BS EN 62694:2016

BSI Standards Publication

Radiation protection instrumentation — Backpack-type radiation detector (BRD) for the detection of illicit trafficking of radioactive material

bsi.

National foreword

This British Standard is the UK implementation of EN 62694:2016. It is identical to IEC 62694:2014.

The UK participation in its preparation was entrusted to Technical Committee NCE/2, Radiation protection and measurement.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English Version

Radiation protection instrumentation - Backpack-type radiation detector (BRD) for the detection of illicit trafficking of radioactive material (IEC 62694:2014)

Instrumentation pour la radioprotection - Détecteur de rayonnement de type sac-à-dos (BRD) pour la détection du trafic illicite des matières radioactives (IEC 62694:2014)

Strahlenschutz-Messgeräte - Rucksack-Strahlenschutzdetektor zum Nachweis von unerlaubtem Transport radioaktiver Materialien (IEC 62694:2014)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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European foreword

This document (EN 62694:2016) consists of the text of IEC 62694:2014 prepared by SC 45B "Radiation protection instrumentation" of IEC/TC 45 "Nuclear instrumentation".

The following dates are fixed:

• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-09-05
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	2019-09-05

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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

Publication	Year	Title	EN/HD	Year
IEC 60050	Series	International Electrotechnical Vocabulary	-	-
IEC 60050-393	2003	International Electrotechnical Vocabulary - Part 393: Nuclear instrumentation - Physical phenomena and basic concepts	-	-
IEC 60050-394	2007	International Electrotechnical Vocabulary - Part 394: Nuclear instrumentation - Instruments, systems, equipment and detectors	-	-
IEC 62706	-	Radiation protection instrumentation - Environmental, electromagnetic and mechanical performance requirements	-	-
IEC 62755	-	Radiation protection instrumentation - Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials	-	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

RADIATION PROTECTION INSTRUMENTATION – BACKPACK-TYPE RADIATION DETECTOR (BRD) FOR THE DETECTION OF ILLICIT TRAFFICKING OF RADIOACTIVE MATERIAL

FOREWORD

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International Standard 62694 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/781/FDIS	45B/790/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.

The committee has decided that the contents of this publication will remain unchanged until the stability 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

RADIATION PROTECTION INSTRUMENTATION – BACKPACK-TYPE RADIATION DETECTOR (BRD) FOR THE DETECTION OF ILLICIT TRAFFICKING OF RADIOACTIVE MATERIAL

1 Scope

This International Standard applies to backpack-type radiation detectors (BRDs) that are used for the detection of illicit trafficking of radioactive material. This standard establishes the operational and performance requirements for BRDs. BRDs are portable instruments designed to be worn during use. They may also be used as temporary area monitors in a stand-alone mode.

BRDs detect gamma radiation and may include neutron detection and/or the identification of gamma-ray emitting radionuclides. This standard establishes performance and testing requirements associated with radiation measurements and the expected electrical, mechanical, and environmental conditions while in use.

2 Normative references

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

IEC 60050 (all parts): *International Electrotechnical Vocabulary* (available at http://www.electropedia.org)

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

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

IEC 62706, *Radiation protection instrumentation – Environmental, electromagnetic and mechanical performance requirements*

IEC 62755, *Radiation protection instrumentation – Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials*

3 Terms and definitions, abbreviations, quantities and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-393 and IEC 60050-394 apply, as well as the following.

3.1.1
accuracy
closeness of the agreement between the result of a measurement and the conventionally true value of the measurand

3.1.2
alarm
audible, visual, or other signal activated when the instrument reading exceeds a preset value, falls outside of a preset range, or when the instrument detects the presence of the source of radiation according to a preset condition

[SOURCE: IEC 60050-393:2003, 393-18-03, modified]

3.1.3
background level
radiation field in which there are no external sources present other than those in the natural background at the location of the measurements

3.1.4
backpack-type radiation detector
instrument composed of several radiation detection components that are placed inside a backpack or other similar enclosure with an external user interface or control device

3.1.5
centre line
horizontal or vertical line that describes the geometrical centre of an object

3.1.6
coefficient of variation
V
ratio of the standard deviation s to the arithmetic mean $\bar{x}$ of a set of n measurements x_i given by the following formula:

$$V = \frac{s}{\bar{x}} = \frac{1}{\bar{x}} \sqrt{\frac{1}{n-1} \sum_{1}^{n} (x_i - \bar{x})^2}$$

[SOURCE: IEC 60050-394:2007, 394-40-14]

3.1.7
energy window
part of the energy spectrum within an upper and lower energy limit

[SOURCE: IEC 60050-394:2007, 394-38-70]

3.1.8
keyhole markup language
KML
is a file format used to display geographic data

Note 1 to entry: For example, see http://www.opengeospatial.org/standards/kml/.

3.1.9
fluence
Φ
the quotient of dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da: Φ = dN/da

[SOURCE: IEC 60050-881:1983, 881-04-18]

3.1.10
fluence rate
the *fluence rate*, $\dot{\phi}$, is the quotient of dΦ by dt, where dΦ is the increment of the fluence in the time interval dt, thus $\dot{\phi} = \frac{d\phi}{dt}$. The unit of fluence rate is $m^{-2}s^{-1}$

[SOURCE: ICRU Report 60:1998]

3.1.11
type test
conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-394:2007, 394-40-02]

3.1.12
user interface
software and/or hardware that manages interactions between a user and equipment

3.1.13
variance
σ^2
measure of dispersion, which is the sum of the squared deviation of observations from their mean divided by one less than the number of observations

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

3.2 Abbreviations

AC	alternating current
BRD	backpack-type radiation detector
cps	counts per second
DC	direct current
DU	depleted uranium
ESD	electrostatic discharge
FIFO	first in first out
GPS	global positioning system
HDPE	high density polyethylene
HEU	highly enriched uranium
HPGe	high purity germanium
KML	keyhole markup language
NORM	naturally occurring radioactive material
PMMA	polymethyl methacrylate
RGPu	reactor grade plutonium
WGPu	weapons grade plutonium
XML	eXtensible Markup Language

3.3 Quantities and units

In the present standard, units of the International System (SI) are used[1]. The definitions of radiation quantities are given in IEC 60050-393 and IEC 60050-394.

