BS IEC 61577-4:2009

BSI British Standards

Radiation protection instrumentation — Radon and radon decay product measuring instruments —

Part 4: Equipment for the production of reference atmospheres containing radon isotopes and their decay products (STAR)

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ISBN 978 0 580 54654 9

ICS 13.280

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2009.

Amendments issued since publication

Amd. No.	Date	Text affected

IEC 61577-4

Edition 1.0 2009-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Radiation protection instrumentation – Radon and radon decay product measuring instruments –
Part 4: Equipment for the production of reference atmospheres containing radon isotopes and their decay products (STAR)

Instrumentation pour la radioprotection – Instruments de mesure du radon et des descendants du radon –
Partie 4: Dispositif pour la réalisation d'atmosphères de référence contenant des isotopes du radon et leurs descendants (STAR)

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX U

ICS 13.280

ISBN 2-8318-1031-3

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RADIATION PROTECTION INSTRUMENTATION – RADON AND RADON DECAY PRODUCT MEASURING INSTRUMENTS –

Part 4: Equipment for the production of reference atmospheres containing radon isotopes and their decay products (STAR)

FOREWORD

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International Standard IEC 61577-4 has been prepared by subcommittee 45B: Radiation protection instrumentation, of IEC technical committee 45: Nuclear instrumentation.

The text of this standard is based on the following documents:

FDIS	Report on voting
45B/598/FDIS	45B/606/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61577 series, under the general title *Radiation protection instrumentation – Radon and radon decay product measuring instruments*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Radon is a radioactive gas produced by the decay of ^{226}Ra, ^{223}Ra and ^{224}Ra, respectively decay products of ^{238}U, ^{235}U and ^{232}Th which are present in the earth's crust. By decay, radon isotopes (i.e. ^{222}Rn, ^{219}Rn, ^{220}Rn) produce three decay chains, each ending in a stable lead isotope.

NOTE In normal conditions, due to the very short half-life of ^{219}Rn, its activity and the activity of its RnDP[1] are considered negligible compared to the activity of the two other series. Its health effects are therefore not important. Thus in this standard ^{219}Rn and its decay products are not considered.

Radon isotopes and their corresponding short-lived Radon Decay Products (RnDP) (i.e. ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po for ^{222}Rn, and ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl for ^{220}Rn) are of considerable importance, as they constitute the major part of the radiological exposure to natural radioactivity for the general public and workers. In some workplaces, for instance in underground mines, spas and waterworks, the workers are exposed to very significant levels of RnDP. These radionuclides are present in variable quantities in the air, in a gaseous form for the radon isotopes, and as very fine particles for the decay products. It is worthwhile for health physicists to be able to measure with a great accuracy the level of this kind of natural radioactivity in the atmosphere. Because the very particular behaviour of these radioactive elements in the atmosphere and in the corresponding measuring instruments, it is necessary to formalize the way such instruments could be tested.

Remark:

In order to facilitate its use, the IEC 61577 series is divided into the following different parts:

IEC 61577-1: This emphasizes the terminology and units of the specific field of radon and radon decay products (RnDP) measurement techniques and presents briefly the concept of System for Test Atmospheres with Radon (STAR) used for test and calibration of radon and RnDP measuring devices.

IEC 61577-2: This part is dedicated to the tests of ^{222}Rn and ^{220}Rn measuring instruments.

IEC 61577-3: This part is dedicated to the tests of $RnDP_{222}$ and $RnDP_{220}$ measuring instruments.

IEC 61577-4: Details how a STAR is constructed and how it can be used for testing.

1 RnDP is the acronym of Radon Decay Products and it is equivalent to Radon Progeny (see [1] in the Bibliography).

RADIATION PROTECTION INSTRUMENTATION – RADON AND RADON DECAY PRODUCT MEASURING INSTRUMENTS –

Part 4: Equipment for the production of reference atmospheres containing radon isotopes and their decay products (STAR)

1 Scope and object

The IEC 61577 series covers the general features concerning test and calibration of radon and radon decay products measuring instruments. It is also intended to help define type tests, which have to be conducted in order to qualify these instruments. These type tests are described in IEC 61577-2 and IEC 61577-3. This standard addresses only the instruments and associated methods for measuring isotopes 220 and 222 of radon and their subsequent short-lived decay products in gases.

IEC 61577-4 concerns the System for Test Atmospheres with Radon (STAR) needed for testing, in a reference atmosphere, the instruments measuring radon and RnDP. The clauses that follow do neither claim to solve all the problems involved in the production of equipment for setting up reference atmospheres for radon and its decay products, nor to describe all the methods for doing so. They do however set out to be a guide enabling those faced with such problems to choose the best methods for adoption in full knowledge of the facts.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-111:1996, *International Electrotechnical Vocabulary (IEV) – Chapter 111: Physics and chemistry*

IEC 60050-393:2003, *International Electrotechnical Vocabulary (IEV) – Part 393: Nuclear instrumentation – Physical phenomena and basic concepts*

IEC 60050-394:2007, *International Electrotechnical Vocabulary (IEV) – Part 394: Nuclear instrumentation – Instruments, systems, equipment and detectors*

IEC 61577 (all parts), *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures*

ISO/IEC Guide 99:2007, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ICRP 32: *Annals of the ICRP, Publication N° 32, Limits for inhalation of Radon Daughters by Workers, Vol. 6, N°1, 1981, Pergamon Press*

ICRP 38: *Annals of the ICRP, Publication N° 38, Radionuclides transformations, Energy and Intensity of Emissions, Vol. 11 - 13, 1983, Pergamon Press*

ICRP 65: *Annals of the ICRP, Publication N° 65, ICRP Publication 65: Protection Against Radon-222 at Home and at Work, Vol. 23/2,* 1994, Pergamon Press

3 Terms, definitions and units

For the purposes of this document, the following terms, definitions and units apply.

Throughout the whole standard, the term RADON is used to denote all the radon isotopes, which are covered by this standard. When a particular isotope is to be referred to, it will be indicated by its chemical symbol preceded by its mass number (e.g. ^{220}Rn, ^{222}Rn). For historical reasons, ^{220}Rn is also called thoron.

The term RADON DECAY PRODUCTS or its abbreviation (RnDP) denotes the whole set of short-lived decay products, which are concerned by this standard. A particular isotope is indicated by its chemical symbol preceded by its mass number. The subscripts $_{222}$, $_{220}$ added to the symbol RnDP refer to the whole set of short-lived decay products of the corresponding radon isotope (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po), (^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl).

All the nuclear data used in this standard refers to ICRP 38, as this standard applies mainly to instruments used for radiation protection purposes.

3.1 General terms and definitions

3.1.1
activity
A
quotient, for an amount of radionuclide in a particular energy state at a given time, of dN by dt, where dN is the expectation value of the number of spontaneous nuclear transitions from this energy state in the time interval of duration dt:

$$A = \frac{\mathrm{d}N}{\mathrm{d}t}$$

NOTE This quantity is expressed in becquerels (Bq).

