into the ground, the water lock and the measuring instrument are attached. First, air from the ground is pumped through the probe pipe into the measuring chamber. After the pumping phase (about 30 s), the detector is automatically activated and the charged radon daughters drift towards the detector due to an electric field inside the chamber, and the α radiation from the radon daughters is registered. After about 10 min, the radon content is determined using the activity from ^{218}Po.

Radon content in water

With the gamma spectrometer described above, it is also possible to measure the radon content in water by using a plastic can with a specified volume. It is important not to stir the water in the process of collecting the sample and to use airtight glass bottles during transportation. It is also important to let the water run long enough before it is collected to make sure that the radon content from water contained in the well is measured and not the water that has been in the pipe a long time.

Measuring gamma radiation from building materials

To determine whether blue concrete or similarly radioactive materials have been used in the construction of a building, a Berthold LB 1210B Geiger–Müller instrument is used to measure the equivalent dose rate [5]. The presence of blue concrete gives increased dose rate values ranging from 0.25 up to 120 μSv h^{-1}, compared to a normal background level around 0.1 μSv h^{-1}.

The intensity of the radiation is expressed in becquerels (Bq or disintegrations per second), while the equivalent absorbed dose, expressed in sieverts (Sv or J kg^{-1}), also takes into account the different effects of α, β and γ radiation on living

Figure 5. A student determining the radon content in air by measuring the γ radiation from ^{214}Pb from a coal container that has been exposed to air and radon gas over three days.

matter, like the potential damaging effects of α radiation.

Student activities

The House of Science can offer different student activities for radon measurements, varying from a few hours to more than a week.

Short visits

During short visits lasting a few hours, the coal container method is used. The students borrow coal containers from the House of Science prior to the visit and have them exposed to radon in their school or in their homes. If the students do not bring coal containers, they can use coal containers exposed in the basement of the House of Science. This experiment is used to demonstrate many of the components of conducting a real radon measurement. The students learn to use the gamma spectrometer (figure 5), to calibrate the energy scale and compensate for background radiation and experimental effects due to temperature and humidity. The interpretations of the results and possible uncertainties are important parts of the exercise. So is the understanding of how statistical variations might affect the measured results and how the precision of the measurement may be improved by doing repeated measurements and calculating a weighted average including error margins.

Visits lasting one to five days

The one day projects are prepared in advance by placing coal containers on different floors and in different rooms in the House of Science or nearby buildings and basements. The students collect the containers and start the measurements. In the projects lasting up to a week (e.g. Summer Research School), the students also take part in planning how to perform the measurements. Discussion of the measurements and conclusions about the radon content and its distribution in the building are important parts of the exercise (figure 6). The measurements with coal containers give an average value of the radon content during the last three days. However, in projects lasting a day or longer the Atmos instrument is often used as well, making it possible to see the natural variations of the radon content, and how the radon content may vary during the week depending on whether the ventilation system is turned on or off.

Longer projects

In the longer projects lasting up to one school term, the students are given a short introduction before forming groups of two or three. Normally the groups choose one main measuring technique during the project. Groups using different techniques are encouraged to collaborate with each other. After the first measurements, they formulate questions and hypotheses which they work with during the project. The students are also asked to write a concluding report and present their work orally, both defending their work and critiquing the work of other students in a final session. The longer projects include studies for finding the dominant radon source and whether the radon content is affected by the weather, the ventilation system and the radon content in the ground. Studying the diffusion and distribution of radon gas in the building is also an important investigation.