Nevertheless, the following units may also be used:

– for energy: electron-volt (symbol: eV), 1 eV = 1,602 × 10^{-19} J;
– for time: years (symbol: y), days (symbol: d), hours (symbol: h), minutes (symbol: min);
– for distance: centimetre (symbol: cm), millimetre (symbol: mm), kilometre (symbol: km);

Multiples and submultiples of SI units will be used, when practicable, according to the SI system.

4 General test procedure

4.1 Nature of test

The tests in this standard are to be considered type tests, unless otherwise stated.

4.2 Standard test conditions

Except where otherwise specified, the tests in this standard shall be performed under the standard test conditions given in Table 1.

4.3 Tests performed under standard test conditions

For these tests, the value of temperature, pressure, relative humidity and gamma and neutron background at the time of the test shall be recorded. Values should be within the standard test conditions given in Table 1.

4.4 Test performed with variation of influence quantities

For those tests intended to determine the effects of variations in an influence quantity (e.g., temperature, humidity), all other influence quantities should be maintained at the standard test conditions given in Table 1 unless otherwise specified in the applicable test method.

4.5 Statistical fluctuations

For tests involving the use of radioactive sources to verify susceptibility to an environmental, electromagnetic, or mechanical condition the ambient dose equivalent rate produced by the sources to verify the BRD response shall be adjusted to reduce the magnitude of the statistical fluctuations.

If the magnitude of the statistical fluctuations of the BRD indication arising from the random nature of radiation alone is a significant fraction of the variation of the indication permitted in the test, then the ambient dose equivalent rate should be increased to ensure that the mean value of such readings may be estimated with sufficient accuracy to demonstrate compliance with the test in question.

It is recommended that the coefficient of variation (*V*, expressed in percentage) for each nominal mean reading be less than or equal to 12 %. For neutron or photon background measurements, attaining a coefficient of variation to meet this requirement may not be possible. Therefore, testing with neutrons or photons at background levels (i.e., testing

[1] International Bureau of Weights and Measures: The International System of Units, 8th edition, 2006.

without radioactive source present) can be performed even when the coefficient of variation is larger than 12 %.

12 % is from statistical analysis techniques for dosimeter testing and has proven to be a simple way of determining when a group of readings are acceptable for compliance testing. The time interval between readings needs be sufficiently long (i.e., larger than the integration time of the instrument) to ensure that the readings are statistically independent.

4.6 Uncertainties in the measurements

Unless otherwise stated for a specific quantity, the uncertainties for any measurable quantity (e.g., radiation field) should not exceed 15 % with a coverage factor of k = 1.

4.7 Background radiation during testing

Testing shall be performed in an area with a nominal natural radiation background that has only natural variation as defined in Table 1.

The gamma-ray background intensity shall be measured using a pressurized ion chamber or similar environmental radiation measurement device that is calibrated to provide the gamma-ray ambient dose equivalent rate, $\dot{H}^{*}(10)$. When testing spectrometric BRDs the gamma-ray background shall be characterized using a high resolution gamma-ray spectrometer (e.g., high purity germanium (HPGe) detector). The measured spectra shall be recorded. If the BRD is equipped with neutron detectors, the neutron background should be the natural background and should not be artificially modified during testing. The neutron background at the test location shall be measured and recorded.

The evaluation of the BRD shall be performed without the benefit of any radiation shielding against the natural background, except for that shielding that is part of the instrument.

4.8 BRD set up

The BRD shall be set up based on the manufacturer’s specifications including background update mode, if applicable. Once set up for testing, no changes shall be made that could affect the overall response of the BRD. If more than one background update mode is available, testing should be performed in all modes when indicated in the specific clauses under the radiological tests.

When performing the radiological tests in Clause 6, the BRD shall be configured and oriented as it would be used. This may be achieved by using a phantom that would represent the human upper torso. The phantom shall be made of polymethyl methacrylate (PMMA).The phantom dimensions shall be 40 cm wide, 60 cm high and 15 cm thick.

The BRD shall be mounted on a stand or fixture made out of a material that does not have a large hydrogen content (e.g., foam, plastic). It is recommended to use materials such as aluminium for mounting the BRD to prevent possible additional moderation of the neutron source.

The reference point of the BRD should be marked by the manufacturer. If marking is not provided by the manufacturer, the reference point is defined as the imaginary point where the three mutually orthogonal lines that go through the center of the length, width and thickness of the BRD intersect (see Figure 2).

For static and dynamic tests described in Clause 6, the reference point of the BRD shall be positioned 1,5 m from the floor or ground surface. The centreline of the source shall be at the same height as the reference point of the BRD, 1,5 m from the floor or ground surface.

For static tests, the distance between the source and the centreline of the BRD shall be between 1 m and 3 m unless otherwise stated.

For dynamic tests, the line of source movement and detector centreline shall be kept parallel, the distance of closest approach between the source and the reference point of the BRD shall be between 1 m and 3 m unless otherwise stated, see Figure 1.

The phantom is not used when the BRD is evaluated for use as a stand-alone area radiation monitor. Testing as an area radiation monitor is performed if such claim is made by the manufacturer.

When performing the tests in Clauses 7, 8, and 9, the BRD shall not be mounted on a phantom. The BRD-to-source distance and the relative orientation and position between the BRD and the radiation source shall be adjusted to reduce the statistical fluctuations as discussed in 4.5. The testing distance, orientation and position of the BRD with respect to source shall be recorded for these tests. Due to the nature of the tests, there is no need for this standard to specify the BRD-to-source distance, and relative orientation and position between the BRD and the source.

4.9 Speed of moving sources and integration time for radionuclide identification

For static tests, the integration time required to perform a radionuclide identification shall be as specified by the manufacturer or a maximum of 1 min (whichever is the shortest).

During the static tests, the source shall be removed and placed back in the same location between trials. There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background surrounding the BRD or shielded during the delay.

For dynamic tests, the source or BRD shall be moved in a configuration that provides no shielding around the source other than that required for the specific test. The source speed shall be 1,2 m·s^{-1} (average walking speed) when tested at a distance of closest approach of 1,5 m, unless otherwise required in a test. If the distance of closest approach, d (expressed in m), is adjusted within 1 m and 3 m then the passage speed, v (expressed in m·s^{-1}), shall be adjusted to $v = v_0 \times d/d_0$,

where v_0 = 1,2 m·s^{-1} and d_0 = 1,5 m.