[IEV 393-14-12]

3.1.2
volumic activity
activity concentration
$C_\mathbf{A}$
quotient of the activity by the total volume of the sample

NOTE 1 For a gas, it is necessary to indicate the temperature and pressure conditions for which the volumic activity, expressed in becquerel per cubic metre, is measured, for example standard temperature and pressure (STP).

NOTE 2 This quantity is expressed in becquerels per cubic metre ($Bq \cdot m^{-3}$).

[IEV 393-14-16]

3.1.3
primary standard
standard that is designed or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity

NOTE The concept of primary standard is equally valid for base quantities and derived quantities.

[VIM, 5.4, modified]

3.1.4
secondary standard
standard whose value is assigned by comparison with a primary standard of the same quantity

[VIM, 5.5, modified]

3.1.5
reference standard
standard generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived

[VIM, 5.6, modified]

3.1.6
mass flow rate
($kg \cdot s^{-1}$)
mass of a gas flowing in a conduit during a unit time

3.1.7
volume flow rate
($m^3 \cdot s^{-1}$)
volume of gas flowing in a conduit during a unit time

3.1.8
aerosol
set of solid or liquid particles in suspension in a gaseous medium

NOTE The range of particle diameter is generally from a few nanometres up to 10 µm.

[IEV 393-11-37]

3.1.9
homogeneous
qualifies a physical medium in which the relevant properties are independent of the position in the medium

[IEV 111-13-08]

3.1.10
conventionally true value of a quantity
v_c
value attributed to a particular quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose

NOTE "Conventionally true value of a quantity" is sometimes called assigned value, best estimate of the value, conventional value or reference value.

[IEV 394-40-10]

3.2 Specific terms and definitions

3.2.1
Potential Alpha Energy
***PAE* or ε_p**
total alpha energy emitted during the decay of RnDP atoms along the decay chain through to ^{210}Pb or ^{208}Pb respectively for the decay chains of the ^{222}Rn and ^{220}Rn

$$\varepsilon_{p\ 222} = [(6{,}003 + 7{,}687) \times N_{218Po} + 7{,}687 \times (N_{214Pb} + N_{214Bi}) + 7{,}687 \times N_{214Po}] \times 1{,}602 \times 10^{-13} \quad \text{(J)}$$

$$\varepsilon_{p\ 220} = [(6{,}779 + 7{,}804) \times N_{216Po} + 7{,}804 \times (N_{212Pb} + N_{212Bi}) + 8{,}785 \times N_{212Po}] \times 1{,}602 \times 10^{-13} \quad \text{(J)}$$

where N is the number of atoms

NOTE 1 The 7,804 MeV alpha energy corresponds to a virtual alpha emission due to the branching ratio of ^{212}Bi.

NOTE 2 Annual Limits of Intake (ALI) can be expressed in the term of PAE_{222} and PAE_{220}. For this reason, PAE_{222} and PAE_{220} are used as health risk indicator.

[ICRP 32]

3.2.2
Potential Alpha Energy Concentration
PAEC or c_p
concentration of any mixture of short-lived radon decay products in air in terms of the alpha energy released during decay through ^{210}Pb or ^{208}Pb

NOTE This quantity is expressed in the SI unit $J \cdot m^{-3}$.

[ICRP 32]

3.2.3
Potential alpha energy exposure
$P_p(T)$
time integral of the potential alpha energy concentration in air, c_p, to which an individual is exposed over a given time period T, e.g. one year

$$P_p(T) = \int_T c_p(t).dt$$

NOTE This quantity is expressed in the SI unit $J \cdot m^{-3} \cdot h$.

[ICRP 65]

3.2.4
equilibrium equivalent concentration
c_{eq}
activity concentration of radon, in radioactive equilibrium with its short-lived decay products that has the same potential alpha energy concentration as the non-equilibrium mixture to which the c_{eq} refers

NOTE This quantity is expressed in the SI unit $Bq \cdot m^{-3}$.

[ICRP 32]

3.2.5
equilibrium factor
F
ratio of equilibrium equivalent concentration to the radon gas concentration

$$F = \frac{c_{eq}}{C_{Rn}}$$

[ICRP 65]

3.2.6
emanating power (or emanation coefficient)
ratio between the number of radon atoms (n) transferred to the pore space of the material and the number (N) of radon atoms present in the material itself, including the pores' space

$$\tau = \frac{n}{N}$$

3.2.7
emanation rate
value of the activity of radon atoms leaving a material per unit mass per unit time

NOTE This is expressed in $Bq \cdot kg^{-1} \cdot s^{-1}$.

3.2.8
deconvolution
mathematical treatment of a set of data resulting from a measurement (i.e. counted events) allowing, through the use of a particular set of equations, to get the value of the original quantity to be measured

3.2.9
Activity Median Aerodynamic Diameter
AMAD [2][2]
median of the activity distribution of diameters of the unit density ($kg \cdot m^{-3}$) spheres that have the same settling velocity as the aerosol particle concerned

3.2.10
Activity Median Thermodynamic Diameter
AMTD
median of the activity distribution of diameters of the unit density ($kg \cdot m^{-3}$) spheres that have the same thermodynamic properties as the aerosol particle concerned

3.2.11
unattached fraction of *PAEC*
fraction of the potential alpha energy concentration of short-lived RnDP that is not attached to the ambient aerosol

NOTE The particle size concerned is in the order of magnitude of nm.

[ICRP 65]

3.2.12
attached fraction
fraction of the potential alpha energy concentration of short-lived RnDP that is attached to the ambient aerosol.

NOTE The sizes of the carrier aerosol, to which most of RnDP are attached, are generally in the 0,1 µm to 0,3 µm range.

3.2.13
grab sampling
collection of a sample (e.g. of air containing radon or aerosol particles) during a period considered short compared with the fluctuations of the quantity under study (e.g. volumic activity of the air)

3.2.14
continuous method
method which ensures a continuous recording of the parameter to be measured, over a defined period of time, and with a time resolution adapted to the phenomenon to be studied

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[2] Numbers in brackets refer to the bibliography.

3.2.15
integrating method
method that relies on the measurement of the integral over a defined sampling and measurement time of the quantity under study

3.2.16
passive sampling
sampling that applies to instruments using no active device like pumps for sampling the atmosphere

NOTE In this case, the sampling is in most instruments mainly made by diffusion.

3.2.17
active sampling
sampling applies to instruments using active devices like pumps for sampling the atmosphere

3.2.18
reference source
radioactive secondary standard source for use in the calibration of the measuring instrument

[IEV 394-40-19]

3.2.19
reference atmosphere
radioactive atmosphere in which the influencing parameters (aerosols, radioactivity, climatic conditions, etc.) are sufficiently well-known or controlled to allow its use in a testing procedure for radon or RnDP measuring instruments. The parameter values concerned are traceable to recognized standards

3.2.20
System for Test Atmospheres with Radon
STAR
system that designates the equipment needed for the creation and the use of a reference atmosphere

3.2.21
High Efficiency Particulate Air filters (HEPA filters)
filters used for the aerosol collection, with a minimum efficiency of 99,97 % for particle size of 0,3 µm

3.3 Units and conversion factors

This standard uses the International System of Units (SI).