Examples of measurements

Figure 6 shows the measured radon content, using coal containers in parts of the House of Science. The highest concentration on the ground floor during week days, 1030 Bq m^{-3}, is found in the lift shaft. In the entrance hall near the lift and the stairs down to the basement the average radon level is 222 Bq m^{-3}. The radon content is lower further away from the stairs. However, during

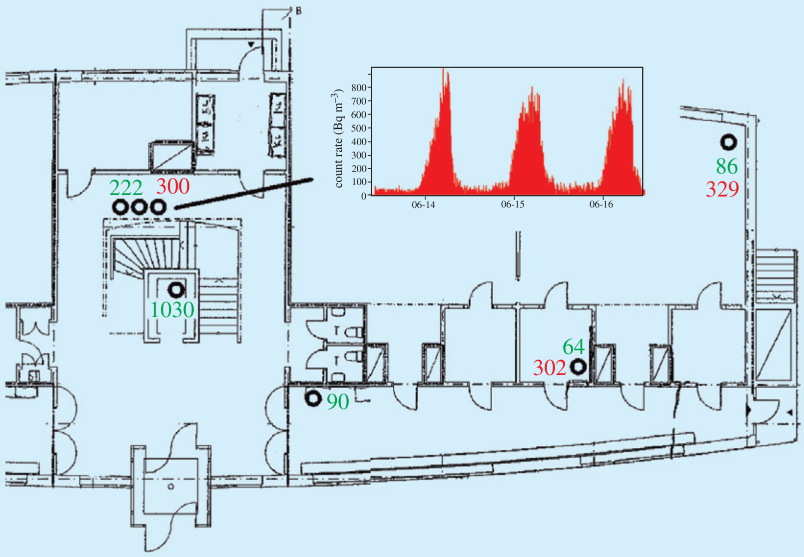

Figure 6. The radon content measured on the ground floor of the House of Science. Black circles represent coal containers. Numbers in green are radon levels in Bq m^{-3} obtained from coal containers exposed during weekdays, while values in red denote measurements that include a weekend. Inserted into the image is a radon time distribution graph from the Atmos instrument covering three weekdays.

the weekends there seems to be an increased and more uniform radon distribution on the whole ground floor. The inserted radon–time distribution graph from a measurement with the Atmos instrument reveals that the radon content actually varies greatly during the weekdays and nights, with only 40 Bq m^{-3} during daytime but around 700 Bq m^{-3} in the early mornings. This depends on whether the ventilation system is on or not. The weighted average from the three coal containers in the entrance hall gave a radon content of 222 ± 9 Bq m^{-3}, agreeing very well with the average value from the measurement with the Atmos instrument, 217 ± 2 Bq m^{-3}. Further measurements with the Atmos instrument show that the radon content on the two floors in the House of Science reaches an equilibrium level of around 700 Bq m^{-3} during the weekends when the ventilation system is turned off, while the radon content in the basement is close to 2000 Bq m^{-3}.

Figure 7 shows that the radon content in a nearby basement is higher during the nights and during the longer weekends when the ventilation system is turned off. It also shows a sudden increase with about 300 Bq m^{-3} in the measured daytime values, which was caused by a sudden drop in the outside temperature with 10 °C, affecting the ventilation and hence the radon content.

Measurements of radon content in ground air with the Markus instrument during the Summer Research School 2006 are shown in figure 8. Measurements outside the House of Science gave values between 19 and 23 kBq m^{-3}. However, in one location repeated measurements gave values between 6 and 9 kBq m^{-3}. It turned out there was a tunnel underneath. Inside the partially ventilated tunnel, the radon content in the air was about 2000 Bq m^{-3}.

Response to the radon projects

The students appreciate coming to the House of Science to learn about radon and to determine the radon content in air, water and soil. As the presence of radon is a potential health hazard, the students are stimulated and interested to learn more about nuclear physics. The visual demonstration of α particles in the Wilson cloud chamber and the possibility of relating the observed activity to the measured radon content in the room (figures 1 and 2) is very popular. The students learn to handle nuclear detectors, to