During the dynamic tests, there shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background surrounding the BRD or shielded during the delay.

NOTE For all dynamic tests, the source or the BRD can be moved relative to each other.

4.10 Radiation sources

Unless otherwise stated, tests involving the use of gamma radiation shall be carried out using ^{137}Cs for gross count measurements and ^{241}Am together with ^{60}Co for radionuclide identification (see Table 1).

The reference source for neutron radiation is ^{252}Cf. The neutron emission rate of the ^{252}Cf source shall be 20 000 s^{-1} (± 20 %) (see Table 1). The unmoderated reference neutron source shall be encapsulated in 1 cm of steel and shielded with 0,5 cm-thick lead in order to attenuate the possible gamma-ray emission from the ^{252}Cf source. The lead shall be placed outside the steel encapsulation. The moderation of the ^{252}Cf is achieved by surrounding the source in the presence of the 1 cm of steel encapsulation and 0,5 cm-thick lead shielding with 4 cm-thick high density polyethylene (HDPE) container (e.g., sphere, cylinder, box).

The sources shall be mounted on a stand or fixture made out of a material that does not have a large hydrogen content (e.g., foam, plastic). It is recommended to use materials such as aluminium for mounting the sources to prevent possible additional scattering and moderation of the neutron source.

The isotopic composition and activity of different naturally occurring radioactive materials (NORM), such as zircon, monazite and allanite, vary widely from sample to sample. Therefore, point sources are used to ensure greater consistency and traceability in performing measurements at different locations and at different times. The approximation of bulk NORM sources is done by surrounding ^{226}Ra and ^{232}Th sources (in equilibrium with their progeny) with 9 cm of polymethyl methacrylate (PMMA) each producing the same ambient dose equivalent rate, see Annex D.

As the ^{241}Am content in plutonium sources varies widely, when testing with WGPu the emission rate of the 60 keV line from ^{241}Am shall be no more than 10 times the emission rate of the 414 keV line for ^{239}Pu (e.g., if the emission rate for ^{239}Pu is 100 s^{-1} then the emission rate for ^{241}Am shall not exceed 1 000 s^{-1}), see Annex C. When needed, copper or cadmium should be used to reduce the contribution from ^{241}Am. The copper or cadmium shielded WGPu source shall be considered the bare WGPu source to be used in all radiological tests that require the use of WGPu.

All radioactive sources used for testing shall be checked for gamma-ray emitting impurities and isotopic composition, using a high purity germanium detector (HPGe), in order to determine the expected correct radionuclide identification by the BRD.

The fluence rate and ambient dose equivalent rate shall be determined using a photon cut-off energy of 40 keV.

When testing with point sources producing an ambient dose equivalent rate close to or below background levels (i.e., 0,05 $\mu Sv \cdot h^{-1}$), the ambient dose equivalent rate shall be calculated as described in Annex D. If parallel beams (i.e., irradiator) are used, the testing laboratory shall describe and record the method used to calculate the ambient dose equivalent rate.

4.11 Functionality tests

For most tests in Clauses 7, 8, and 9 the BRD functionality is evaluated prior to and after the test and in some cases during the test as well. The BRD response after the test (post-test measurement) is compared with that measured prior to the test (pre-test measurement). Therefore, the source location relative to the BRD shall be the same for both the pre-test and post-test.

For BRDs without gamma-ray spectrometry capabilities, the gamma-ray measurements are performed using a ^{137}Cs source, producing an ambient dose equivalent rate of at least 0,2 $\mu Sv \cdot h^{-1} \pm 20$ % ($k = 1$) at the reference point of the BRD, unless otherwise stated in a test.

For BRDs with gamma-ray spectrometry capabilities, the gamma-ray measurements are performed using ^{241}Am and ^{60}Co sources placed simultaneously in front of the BRD, each source producing an ambient dose equivalent rate of at least 0,1 $\mu Sv \cdot h^{-1} \pm 20$ % ($k = 1$) at the reference point of the BRD, unless otherwise stated in a test.

The neutron measurements (if applicable) are performed using the moderated ^{252}Cf source with an emission rate of 20 000 s^{-1} listed in 4.10 unless otherwise stated in a test.

Statistical fluctuations should be considered during these tests, see 4.5.

The pre-test and post-test measurements shall be carried out as follows:

Pre-test:

a) Record 10 independent gamma count rate or ambient dose equivalent rate readings (if the BRD has a unit-less display record the displayed level).
b) Verify that the gamma alarm is activated.

c) If the BRD is equipped with a neutron sensor, verify that the system indicates the presence of a neutron source and record 10 independent neutron count rate readings.
d) Verify that the neutron alarm is activated.
e) Calculate the mean and standard deviation of the count rate or ambient dose equivalent rate readings.
f) If the BRD has radionuclide identification capabilities, collect three spectra using an integration time of 1 min or that stated by the manufacturer (whichever is the shortest, see 4.9) and record the radionuclides identified.

Post-test:

g) Place the sources in the same location relative to the BRD as for the pre-test.
h) Record the same information as in the pre-test steps a) through f).
i) In addition calculate the difference (expressed in percentage) between the post-test measured mean count rate or ambient dose equivalent rate readings and the corresponding values measured in the pre-test.

Acceptance criteria:

The results are acceptable if changes in response between the pre-test and post-test do not exceed:

- ±15 % relative to the gamma readings pre-test values.
- ±15 % relative to the neutron readings pre-test values.

For instruments with a unit-less display, the manufacturer shall provide a table to convert the unit-less reading into a gamma and/or neutron response (i.e., count rate, ambient dose equivalent rate). For instruments with a unit-less display, the post-test gamma and neutron response shall not have changed from the pre-test response by more than ±1 unit.

The complete and correct results for identification at each post-test shall be the same or better than the identification results obtained at the pre-test. For example, if during a pre-test there are complete and correct results in two out of three trials, then the complete and correct results at each post-test point shall be two or more.

Depending on the environmental, mechanical or electromagnetic test, the BRD response during the test can be verified in two different ways, with or without radioactive sources present. When tested using radioactive sources, the BRD response during the test is performed in the same manner as the post-test. When tested without radioactive sources, the BRD response during testing is observed as not to produce any alarm, radionuclide identifications or spurious indication as a result of the environmental, mechanical or electromagnetic test.