NOTE The following "non-standard" units are still sometimes used:

Curie (Ci), a unit of activity:	1 Ci = $3,7 \times 10^{10}$ Bq
$MeV \cdot l^{-1}$, a unit of potential alpha energy concentration	1 $MeV \cdot l^{-1}$ = $1,6 \times 10^{-4}$ $\mu J \cdot m^{-3}$

The following conversion factors are given for information:

Working Level (WL), a quantity of volume potential alpha energy	1 WL = 20,8 $\mu J \cdot m^{-3}$
Working Level Month (WLM), a quantity of exposure to potential alpha energy	1 WLM = 3,6 $mJ \cdot h \cdot m^{-3}$

- A ^{222}Rn activity concentration of 1 $Bq \cdot m^{-3}$ in equilibrium with its $RnDP_{222}$, is equivalent to a Potential Alpha Energy,Concentration, $PAEC_{222}$ of $5,62 \times 10^{-9}$ $J \cdot m^{-3}$.

- A ^{220}Rn activity concentration of 1 $Bq.m^{-3}$ in equilibrium with its $RnDP_{220}$, is equivalent to a Potential Alpha Energy,Concentration, $PAEC_{220}$ of $75,8 \times 10^{-9}$ $J \cdot m^{-3}$.

4 General description of a System for Test Atmospheres with Radon (STAR)

4.1 General

The need for a reference atmosphere arises from the necessity for a complete and standardized testing, under controlled conditions, of the measuring instruments concerned.

The various examples illustrated indicate a need for a test facility related directly to the elements to be measured. Such a facility will consist of four inseparable parts:

– the equipment for producing the atmosphere;

– the equipment for containing the atmosphere;

– the reference atmosphere thus created;

– the equipment and methods for monitoring this atmosphere.

Equipment used to characterise the atmosphere shall be traceable to a primary standard.

In order to simplify the text of this standard, such a system is referred to as a "STAR" (an acronym for System for Test Atmospheres with Radon).

The Figure 1 shows the general components of a complete STAR.

It is also called “Radon Chamber”; however, this term does not imply the same integrated concept.

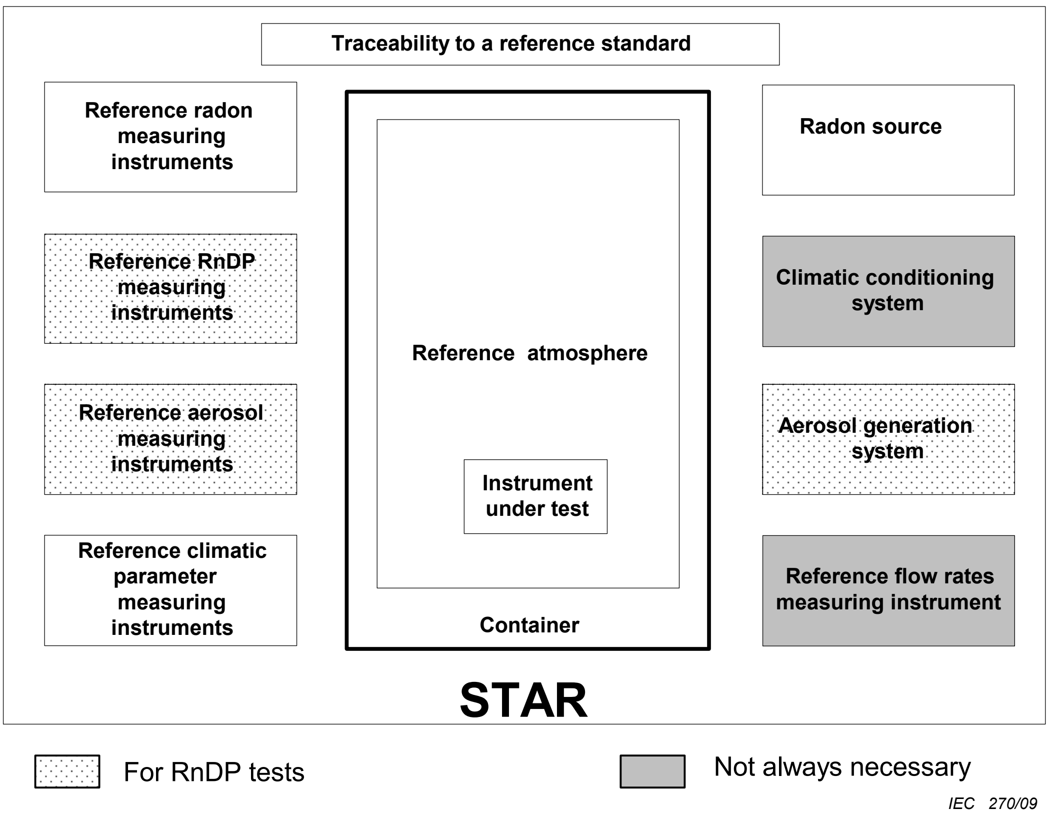
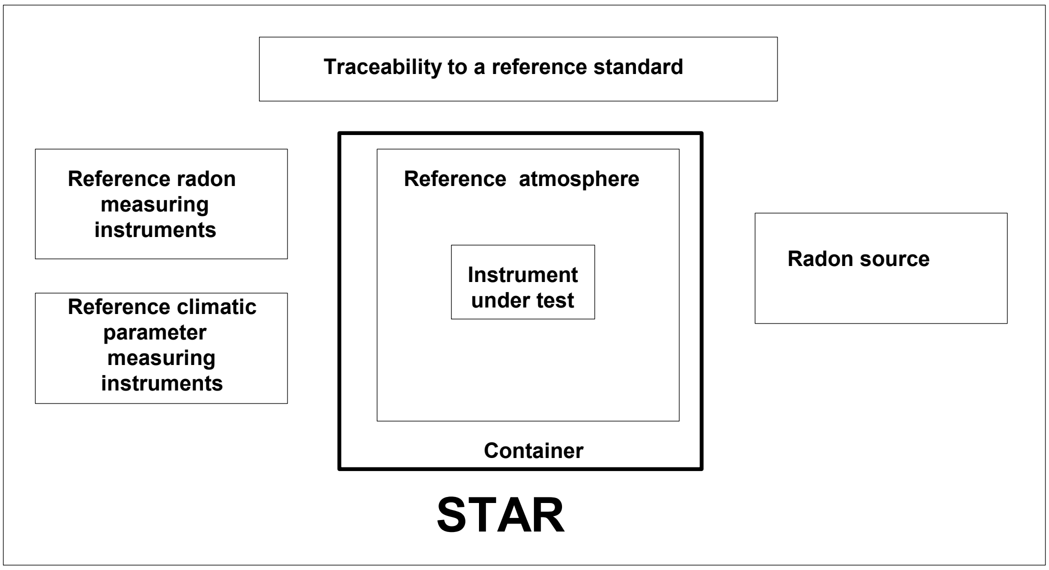


Figure 1 – Components of a STAR: general case

In some cases, a STAR may comprise only parts of the complete scheme. As an example, STAR used only for testing radon instruments, which are not affected by aerosols and RnDP in the atmosphere, do not need special equipment for controlling quantities relating to these effects. Figure 2 illustrates this minimum configuration.