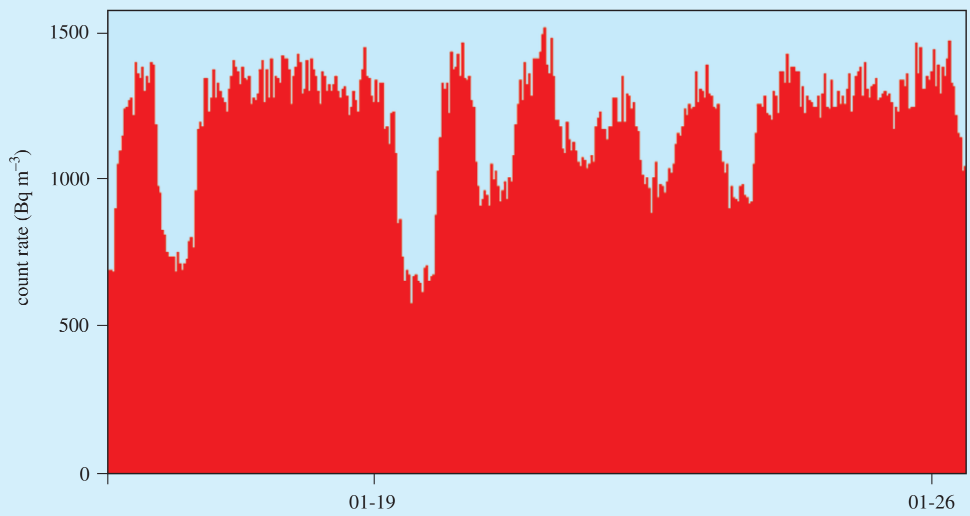

Figure 7. A radon–time distribution graph covering 10 days, measured in a basement with the Atmos instrument.

Figure 8. Measurements of radon content in ground air with the Markus instrument during the Summer Research School 2006.

plan and make measurements, analyse, discuss and present their results. If high levels of radon are found in a school or in a student's home, contact with the public health authorities is recommended.

The radon experiments are greatly in demand in the House of Science. In 2006 a total of 34 radon projects were carried out; 21 classes analysed the radon content in their schools or homes performing the final measurements in the House of Science physics laboratory, ten groups of students worked for one day with radon measurements and three groups of about 20 students worked for a full term on a radon project.

Further developments

Due to the popularity of the radon measurement projects, we intend to increase the number of mobile detectors for continuous radon measurements to be used outside the laboratory. Having several such detectors also makes it possible to study how the radon content varies at different locations in a building due to changing conditions, like closing of a door or opening a window. We also intend to equip the laboratory with small, mobile, relatively robust and easy-to-use Geiger–Müller or similar type detectors, which can be used by students doing project work in their schools.

House of Science

The radon projects are organized by Stockholm House of Science, a science laboratory for physics, astronomy and biotechnology devoted to schools. The aim is to make modern science accessible to teachers, school classes and individual students, and to interest the students in today's natural science [6, 7]. The House of Science in the AlbaNova University Centre is part of Stockholm University and the Royal Institute of Technology.

Summary

The radon measurement projects are a good way to interest students and to introduce nuclear and experimental physics. Radon exists at some level in practically all buildings and, as it is known to be a possible health hazard, this stimulates discussion and interest in radioactivity and nuclear physics in general. These projects give the students the opportunity to use mobile detectors, either at home, in their school, at the House of Science or elsewhere, and to plan and carry out measurements. The popularity of the different radon measurement projects will lead to the purchase of a number of robust mobile detectors to allow the students to make more experiments on their own.

Film text

The 1930s movie of the Wilson cloud chamber (online at stacks.iop.org/physed/42/281), with a sensitive surface of 40 × 40 cm^2, shows the ionizing radiation in the basement. The thicker tracks are from α particles emitted in the decay of the radon and polonium nuclei. The radon content in the room was measured to be around 1600 Bq m^{-3}. Due to the high radon content and the closeness to the surrounding radon source in the rock, tracks from α particles emitted from the consecutive decays of the short-lived radon-220 (half-life 52 s) and polonium-216 (half-life 0.16 s) in the thorium series can be seen as a 'V'. Thinner tracks are mainly for electrons.

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Erik Johansson is Professor at Stockholm University and Director emeritus at Stockholm House of Science.

Christer Nilsson is responsible for the physics laboratory at Stockholm House of Science.

Staffan Wachtmeister is a PhD student in physics at Stockholm University and assistant at the House of Science.