NOTE When performing sequential tests (e.g., temperature followed by humidity followed by moisture), trends in the pre-test measurements may indicate degradation in the BRD performance (if source-to-detector distances and geometries are kept the same throughout the tests).

5 General requirements

5.1 Mass

5.1.1 Requirements

The BRD without gamma-ray spectrometry capabilities should weigh less than 10 kg including batteries and external user interface.

The manufacturer shall provide the weight for gamma-ray spectrometry type BRDs.

5.1.2 Method of test

Weigh the BRD together with the external user interface and record the result of the measurement. Review the manufacturer documentation and verify that the weight of the BRD and the external user interface are provided. The results of the verification shall be recorded.

5.2 Design requirements

5.2.1 Requirements

The BRD should be designed to:

a) Distribute weight, as much as practical, with the heavier side being closer to the wearer's back and the weight distributed as evenly as possible from left to right for good balance,
b) Be easy to wear, remove, and have adjustable openings around arms, and
c) Look like a normal backpack to the maximum extent practical.

5.2.2 Method of test

The BRD shall be inspected and the results of the inspection shall be recorded.

5.3 Marking

5.3.1 Requirements

All external controls, displays, and adjustments shall be identifiable according to their functions. External markings on the controls, displays and adjustments shall be easily readable and remain fixed after normal decontamination procedures (e.g., water and mild, non-abrasive detergent). Internal controls needed for operation shall be identified through markings and identification in technical manuals.

5.3.2 Method of test

The BRD as used shall be inspected and the results of the inspection shall be recorded. The decontamination procedure is performed by cleaning the instrument with mild soap and a damp towel and verifying that no marking is removed. Review the technical manuals to identify the internal controls markings.

5.4 Switches

5.4.1 Requirements

Controls and adjustments that affect calibration and alarm settings shall be designed so that access to them is limited to authorized personnel.

Switches and other controls should be designed to ensure that the BRD can be operated properly when the user is wearing gloves while minimizing accidental switch operation.

5.4.2 Method of test

Verify by inspection of the BRD or manufacturer provided documentation that the controls and adjustments that affect calibration and alarm settings are designed so that access to them is limited to authorized personnel.

Three users shall individually operate the BRD, including switching modes and/or performing functions while wearing gloves. Each user shall record whether multiple switches are activated while operating the BRD. For test purposes, insulated gloves (i.e., cold weather protection type gloves) should be used to verify the requirement.

5.5 Effective range of measurement – Energy

5.5.1 Requirements

The effective photon energy response range shall be stated by the manufacturer and should be at least 50 keV to 3 000 keV.

5.5.2 Method of test

Review the manufacturer documentation and verify that the required information is provided. The results of the verification shall be recorded.

5.6 Effective range of measurement – Count rate

5.6.1 Requirements

The manufacturer shall state the measurement range for the gamma-ray ambient dose equivalent rate and/or count rate based on ^{137}Cs (662 keV).

If the BRD has neutron detection capabilities, the manufacturer shall state the measurement range for the neutron count rate based on unmoderated ^{252}Cf.

If the BRD has radionuclide identification capabilities, the manufacturer shall state the maximum gamma-ray ambient dose equivalent rate and/or count rate, based on ^{137}Cs (662 keV), at which the instrument can still perform a radionuclide identification.

5.6.2 Method of test

Review the manufacturer documentation and verify that the required information is provided. The results of the verification shall be recorded.

5.7 Operating parameters

5.7.1 Requirements

The manufacturer shall provide the list of values for the recommended operating parameters that can affect the instrument response (e.g., default alarm thresholds, detector voltage, background update mode, gain, radionuclide library, identification/integration time). The manufacturer provided values shall be used throughout testing.

BRDs with radionuclide identification capabilities shall have a variable acquisition time for static measurement.

The manufacturer shall state if the BRD may be used as a temporary area monitor in a stand-alone mode.

5.7.2 Method of test

Review the manufacturer documentation and inspect the BRD, verify that the required information is provided and that the BRD uses the manufacturer recommended operating parameters. Record the results of the verification.

5.8 Explosive atmospheres

5.8.1 Requirements

The manufacturer shall state whether or not the BRD is certified for use in explosive atmospheres. If certification is claimed, documentation shall be provided. Certification shall be based on IEC 60079-11 or equivalent standard such as UL-913.

5.8.2 Method of test

Inspect documentation provided by the manufacturer. The documentation shall state whether or not the BRD is suitable for use in explosive atmospheres. Verify that a certificate of compliance is provided if the manufacturer claims that the BRD may be used in explosive atmospheres. Record the results of the verification.

5.9 Diagnostics

5.9.1 Requirements

The BRD shall continuously monitor functionality (e.g., gain stabilization, high voltage, count rate), and diagnose malfunctions without user interaction. If a radioactive source (either internal or external) is used to test functionality, the manufacturer shall provide the source location, radionuclide and source activity.

5.9.2 Method of test

Functionality is verified during the test process. Any malfunctions shall be recorded as they are observed including whether the BRD provided information to the user. Review the manufacturer provided documentation and check if a radioactive source (either internal or external) is used to test functionality, record manufacturer provided information about the source location, radionuclide and source activity.

5.10 Power supply

5.10.1 Requirements

a) The BRD shall have the ability to support a continuous operating time of 8 h without replacing batteries.
b) If the BRD has spectrometry capabilities, the manufacturer shall specify the number of spectra that can be recorded over the battery life.
c) The BRD should have the ability to operate from an external power source (AC or DC).
d) The manufacturer shall state the expected continuous operating time using the recommended batteries and the conditions (i.e., functional and environmental) used to determine this time.
e) If battery accessibility is required, then the battery compartment shall be accessible without special tools.
f) The BRD should be equipped with a visible direct indicator of battery life.
g) Provided battery chargers shall meet appropriate electrical standards, and shall be capable of operating from single phase AC power with voltage between 100 V and 240 V and frequency from 47 Hz to 63 Hz.
h) Rechargeable-type batteries should be fully recharged within 4 h when starting from an empty charge.
i) If rechargeable batteries are used, a lamp or similar display shall be available to indicate when the batteries are fully charged.
j) Setup BRD parameters and stored data shall not be affected by loss of power.
k) Markings indicating required battery orientation for replacement shall be clearly visible to the user.