IEC 271/09

Figure 2 – Minimum requirements for a STAR

The equipment used for containing the reference atmosphere can be classified into two main categories:

– large containers (internal volume of several m^3), often designed as "walk in", allow the equipment to be handled inside it, by operators;
– small containers only for the equipment under test.

4.2 Mode of operation of a STAR

4.2.1 Static mode of operation

With the static mode of operation, the conditions inside the container are settled at the beginning of the operation.

The radon sources are placed inside or outside the container. The static mode of operation may include the use of an internal fan for the purpose of homogenisation of the atmosphere.

NOTE Containers for static mode of operation are relatively simple to set up and to use, and they enable a diverse set of atmospheres to be created and manipulated. However, there are only limited possibilities when it comes to controlling the internal conditions (atmospheres, aerosols, etc.).

4.2.2 Dynamic mode of operation

With the dynamic mode of operation, atmosphere conditions in the container can be controlled and modified during the exposition of the apparatus to be tested.

Dynamic mode of operation always incorporates some method of renewing, totally or partially, the internal atmosphere (Figure 3).

Dynamic mode can be used in two ways (Figure 3):

– with a closed loop (recirculation of the atmosphere),
– with an open loop (partial or total evacuation).

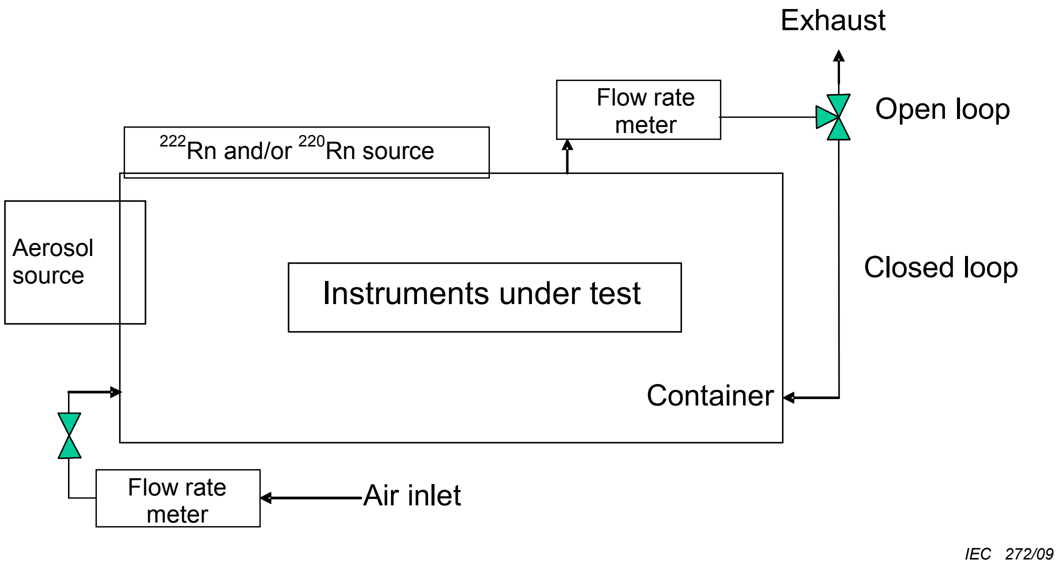


Figure 3 – Dynamic mode of operation of a STAR

The radon sources are generally located outside the container, thus allowing some control, or at least a continuous monitoring, of the internal conditions.

The aerosol source is located inside or outside the container.

The use of an open-air circuit may have influence on the radioactive releases to the environment.

The closed loop is used to control the aerosol concentration or the equilibrium factor in the container.

The different modes of operation of a STAR may involve various air-flow conditions that influence the homogeneity or the behaviour of RnDP:

a) Convection

Convection shall be taken into account in static or very low air exchange rate conditions. This phenomenon may, in these experimental conditions, modify the homogeneity of the STAR atmosphere.

b) Forced air movement

Forced air movement may have an influence on aerosol behaviour, mainly by turbulent diffusion and impaction phenomena, leading to changes in the deposition of RnDP on surfaces (walls, instrument, etc.). It may also be important for the homogeneity of the atmosphere.

Air exchange rates have a strong influence on the RnDP concentration in the reference atmosphere.

5 Characteristics of a STAR

5.1 General

This clause describes the characteristics for STARs dedicated to radon reference atmosphere and, for STARs dedicated to radon and RnDP reference atmosphere.

5.2 STAR for radon

5.2.1 General

This type of STAR shall be used only for testing instruments that do not depend on aerosol parameters. Therefore, instruments measuring radon with an open detector cannot be tested with this STAR.

5.2.2 Technical characteristics of STAR containers

A STAR container shall be sufficiently leak proof:

– to ensure safety through the effective confinement of any radioactivity it might contain;
– to prevent any unforeseen change due to leakage of the reference atmosphere.

If, in addition, the container is to be provided with means for carrying out tests under pressure, it shall withstand the internal pressure required for such tests and be in conformity with all relevant regulations related to pressure vessels.

The walls shall be thermally insulated (for example with $R_{th} > 3\ m^2 \cdot K \cdot W^{-1}$) when tests with variation of temperature and humidity, according to Table 2, are conducted. Where the atmosphere in the container is to be continuously renewed, its internal shape should be designed so as to avoid badly ventilated "dead" zones capable of leading to a non-uniform distribution of activities throughout the volume. Such a design might also facilitate the processes of evacuation and decontamination of the atmosphere.

The internal walls of the container should be made of a smooth material which cannot corrode and is a good electrical conductor. These qualities not only facilitate decontamination and limit the trapping of aerosols by diffusion to a minimum, but they also prevent any stray collection of RnDPs through electrostatic effects.

Whatever the type of container used, the manipulation of equipment during tests shall as far as possible be carried out from the outside, either by remote control or by the use of glove apertures so as to cause the least possible disturbance to the internal conditions.

For the same reason, the largest containers should be fitted with an airlock, both for the introduction of instruments and for the entrance and exit of operators.

The electricity supply should be stable both in voltage and frequency and should provide sufficient power.

NOTE A suitable location shall be available to store passive integrating detectors where the radon level is minimal.

5.2.3 Radon sources

5.2.3.1 Solid sources

Solid sources generally consist of a salt of ^{226}Ra or ^{228}Th to generate ^{222}Rn and ^{220}Rn, respectively. The salt may be pure or it may be mixed with, or trapped on a matrix. The nature of the material will determine the value of the emanating power and of emanation rate and thus the capacity of the source to supply large amounts of radon.

The emanation rate should be constant. But, since the emanating power is highly dependent on certain physical parameters (relative humidity, etc), the use of such sources will require considerable precautions to be taken (control of temperature, humidity, etc). Nevertheless, these sources are very widely used because of easily handling.