5.10.2 Method of test

The following test methods match the list of requirements. Start the test by installing fresh or newly charged batteries.

a) Turn on the BRD and leave it on for 8 h operating in a nominal background environment. Every hour, expose the BRD to the ^{137}Cs and moderated ^{252}Cf (if applicable) check sources for 1 min and verify that the BRD alarms. If the BRD does not function for the full

8 h, record the elapsed time and whether a low battery indication was provided. Swap or recharge the battery, and repeat the process two more times.

b) If the BRD has spectrometry capabilities, review the manufacturer provided information specifying the number of spectra that can be acquired and processed over the battery life.
c) Verify by inspection of the BRD.
d) Verify by review of the provided manufacturer documentation.
e) Verify by inspection of the BRD.
f) Verify by inspection of the BRD.
g) Verify by inspection of the BRD or manufacturer provided documentation.
h) Verify by recharging a fully discharged battery. After 4 h verify that the battery is fully charged.
i) Verify by inspection of the BRD battery charger and by fully charging the BRD battery.
j) Verify by inspection of the BRD after changing the batteries.
k) Verify by inspection of the BRD.

5.11 Data format

5.11.1 Requirements

If the BRD has the ability to store data (i.e., data output file), the stored data shall be contained in data sets.

For gamma-only BRDs the stored data shall contain as a minimum:

a) Manufacturer name
b) Instrument model
c) Serial number
d) Software version
e) Instrument class (e.g., Backpack)
f) Gamma detector kind (e.g., Sodium Iodide (NaI(Tl)), Geiger Muller (GM) Tube, polyvinyl toluene (PVT))
g) Date and time of measurement
h) Measured background radiation levels (i.e., count rate or exposure rate or ambient dose equivalent rate, or total counts or exposure or ambient dose equivalent with associated measurement time duration as applicable)
i) Measured gamma-ray radiation levels (i.e., count rate or exposure rate or ambient dose equivalent rate, or total counts or exposure or ambient dose equivalent with associated measurement time duration as applicable)
j) Gamma-ray alarm indication

   In addition, if the BRD has energy window capabilities the stored data shall contain as a minimum:

k) Measured gamma-ray radiation levels in each energy window (i.e., count rate and/or counts with associated measurement time duration)
l) Energy window alarm indication

   In addition, if the BRD has neutron detection capabilities the stored data shall contain as a minimum:

m) Neutron detector type (e.g., Helium-3 (^{3}He), Lithium-Glass)
n) Background neutron level (i.e. count rate and/or counts with associated measurement time duration, level indication)
o) Measured neutron radiation levels (i.e., count rate and/or counts with associated measurement time duration)

p) Neutron alarm indication

In addition, if the BRD has radionuclide identification capabilities the stored data shall contain as a minimum:

q) Background spectrum

r) Live time and real time for background spectrum

s) Unprocessed measured spectrum

t) Live time and real time for measured spectrum

u) Energy calibration for each background and measured spectrum

v) Radionuclide identification results

w) Confidence indication

In addition, if the BRD has geolocation capabilities (e.g., GPS) the data set:

x) Shall contain the BRD location (latitude/longitude)

y) May contain the location information in a “KML” type file

In addition, the BRD should store the following data when the instrument is required to provide any of these responses:

z) Operating modes (e.g., “search” mode and “monitor” mode)

aa) Operational parameters

bb) Indication of battery status

cc) System failures

dd) Diagnostic results

ee) Indicate changes in operational status (e.g., alarm, monitoring background, fault, dwell, search)

ff) Over-range indication for detection

gg) Indication of background changes that can affect the overall sensitivity of the instrument

hh) Low-count rate for identification

ii) High-count rate for identification

jj) Over-range indication for identification

The output data shall be in an XML N42 format (see IEC 62755).

5.11.2 Method of test

Expose the BRD to the ^{241}Am and ^{60}Co reference sources at a distance where the gamma signal is appreciably strong but not strong enough for the BRD to trigger a gamma alarm. Move the gamma sources closer to the BRD to trigger a gamma alarm. In a similar manner, if the BRD is equipped with a neutron detector, repeat the same procedure with the gamma sources replaced by a moderated reference ^{252}Cf source.

If the BRD has radionuclide identification capabilities and requires the user to start an identification, place the ^{241}Am and ^{60}Co reference sources at a distance where an increase in the gamma signal is detected (a field of at least 0,05 $\mu Sv \cdot h^{-1}$ above background from each source) and perform a 1 min measurement or for a time as stated by the manufacturer (whichever is the shortest).

If the BRD has geolocation capabilities, verify that the actual longitude and latitude is recorded by the BRD.

Verify that all these measurements are recorded in the data set in the correct time sequence. Verify that the data set contains the data elements listed in the requirements. Use XML tools to verify compliance with the IEC 62755 standard. Verify that the XML document containing the data set information validates against the N42 schema (see IEC 62755).

NOTE A validation tool can be found at https://secwww.jhuapl.edu/n42/Account/LogOn.

5.12 Data storage

5.12.1 Requirements

If the BRD has the ability to store data, the memory shall be sufficient for storing all the data under alarm conditions over the operating time of the BRD (8 h). When the data storage is full, the new measurement event data should overwrite existing measurement event data. The oldest non-alarming data sets shall be overwritten first (first-in, first-out (FIFO)). When no non-alarming data sets remain, the oldest alarming data set shall be overwritten first (FIFO).

5.12.2 Method of test

Verify by review of the provided manual and inspection of the BRD during test execution.

NOTE Depending on the BRD data storage functionality during background and source measurements, the results of the “power supply” tests could be used to verify the data storage requirements.

5.13 Communication interface

5.13.1 Requirements

If the BRD has the ability to store data, the BRD shall be able to transfer data to an external device, such as a computer. The transfer should be based on a bi-directional port that meets the requirements of Ethernet, USB, wireless, or other electronic means such as a removable media device. Consideration should be given to data security when using wireless data transfer techniques. The communication technique used shall conform to applicable IEEE protocols. Communication protocols shall be described in the technical manual and proprietary formats shall not be used.

The BRD shall be capable of operating independently of any peripheral device or remote station, and it shall be unaffected by any malfunction of a peripheral device.

5.13.2 Method of test

Verify by review of the provided manufacturer documentation and by transmission of the data collected by the BRD under 5.11.2. Record the results of the verification.

To verify that the BRD is capable of operating independently of any peripheral device or remote station, disconnect any peripheral device or remote station during the data collection as described in 5.11.2. Verify that the BRD can be operated as described in the manufacturer provided documentation. Record the results of the verification.

5.14 User interface

5.14.1 Display

5.14.1.1 Requirements

The BRD shall have an external display unit that can be carried by the user. The display shall be readable at least between 150 lux and 10 000 lux.

5.14.1.2 Method of test

The display shall be exposed to 150 lux (–30 %, k = 1) and 10 000 lux (+30 %, k = 1). The display shall be readable in both low and high light levels by 3 users. Verify that all the indications are readable at 150 lux and 10 000 lux. Expose the BRD to the ^{137}Cs and ^{252}Cf test sources and verify that the alarm indications are visible at 150 lux and 10 000 lux. Record the results of the observations.

5.14.2 Basic indications

5.14.2.1 Requirements

The following indications shall be provided at the user interface:

a) Detector response (gamma ambient dose equivalent rate and/or count rate and, when provided, neutron count rate).
b) Battery status.

The manufacturer shall state the update rate for all the indications displayed by the user interface. The gamma and neutron (when provided) ambient dose equivalent rate and/or count rate indication should be updated at a minimum rate of once per second.

5.14.2.2 Method of test

Expose the BRD to the ^{137}Cs and the moderated ^{252}Cf source. The display shall be observed to verify the type of response displayed by the BRD. Review the manufacturer provided documentation to verify the updating rate.

Verify that the battery status is displayed. Record the results of the verification.

5.14.3 Additional indications

5.14.3.1 Requirements

The following shall be automatically displayed at the user interface:

a) Alarm indication (visual, audible and vibrational), with alarm type (gamma and/or neutron) and level (user selectable).
b) Changes in state of health (i.e., communication status, detector status, geolocation status, energy stabilization).
c) Over-range indication.
d) Changes in radiation fields that can affect the overall instrument response.

The following should be displayed at the user interface:

e) Ability to display geolocation and detector response data on the same display, when available (e.g., map showing alarm data).

5.14.3.2 Method of test

Displays at the user interface level are verified during testing:

a) Alarm indication (visual, audible and vibrational, with alarm type (gamma and/or neutron) and level (user selectable)), verified in 6.2 and 6.3
b) Changes in state of health (i.e., communication status, detector status, geolocation status, energy stabilization), verified throughout radiological test in Clause 6.
c) Over-range indication, verified in 6.7.
d) Changes in radiation fields that can affect the overall instrument response capability, verified in 6.9.
e) When applicable, verify the ability to display geolocation and detector response data on same display by inspection of the manufacturer provided documentation or the BRD.

5.14.4 Indications for BRDs with radionuclide identification capabilities

5.14.4.1 Requirements

The following indications and functions shall be provided when identification capabilities are available:

a) Radionuclide identification results.

And it should provide the:

b) Confidence indicator.
c) Ability to access spectra.

The manufacturer shall provide the update rate for real time (i.e., dynamic) identification measurements.

5.14.4.2 Method of test

Verify that if the BRD has radionuclide identification capabilities the results of the identification and the confidence indicator are displayed. Check that the BRD has the ability to access spectra. Review the manufacturer provided documentation to verify the update rate. Record the results of the verification.

5.14.5 Indications for BRDs with radionuclide directionality capabilities

5.14.5.1 Requirements

The following indications and functions shall be provided when directionality capabilities are available:

a) Directional pointer

5.14.5.2 Method of test

When directionality capabilities are available, indication and functions for the directional pointer are verified in 6.6.

5.14.6 Basic functions and controls

5.14.6.1 Requirements

The following functions and controls shall be provided at the user interface:

a) Ability to reset alarms
b) Ability to mute audible alarms
c) Ability to go silent (mute radio emissions, acoustical emissions, and perceptible vibrations)
d) Ability to modify date and time
e) Ability to reset (reacquire) background if the BRD supports this function
f) Ability to test the visual or audible alarms without the use of radiation sources

5.14.6.2 Method of test

Verify by inspection of the manufacture provided documentation(s) and by performing the following BRD functions:

a) Reset alarms
b) Mute audible alarms
c) Go silent (mute radio emissions, acoustical emissions, and perceptible vibrations)

d) Modify date and time
e) Reset (reacquire) background
f) Activate the visual and audible alarms without the use of radiation sources

Record the results of the verification.

5.14.7 Restricted functions and controls

5.14.7.1 Requirements

The following information and controls shall be provided through the use of access controls or special commands through the user interface or an external computer:

a) Access to and control of operating parameters
b) Access to alarm history
c) Access to count rate time history profiles including gamma and, when available, neutron radiation
d) Access to background radiation information, when background measurements are available
e) Access to alarm selection criteria
f) Access to the radionuclide library (when radionuclide identification capabilities are provided)

5.14.7.2 Method of test

Verify by inspection of the manufacturer provided documentation(s) and by performing the following BRD actions:

a) Access the operating parameters to verify requirement
b) Access the alarm history to verify requirement
c) Access the count rate time history profiles including gamma and when available, neutron radiation to verify requirement
d) Access the background radiation information, when available, to verify requirement
e) Access the alarm selection criteria to verify requirement
f) Access the radionuclide library (when radionuclide identification capabilities are provided) to verify requirement

Record the results of the verification.

6 Radiation detection requirements

6.1 False alarm test

6.1.1 Requirements

When tested in an area with a stable background (only natural fluctuations) at the levels stated in Table 1, the false alarm rate shall be less than 1 alarm over a period of 1 h.

6.1.2 Method of test

a) The BRD shall be set up as described in 4.8.
b) The reference point of the BRD shall be 1,5 m from the floor or ground surface.
c) The BRD shall be mounted in front of the phantom, see Figure 1.

d) Observe the BRD over a period of 10 h in an area that has a stable and controlled background. Record all alarms and radionuclides identified (when applicable) displayed during the 10 h period.

e) The results are acceptable if there are no more than 5 alarms over the test interval (based on 95 % upper confidence bound for a Poisson distribution, see Annex A).