NOTE Some other solid sources are simply constructed using uranium or thorium ore or tailings packed in a closed container; although this kind of source may be cheap to build and easy to operate, its stability is difficult to obtain.

5.2.3.2 Liquid sources

Liquid sources generally consist of an acid solution of a salt of ^{226}Ra or ^{228}Th in order to obtain ^{222}Rn or ^{220}Rn, respectively. After a time that depends on the half-life of the radon isotope in question, the daughters are in secular equilibrium with the parent nuclide forming the source.

By careful degassing of the solution, it is then possible to recover the radon formed either:

– in a single operation, or
– continuously.

In the latter case, a simple calculation enables the radon flow rate to be obtained in terms of the activity of the source and the flow rate of the carrier gas.

The main application of these types of sources is the calibration of the reference instruments. Precaution shall be taken to avoid contamination risks.

Permeation capsules containing ^{226}Ra in solution with a certified emanation rate are also used for calibration purposes.

5.2.3.3 Gaseous sources

Ampoules containing radon are also used as a gaseous source for generation of the STAR atmosphere. Properly calibrated radon sources in glass bulbs or stainless steel containers can be used for the standardisation of the STAR atmosphere [3, 4, 14].

NOTE Using this type of source, care shall be taken to ensure the complete transfer of the radon contained in the ampoule.

Standard ^{222}Rn gas sources are available to be used for calibration purposes.

5.2.4 ^{222}Rn and ^{220}Rn analysis and control

The radon activity concentration in a STAR is chosen according to the mode of operation. This radon activity concentration in the STAR container can be:

– kept at a constant level;
– modified in order to reach several constant levels;
– allowed to decrease with radon decay constant after injection of the radon activity in the container;
– allowed to increase until a plateau is reached.

The means used to analyse the radioactivity of the STAR will be chosen according to the tests that are planned. The conventionally true value of radon activity concentration of the reference atmosphere is traceable to national or international standards.

Auxiliary measuring equipment, if possible traceable to reference standards, will be added according to the tests to be carried out.

If, for example, a significant quantity to be investigated is the gamma radiation, an instrument for measuring this type of radiation will then be required.

In order to compare the conventionally true value of the radon activity concentration with the value measured by the instrument to be tested, the radon activity concentration in the container shall be homogeneous. In order to ensure homogeneity of the reference atmosphere, this homogeneity shall be tested.

5.2.5 Analysis and control of climatic parameters

The main climatic parameters, temperature, pressure, and relative humidity shall be measured.

Because the temperature, relative humidity and, atmospheric pressure are influence quantities for the response of the detectors and sampling system of the instrument under test, the value of those quantities shall be taken into account for the determination of the radon or thoron activity concentration of the reference atmosphere.

When a STAR is used for the determination of the influence of climatic parameters, those parameters shall be controlled.

5.3 STAR for radon and RnDP

5.3.1 General

This type of STAR includes, at least, all the requirements of STAR for radon described in 5.2 and special requests related to RnDP that are described below.

5.3.2 Technical characteristics of STAR containers

Technical characteristics of STAR containers are defined in 5.2.2.

In addition, internal dimensions of STAR containers should achieve the best possible compromise between two contradictory requirements:

– to be as small as possible so as to limit any non-uniformity in the atmosphere that might detract from the quality of the measurements;
– to be as large as possible so as to reduce wall effects to a minimum, and to accommodate a large number of instruments under test.

5.3.3 RnDP sources

RnDP atmospheres are formed in air containing radon and natural or artificial aerosols. Therefore, RnDP sources are the result of the mixture of a radon source and an aerosol source. After decay of radon, the freshly generated RnDPs formed clusters (particles diameters in the order of magnitude of nm) of which a part will attach to the ambient aerosol. Those two parts are called unattached fraction (clusters) and attached fraction. They will deposit on surfaces inside the container depending on the particles diameters. Ranges of values found in real atmospheres for radon volumic activity, aerosol size and concentration, RnDP activity concentrations as well as fractions of the unattached RnDP are given in Table A.1 (Annex A).

In order to set up the RnDP concentration or the PAEC to a defined value, the radon and aerosol sources shall be stable during performance of the tests. It is possible, within certain limits, to adjust the RnDP concentration and the value of the unattached fraction in the carrier gas. Such changes require a modification of the ambient aerosol (number of condensation nuclei, particle size distribution), which can be achieved by using an aerosol generator and/or electrostatic precipitation equipment or filter. In general, the lower the volume number of particles is, the higher the unattached fraction is, though other factors such as air movement also affect the unattached fraction. In order to modify the above parameters, aerosol generators, filtration devices, electrostatic precipitators, ion generators, etc. can be used.

Different types of radon sources have been described above. As for aerosol sources, commercial pneumatic aerosol generators or carnauba wax generators are most often used.

5.3.4 RnDP analysis and control

The following devices or equipment shall be used to measure or monitor the characteristic values (Table 1) of the atmospheres produced in a STAR:

- a device for measuring radon continuously or semi-continuously, with a sensitivity adapted to the range of measurement to be processed and with its own recording device;
- a device to measure the number of aerosol particles per unit volume;
- a device for measuring the size distribution of aerosol particles;
- a device to measure the unattached and attached fraction of RnDP (see Note1);
- a device for measuring RnDPs (see Note 2).

NOTE 1 The unattached fraction can be measured using a screen diffusion technique such as single screen or graded screen array [10].

NOTE 2 The device for measuring RnDPs which may consist of a filter/screen sampling system combined with a counting device for analysis of the radioactivity of the filter/screen, and the use of a method of deconvolution.

This equipment should be carefully calibrated against reference standards before being used for the measurements of the STAR atmosphere.

Unlike radon sources, standard RnDP sources do not exist. The conventionally true value of PAEC of the reference atmosphere is obtained by using a reference instrument.

Attention shall be drawn to the sampling system of the RnDP measuring instruments. This part of the instrument shall be designed to minimise the deposition of aerosol particles on surfaces of the sampling systems.

Also, when active sampling is used, the sampling rate or the volume sampled shall be measured accurately, whatever type of equipment is used to measure radon volumic activity or PAEC. Because results of the measurement are expressed in the form of an activity or potential alpha energy per unit volume, sampling flow rate or sampled volume of a reference instrument needs to be calibrated with appropriate standard.

The STAR equipment shall allow for the measurement or the generation of the sampling rates or the volumes sampled by the apparatus under test as well as by the measuring devices belonging to the STAR. The measurement of the flow rates shall be supplemented by a measurement of the gas temperature and of the pressure, and possibly by a measurement of the density of the radon carrier gas (e.g. CO_2 in certain instruments for measurements in soils). The flow rate will be measured either as a mass-flow or as a volume-flow, and will be expressed by making the necessary corrections for pressure and volume to 1 013 hPa and 20 °C. The ranges of flow rates to be measured depend on the equipment to be tested.

Uncertainties on the flow rate or the volume sampled should be of the same order of magnitude as the other sources of uncertainties.