When applicable, repeat steps a) through e) for all possible BRD background modes of operation.

NOTE The battery may need to be replaced during the test.

6.2 Alarm response to photon radiation

6.2.1 Requirements

An alarm shall be triggered when the measured radiation level is greater than the alarm setting. This requirement shall be verified using bare ^{60}Co, ^{137}Cs and ^{241}Am for angles between 0° to 90° and 270° to 360° in two orthogonal planes (see Figure 1 and Figure 2). Each of these sources shall be moving at a speed of 1,2 $m \cdot s^{-1}$ (at a distance of closest approach of 1,5 m) and producing a photon fluence rate of 4 $photons \cdot s^{-1} \cdot cm^{-2}$ (± 5 %, k = 1) at the reference point of the BRD at the point of closest approach. Alarms shall activate no later than 2 s after the source passes through the point that is closest to the BRD. The response is also acceptable if the gamma alarm is activated before the closest distance is reached.

6.2.2 Method of test

a) The BRD shall be set up as described in 4.8.

b) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).

c) The BRD shall be mounted on the phantom.

d) Figure 1 shows the test set up when the BRD is tested in the vertical position.

e) The BRD is tested with each source moving past the BRD at a distance of closest approach of 1,5 m and a speed of 1,2 $m \cdot s^{-1}$.

f) The distance of closest approach of the source to the BRD reference point may vary between 1 m and 3 m; the speed of 1,2 $m \cdot s^{-1}$ shall be adjusted as described in 4.9 if the distance of closest approach used for the test is other than 1,5 m.

g) The 0° reference angle of the BRD shall be facing the source, see Figure 1.

h) The ^{60}Co source shall start its movement from a position where the BRD is not able to detect its presence and then go past the BRD to a position where it is again not able to detect its presence.

i) The ^{60}Co source shall produce a fluence rate of 4 $photons \cdot s^{-1} \cdot cm^{-2}$ (± 10 %, k = 1) at the distance of closest approach between the BRD reference point and the center of the source.

   NOTE 1 This photon fluence rate can be achieved by adjusting the source to BRD distance. Annex C gives an explanation of how to achieve the required photon fluence rate. The fluence rate data referenced to air, i.e. without the presence of the phantom.

j) The BRD shall alarm no later than 2 s after reaching the point of closest approach to the source (4 $photons \cdot s^{-1} \cdot cm^{-2}$ photon fluence rate). The response is also acceptable if the gamma alarm is activated before the 4 $photons \cdot s^{-1} \cdot cm^{-2}$ field is reached.

k) The BRD alarm shall be reset between each trial, if appropriate.

l) There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background surrounding the BRD or shielded during the delay.

m) Repeat the test for 9 additional trials for a total of 10 trials.

n) The entire BRD and phantom shall be rotated to the following angles: 45°, 90°, 270° and 315° shown in Figure 1 in the horizontal plane (180° of coverage on the side of the BRD where the phantom is not between the source and the BRD) as well as in the vertical plane, see Figure 2. Steps a) through m) shall be repeated for each angle. The test shall be performed with the backpack positioned vertically and horizontally relative to the ground surface, see Figure 2.

NOTE 2 The tests in the vertical orientation can be performed laying the phantom on flat surface and rotating it relative to the source position.

o) At each angle the reference point of the BRD shall be used to measure the source-to-detector distance of closest approach. The source-to-detector distance of closest approach shall be kept the same for all angles.

p) Performance is acceptable if the BRD alarms in 96 out of 100 total trials for each source (this corresponds to a probability between 0,9 and 0,95 with a 95 % confidence interval).

NOTE 3 There is a total of 100 trials per source because for each source the test is composed of 5 angles in the horizontal plane plus 5 angles in the vertical plane, this means a total of 10 angles, and there are 10 trials per angle.

q) Repeat steps a) through p) for ^{137}Cs and ^{241}Am.

When applicable, repeat steps a) through q) for all possible BRD background modes of operation.

If the BRD has energy window capabilities, the manufacturer provided documentation shall list the energy window settings (i.e., Window Start Energy Values, Window End Energy Values) and the expected alarm indication for the ^{60}Co, ^{137}Cs and ^{241}Am sources. Verify that for each source and angle (steps a) through q)) the expected energy window alarm is triggered. Performance is acceptable if the correct BRD energy windows alarms are triggered in 96 out of 100 total trials for each source.

6.3 Alarm response to neutron radiation

6.3.1 Requirements

If the BRD is equipped with a neutron detector, an alarm shall be triggered when the BRD reference point is exposed to a ^{252}Cf neutron emission rate of 20 000 s^{-1} (± 20 %, k = 1), at a transient speed of 1,2 $m \cdot s^{-1}$, the distance of closest approach shall be 1 m. This requirement shall be verified using moderated ^{252}Cf (see Table 1) for angles between 0° to 90° and 270° to 360° in two orthogonal planes (see Figure 1 and Figure 2). Alarms shall activate no later than 3 s after the source passes through the point of closest approach to the BRD. The response is also acceptable if the neutron alarm is activated before the source reaches the point of closest approach.

6.3.2 Method of test

a) The BRD shall be set up as described in 4.8.

b) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).

c) The BRD shall be mounted on the phantom.

d) The BRD is tested with the moderated ^{252}Cf source with an emission rate of 20 000 s^{-1} (± 20 %, k = 1) moving past the BRD at 1,2 $m \cdot s^{-1}$, see 4.10.

e) The distance of closest approach to the BRD reference point being 1 m.

f) The 0° reference angle of the BRD shall be facing the source, see Figure 1.

g) The moderated ^{252}Cf source shall start its movement from a position where the BRD is not able to detect its presence and then go past the BRD to a position where it is again not able to detect its presence.

h) The instrument shall alarm no later than 3 s of exposure at the point of closest approach to the BRD. The response is acceptable if the neutron alarm is activated before the source reaches the distance of closest approach.

i) The BRD alarm shall be reset between each trial, if appropriate.

j) There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background surrounding the BRD or shielded during the delay.

k) Repeat the test for 9 additional trials for a total of 10 trials.

l) The entire BRD and phantom shall be rotated to the following angles: 45°, 90°, 270° and 315° shown in Figure 1 in the horizontal plane (180° of coverage on the side of the BRD where the phantom is not between the source and the BRD) as well as in the vertical plane, see Figure 2. Steps a) through k) shall be repeated for each angle. The test shall be performed with the backpack positioned vertically and horizontally relative to the ground surface, see Figure 2.