5.3.5 Sampling flow rate of equipment under test

The sampling devices used for the actual functioning of the STAR will generally have flow rates in the order of some $m^3 \cdot h^{-1}$ and should have an overall error factor less than one percent.

The sampling flow rate is a quantity of considerable significance, firstly because of the uncertainties associated with the measurement, and secondly because of possible associated losses in the sampling device (self-absorption in the sampling filters, loss of aerosols in the aerodynamic sampling circuit).

Thus a STAR shall provide a set of air-flow-rate measuring devices with a sufficiently high-precision to assess the sampling characteristics of an instrument to be tested. Calibration of the flow rate measuring devices shall be done in a specific facility.

The ranges of flow rates to be monitored depend on where the equipment being tested is to be used. Individual instruments or those requiring a low sensitivity (surveillance of underground atmospheres, integrating instruments, etc.) will have sampling rates ranging from some 10^{-3} $m^3 \cdot h^{-1}$ to 1 $m^3 \cdot h^{-1}$, while instruments for monitoring the environment will cover a much wider range from 0,1 $m^3 \cdot h^{-1}$ to 100 $m^3 \cdot h^{-1}$.

Equipment under test with high sampling flow rates may significantly change STAR conditions in respect to aerosol concentration, volumic activity and homogeneity.

5.3.6 Analysis and control of climatic parameters

Climatic parameters such as temperature, atmospheric pressure and relative humidity shall be measured. When a STAR is used for the determination of the influence of climatic parameters, those parameters shall be measured and controlled.

These parameters should be tested to assess the homogeneity of the STAR atmosphere, for example with the measurement of flow rates or velocity profile at dynamic conditions.

6 Requirements for the reference atmosphere provided by STAR

6.1 General

The STAR should be chosen according to the instrument to be tested.

With respect to the test requirements, the operating conditions inside STAR shall lie within specified limits depending on the equipment used for monitoring and analysis. This shall assure its capability of achieving the accuracy required.

The precision of the indication of certain types of instruments may be influenced by different influence quantities, for example temperature, aerosol size and aerosol plate-out on the walls of the STAR, equilibrium factor, aerodynamic properties of the sampling device, etc.

The tests conducted with a STAR should indicate, after agreement between manufacturer and user, the values of the influence quantities used, both for reference and variable conditions.

Characteristics of atmospheres that can be simulated in a STAR can be found in Annex A.

6.2 Reference conditions

Table 1 contains the set of parameters which are relevant for monitoring the reference atmosphere to carry out type tests of instruments for radon decay products. When the STAR is used for tests of radon instruments only, the set of parameters can be reasonable reduced. At least, the climatic parameters temperature, relative humidity, atmospheric pressure, and ambient gamma dose rate shall be monitored.

Table 1 – Reference and standard test conditions

Influence quantity	Reference conditions	Standard test conditions
Temperature	20 °C	18 °C to 22 °C
Relative humidity	50 %	40 % to 60 %
Atmospheric Pressure	1 013 hPa	860 hPa to 1 060 hPa
Ambient γ dose rate		<0,25 $\mu Sv \cdot h^{-1}$
Unattached fraction		<0,25
Volume number of aerosols	10^{10} particle·m^{-3}	10^{8} particule·m^{-3} to 10^{12} particle·m^{-3}
Aerosol size (AMTD or AMAD)*	0,2 µm	0,1 µm to 0,3 µm
* No requirement on the geometric standard deviation.		

The standard sampling flow rate needed for testing a particular device is defined by the manufacturer of the device under test.

The protocols for testing the instruments are described in IEC 61577-2 and IEC 61577-3.

The STAR should be capable of being used for testing equipment with values of radon volumic activity varying from 1/3 to 2/3 of each range of measurement indicated on the equipment under test. A value situated between 100 $Bq \cdot m^{-3}$ and 1 000 $Bq \cdot m^{-3}$ can be adopted for the activity of ^{222}Rn and 0,4 for the equilibrium factor as basic standard test conditions, enabling one identical operating point to be obtained for all the equipments under test. Other values can be agreed upon between the operator of the STAR and the manufacturer of the instrument.

6.3 Influence quantities

6.3.1 General

The Table 2 summarizes the range of variation of the influence quantities.

Table 2 – Tests with variation of the influence quantities

Influence quantities	Range of values (unless otherwise indicated by the manufacturer)
Temperature	–25 °C to + 50 °C
Relative humidity	10 % to 100 % (condensing)
Atmospheric pressure	800 hPa to 1 080 hPa
Ambient γ dose rate	to be defined between STAR operator and manufacturer or user
^{222}Rn volumic activity (for ^{220}Rn measuring instruments)	10 $Bq \cdot m^{-3}$ to 1 $MBq \cdot m^{-3}$
^{220}Rn volumic activity (for ^{222}Rn measuring instruments)	10 $Bq \cdot m^{-3}$ to 1 $MBq \cdot m^{-3}$
c_{eq222} ($c_{eq_{220}}$ measuring instruments)	2 $Bq \cdot m^{-3}$ to 1 $MBq \cdot m^{-3}$
c_{eq220} ($c_{eq_{222}}$ measuring instruments)	0,05 $Bq \cdot m^{-3}$ to 100 $Bq \cdot m^{-3}$
Unattached fraction of $RnDP_{222}$	up to 0,9
Volume number of aerosols	10^{8} particle·m^{-3} to 10^{12} particle·m^{-3}
Aerosol size[a] (AMTD or AMAD)	10^{-3} µm to 10 µm
[a] Tests with variation of aerosol size will be done after agreement between STAR operator, manufacturer and user.	

6.3.2 Temperature

Temperature is a quantity of considerable significance. It has an effect on the measuring devices in the detection system, on the associated analogue electronics and on the system used for displaying the results (liquid crystal display). It affects the aerodynamic characteristics of the sampling devices and the lifetime of primary or secondary batteries. It can also affect the parameters governing the behaviour of aerosols.

The reference temperature will be +20 °C with tolerances allowing variations from +18 °C to +22 °C.

The temperature range being used for the tests with variation of the influence quantities should be in accordance with the different atmospheres described in Annex A:

– –25 °C to +50 °C for external atmospheres;
– +5 °C to +40 °C for domestic atmospheres;
– 0 °C to +60 °C for underground atmospheres;
– –10 °C to +50 °C for soil atmospheres.

Other temperature ranges can be used after agreement between manufacturer and user.

6.3.3 Relative humidity

The humidity of the test atmosphere is a quantity of considerable significance for detection systems. In particular, condensation onto a detector, for example, can cause a reduction in performance and possibly bring about contamination. It also has a significant effect on the physical behaviour of aerosols and possibly on the operation of the sampling systems (clogging of hygroscopic filters, electrostatic collection systems, etc.).

The reference value will be 50 % RH with tolerances allowing variations from 40 % RH to 60 % RH.

The range of relative humidity being used for the tests with variation of the influence quantities should be in accordance with the different atmospheres described in Annex A:

– 10 % RH to 100 % RH (condensing) for external atmospheres;
– 10 % RH to 70 % RH for domestic atmospheres;
– 10 % RH to 100 % RH (condensing) for underground atmospheres;
– 80 % RH to 100 % RH (condensing) for soil atmospheres.

Other relative humidity ranges can be used after agreement between manufacturer and user.

6.3.4 Atmospheric pressure

Atmospheric pressure is a quantity of considerable significance for radioactivity measurements in certain cases:

– measuring instruments operating under pressure (e.g. measurement of radon in drilling);
– detectors needing a large path for alpha particles in air: in this case, the detection efficiency may be changed by a variation in pressure.

The characteristics of the sampling devices may be sensitive to pressure variations and the system for measuring the sampling rates of the STAR shall enable this effect to be quantified.

The reference value is 1 013 hPa.

The range of variation in atmospheric pressure (apart from instruments under pressure which should be tested up to their maximum operating pressure) is from 800 hPa to 1 080 hPa.

Other pressure ranges can be used after agreement between manufacturer and user.

6.3.5 Ambient gamma field

The standard test conditions should be conducted with an effective dose rate below 0,25 $\mu Sv \cdot h^{-1}$.

The ambient gamma field can have a considerable effect on the response of measuring instruments. For example, instruments using the detection of beta-particles, or ionization chambers are also sensitive to ambient γ radiation. Tests of this type of instrument should specify the magnitude of this effect under test conditions.

6.3.6 Working range for exposure to RnDP

The range of PAEC instruments normally covers the working range to assess exposure to RnDP. Attention should be given to the fact that, for testing measuring devices in the upper part of their range of operation, the atmosphere should be kept at a high level of stability for a time period lasting at least one day.

6.3.7 Working range for aerosols

The working range for aerosols shall cover at least the typical range of size and distribution of the aerosol existing in the atmosphere for the measurement of which the instrument under test has been designed. In particular cases, this range may be extended or restricted after agreement between manufacturer and user.

The reference aerosol size will have an AMAD of 0,2 µm and the standard deviation of the distribution as well as the nature of the aerosol will depend upon the aerosol generator used.

The aerosol size to be used with tests with variation of the influence quantities will range from 10^{-3} µm to several tens of µm.

One has to keep in mind that the quality of the aerosol sampling will have a great influence on the measurement result (i.e. bad designed air inlet may cause aerosol losses by deposition).

6.3.8 Exposure time for the instrument under test

Time shall be considered as a quantity of considerable significance for all instruments using integration or grab sampling. For other types of instruments, it should be taken into account if the duration of the analysis, either of the background noise or of the signal, is variable or adjustable (e.g. by modification of the detection threshold, etc.).

Furthermore, if the instrument under test has a time constant which is large compared with the time occupied by fluctuations experienced during use, the STAR shall allow for a simulation of these fluctuations which is as close to reality as possible.

7 Calibration and traceability of measurement methods and instruments used in a STAR

7.1 Traceability chains

The operator of the STAR shall ensure that all relevant measurement results are traceable to an appropriate primary standard using SI units.

The following measurements are directly traceable:

– temperature,
– humidity,
– atmospheric pressure,
– volumic activity of ^{222}Rn,
– sampled air volume.

Procedures for tracing back the measurements to recognised standards are not established for all quantities. This concerns measurements of volume number and distribution of aerosol particles in particular. The STAR operator should set up appropriate procedures to validate these measurements. The validation may include interlaboratory comparisons [6, 7, 9, 11, 12, 13, 15, 16].

The traceability of radon activity concentration in a reference chamber is established by using either a radon gas primary standard or one or more reference instruments (secondary standard). Radon gas activity concentration is produced by insertion of a known amount of radon gas activity into a calibrated reference volume. A traceable amount of radon gas activity can be either supplied by primary standard laboratories or obtained by quantitative extraction of radon gas from a certified ^{226}Ra solution (bubbler method). The radon gas is introduced into the test instrument either by enclosing the instrument into the reference volume or by quantitative transfer from the reference volume into the instrument. The activity concentration chosen for the point of calibration is calculated and compared to the output from the system under evaluation so as to calculate the calibration factor and thereby calibrate the instrument. The system can then be used as a secondary standard or reference instrument.

The $PAEC_{222}$ and $RnDP_{222}$ volumic activity of the reference atmosphere can be traced by sampling the $RnDP_{222}$ using a filter assembly, preferably, in an open face device. After sampling, the nuclear disintegration on the filter is measured by an alpha and a gamma spectrometer, simultaneously. The equipment shall be able to detect alpha particles emitted by ^{218}Po and ^{214}Po and gammas from ^{214}Pb and ^{214}Bi. From the number of disintegrations of ^{218}Po and ^{214}Po, the $RnDP_{222}$ activity and the potential alpha-energy are calculated. Volumic activities and PAEC are obtained after dividing by the sampled air volume. In order to calibrate the equipment taking the measuring geometry into account a sealed surface source containing ^{226}Ra in equilibrium with ^{222}Rn and $RnDP_{222}$ can be applied. The active areas of the sealed source and the aerosol filter should preferably have the same dimensions. The source is used to calibrate the alpha counts measured in terms of disintegration on the whole filter by exploiting the relation of gamma measurement and source activity of the corresponding ^{214}Bi. [5,8]

7.2 Quality assurance

The laboratory, where the STAR is, shall maintain a quality assurance system for the STAR activities.

Quality assurance shall include verification of quality control which involves all the actions by which the adequacy of equipment, instruments and procedures are assessed against established requirements. It shall ensure that equipment and instruments function correctly, that the procedures are correctly established and followed, that analyses are correctly performed, that quantifiable errors are within acceptable limits, and that records are correctly and promptly maintained. The quality assurance programme and the regular checks performed for quality control shall be fully documented.

General requirements for the competence of testing laboratories are set out by ISO/IEC 17025.

Annex A
(informative)

Characteristics of atmospheres that can be simulated in a STAR

A.1 General

The instruments to be tested in a STAR are designed to be used in different atmospheres, as described hereafter. The STAR therefore shall be able to simulate at least part of the characteristics of these atmospheres.

The Table A.1 provides information concerning the typical values found in these atmospheres. Working ranges of the apparatus to be tested are included in those typical values.

A.2 Outdoor atmosphere

An outdoor atmosphere is characterized by a range of radon volume activities and a distribution of aerosols typical to those encountered naturally over terrestrial surfaces.

A.3 Indoor atmosphere

An indoor atmosphere is characterized by a range of radon volume activities and a distribution of aerosols typical to those encountered in a building. The latter is partly dependent on the life style of the inhabitants (cooking, tobacco smoke, ventilation, etc.), or on the level of working activity.

A.4 Underground atmosphere

An underground atmosphere is characterized mainly by its range of radon volume activities and by the residence time of the air. It may also be saturated with moisture.

In the case of mines, the particle size distribution and the electric charge of the aerosols in such an atmosphere are markedly variable both in space and time and may be influenced by engine exhausts, oil fumes, smoke from blasting, etc.

A.5 Soil atmosphere

A soil atmosphere is characterized mainly by its range of radon volume activities. It is also often saturated with moisture.

This standard concerns also soil atmosphere, because soil radon is of considerable interest for radiation protection purposes, as the major source of radon for dwelling and indoor working places. Therefore, measurements have to be made in order to assess the propensity of a soil to produce radon (i.e. before to build a dwelling).

In some cases, the carrier gas can be different from air, i.e. CO_2.

Table A.1 – Atmosphere characteristic ranges (typical values)

	Working Ranges			
	Outdoor* atmosphere	**Indoor** atmosphere**	**Underground atmosphere**	**Soil atmosphere**
^{222}Rn volumic activity	10 Bq · m^{-3} to 50 kBq · m^{-3}	10 Bq · m^{-3} to 100 kBq · m^{-3}	100 Bq · m^{-3} to 1 MBq · m^{-3}.	100 Bq · m^{-3} to 1 MBq · m^{-3}
^{220}Rn volumic activity	10 Bq · m^{-3} to 10 kBq · m^{-3}	10 Bq · m^{-3} to 50 kBq · m^{-3}	100 Bq · m^{-3} to 5 MBq · m^{-3}	100 Bq · m^{-3} to 1 MBq · m^{-3}
Equilibrium factor F for ^{222}Rn	0,2 to 0,6	0,2 to 0,8	0,1 to 0,8	N/A (not applicable)
Unattached fraction of $RnDP_{222}$	0,03 to 0,9	0,03 to 0,7	0,03 to 0,9	N/A
$PAEC_{222}$	11 nJ · m^{-3} to 170 µJ · m^{-3}	11µJ · m^{-3} to 450 µJ · m^{-3}	56 nJ · m^{-3} to 4,5 mJ · m^{-3}	N/A
$PAEC_{220}$	4 nJ · m^{-3} to 152 nJ · m^{-3}	4 nJ · m^{-3} to 6 µJ · m^{-3}	No data	N/A
c_{eq222}	2 Bq · m^{-3} to 30 kBq · m^{-3}	2 Bq · m^{-3} to 80 kBq · m^{-3}	10 Bq · m^{-3} to 0,8 MBq · m^{-3}	N/A
c_{eq220}	0,05 Bq · m^{-3} to 2 Bq · m^{-3}	0,05 Bq · m^{-3} to 76 Bq · m^{-3}	No data	N/A
Volume number of aerosols	10^{6} particle · m^{-3} to 10^{12} particle · m^{-3}	10^{8} particle · m^{-3} to 10^{14} particle · m^{-3}	10^{10} particle · m^{-3} to 10^{14} particle · m^{-3}	N/A
Aerosol size	10^{-3} µm to 0,5 µm	10^{-3} µm to 10 µm	10^{-3} µm to 10 µm	N/A

* In the neighbourhood of uranium mine tailings, outdoor radon volumic activity may rise up to 50 kBq · m^{-3}.

** In storage areas for radium sources, radon volumic activity can range up to 100 kBq · m^{-3}.

Remark: In certain cases the range of volume activities may cover over six orders of magnitude.

Bibliography

[1] P. K. Hopke, Health Physics, vol 64, n°5, p 459 (1993)

[2] W. C.Hinds, Aerosol Technology, Properties, Behavior and measurement of airborne Particles (1999)

[3] R. Dersch, U. Schötzig, Production and measurement of ^{222}Rn standards, Appl. Radiat. Isot., Vol. 49, p.1171-1174, (1998)

[4] J. L. Picolo, D. Pressyanov, P. Blanchis, N. Michielsen, V. Voisin and K. Turek. A radon-222 metrological chain from primary standard to field detectors. International Conference on radionuclide metrological and its applications, ICRM'99, Prague. (1999).

[5] A. Paul, S. Röttger, A.Honig, T.Sulima, A. Buchholz and U.Keyser, Measurement of short-lived radon progenies by $\alpha\gamma$-spectrometry at the radon reference chamber. Nuclear Instruments and Methods in Physics Research, Vol. A434, p.303-312, (1999)

[6] Maringer et al. The Austrian radon intercomparison exercise 1992-1996. Proc. IRPA reg. Symp. Rad. Prot. In Neighbouring Countries of central Europe, Tech Univ. Prague, p 150-153 (1997)

[7] G. Butterweck, Ch. Schuler, A. Paul, A. Honig, R. Dersch, V. Schmidt, P. Hamel, H. Buchenröder, A. Rox and W. Herzog. Intercomparison exercise of the PTB, BfS, MPA and PSI calibration facilities for radon gas concentration. Radiat. Prot. Dosim. 98(2):219-222 (2002)

[8] R. Falk, N. Hagberg, L. Mjönes, H. Möre, L. Nyblom and G. A. Swedjemark. Standards, calibration and quality assurance of ^{222}Rn measurements in Sweden, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 339, Issues 1-2, 22 January 1994, Pages 254-263

[9] A. Röttger, A. Honig, G. Butterweck, Ch. Schuler, V. Schmidt, H. Buchenröder, A. Rox, G.M. Kendall, J.C.H. Miles, I. Burian, N. Michielsen, V. Voisin, F.J. Maringer, A. Vargas, Intercomparison exercise of calibration facilities for radon gas activity concentration, VII International Symposium on Natural Radiation Environment (NRE VII), 20–24 May, Rhodes, Greece (2002)

[10] Y. S. Cheng, J. A. Keating and G. M. Kanapilly, Theory and calibration of a screen-type diffusion battery. Journal of Aerosol Science, Vol.11, p.549-556 (1980)

[11] Pineau, J.F., "Results of the 1st European Intercomparison of radon and radon daughters measurement methods and devices in an underground mine atmosphere" - CEC 1424/1/84, nov. 1985

[12] Bertrand, C., Gibaud, C., Janot, M., Pineau, J.F., "Results of the 2nd European Intercomparison of radon and radon daughters measurement methods and devices in an underground mine atmosphere" - CEC B16/0340/F (1990)

[13] Knutson, E. O. (editor). International intercalibration and intercomparison programme for radon, thoron and daughters measuring equipment:

Part I. Radon measurement. Paris, OECD (1983)

Part II. Radon measurement. Paris, OECD (1983)

Part III. Radon measurement. Paris, OECD (1983)

[14] E.Gargioni, A.Honig, A.Röttger, 'Development of a calibration facility for the measurement of the thoron activity concentration', Nuclear Instr. And Meth. In Phys. Research, A 506, 2003, 166-172

[15] Röttger, A., Honig, A., Butterweck, G., Schuler, Ch., Schmidt, V., Buchröder, H., Rox, A., Kendall, G.M., Miles, J.C.H., Burian, I., Michielsen, N., Maringer, F.J., Vargas, A.. Comparison of calibration facilities for radon activity concentration: Euromet Project 657. Metrologia, 2005, 42, Tech. Suppl. 06003

[16] Tokonami, S., Ishimori, Y., Ishikawa, T., Yamazaki, K., Yamada, Y.. Intercomparison exercise of measurement techniques for radon, radon decay products and their particle size distributions at NIRS. Jpn. J. Health Phys., 40(2):193-190 (2005)

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