   NOTE 1 The tests in the vertical orientation can be performed laying the phantom on flat surface and rotating it relative to the source position.

m) At each angle the reference point of the BRD shall be used to measure the source-to-detector distance of closest approach. The source-to-detector distance of closest approach shall be kept the same for all angles.

n) Performance is acceptable if the BRD alarms in 96 out of 100 total trials for each source (this corresponds to a probability between 0,9 and 0,95 with a 95 % confidence interval).

NOTE 2 There is a total of 100 trials per source because for each source the test is composed of 5 angles in the horizontal plane plus 5 angles in the vertical plane, this means a total of 10 angles, and there are 10 trials per angle.

When applicable, repeat steps a) through n) for all possible BRD background modes of operation.

NOTE 3 The presence of the phantom will modify the energy spectrum of the neutron source but the source-to-detector distance of closest approach is kept constant during the test.

6.4 Personal radiation protection alarm and response time

6.4.1 Requirements

The instrument shall alarm when it is exposed to an increase in the ambient radiation level greater than the personal protection alarm threshold within 2 s of the step change. The manufacturer should state the alarm threshold value.

6.4.2 Method of test

a) Verify that the manufacturer states the personal radiation protection alarm threshold value. Record the result of the verification.

b) The BRD shall be set up as described in 4.8.

c) The reference point of the BRD does not need to be 1,5 m from the floor or ground surface, the height of the reference point of the BRD to the floor or ground surface used for the test shall be recorded.

d) The BRD shall be mounted on the phantom.

e) Using a ^{137}Cs source, increase the ambient dose equivalent rate at the reference point of the BRD to 30 % above the personal-protection alarm threshold in a period of no more than 1 s. Leave the ^{137}Cs source in front of the BRD for at least 30 s.

f) Verify that this increase in the radiation field triggered the personal protection alarm in less than or equal to 2 s.

g) Repeat steps a) through f) for 2 additional trials for a total of 3 trials.

h) Performance is acceptable if the BRD alarms in less than or equal to 2 s in 3 out of 3 trials.

When applicable, repeat steps b) through h) for all possible BRD modes of operation (e.g., background, identification).

6.5 Gamma-ray ambient dose equivalent rate indication

6.5.1 Requirements

If the BRD provides a gamma-ray ambient dose equivalent rate indication, the difference in the response of the BRD to the reference ambient dose equivalent rate from ^{137}Cs shall not exceed ±30 % for ambient dose equivalent rates from 1 $\mu Sv \cdot h^{-1}$ to the manufacturer-stated maximum value of the instrument.

6.5.2 Method of test

a) The BRD shall be set up as described in 4.8; the source to BRD distance can be adjusted to achieve the required radiation fields.

b) The reference point of the BRD does not need to be 1,5 m from the floor or ground surface, the height of the reference point of the BRD to the floor or ground surface used for the test shall be recorded.

c) The BRD shall be mounted on the phantom.

d) Use ^{137}Cs to produce an ambient dose equivalent rate of 1 $\mu Sv \cdot h^{-1}$ (± 10 %, k = 1), 50 $\mu Sv \cdot h^{-1}$ (± 10 %, k = 1), and 80 % (± 10 %, k = 1) of the manufacturer-stated maximum response at the reference point of the BRD. Use Annex D to determine the ambient dose equivalent rate.

e) Record 10 BRD readings at each of the three ambient dose equivalent rates and calculate the mean value and standard deviation.

f) The mean ambient dose equivalent rate indicated by the BRD shall be within 30 % of each applied ambient dose equivalent rate.

When applicable, repeat steps a) through f) for all possible BRD background modes of operation.

6.6 Angular dependence and verification of directional indication

6.6.1 Requirements

The angular response (i.e., count rate, ambient dose equivalent rate, radiation level) of the BRD shall be provided by the manufacturer for ^{241}Am, ^{137}Cs, and ^{60}Co, and for moderated ^{252}Cf (when the BRD is equipped with a neutron detector). The response of the BRD should be consistent with the manufacturer claim over the entire 360° rotation in the horizontal plane (centerline of the source and BRD, see Figure 1). This requirement shall be tested using ^{241}Am, ^{137}Cs, and ^{60}Co, and moderated ^{252}Cf for neutrons. For each source, the angular response of the BRD in the horizontal plane shall be measured from 0° to 360° in 45° increments.

In addition, if directional indication is provided, each exposure direction shall be indicated on the BRD.

6.6.2 Method of test

a) The BRD shall be set up as described in 4.8.

b) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).

c) The BRD shall be mounted on the phantom.

d) The angular response shall be determined by placing each source around the BRD in 45° increments in the horizontal plane with each source placed at a minimum distance of 50 cm.

e) At each angle the reference point of the BRD shall be used to measure the source-to-detector distance. The source-to-detector distance shall be kept the same for all angles and sources. Record the source-to-detector distance used for the test.

f) For each of the gamma sources the ambient dose equivalent rate at the reference point of the BRD at the reference angle (0°) should be at least 0,1 $\mu Sv \cdot h^{-1}$ (± 10 %, k = 1) above background. Record the ambient dose equivalent rate used for the test.

g) The 0° reference angle of the BRD (in the horizontal source plane) shall be facing the source, see Figure 1 and Figure 2. The BRD shall be positioned vertically relative to the ground surface.

h) Place the ^{241}Am at the 0° reference angle and predetermined source-to-detector distance for at least 30 s. Record 10 BRD readings (e.g., count rate, ambient dose equivalent rate) determine the mean and standard deviation of the response.

i) For BRDs with directional indication, record the source direction provided by the BRD. Each indicated direction should be within ± 15° of the actual direction. For those that do not provide a numerical indication of angle, the non-numerical directional indication should be clear and unambiguous. To evaluate the results for these BRDs, divide the area around the BRD into 4 sections. For verification, the ± 15° tolerance could be taken with respect to the boundaries between the sectors.

j) The entire BRD and phantom shall be rotated to the following angles: 45°, 90°, 135°, 180°, 225°, 270° and 315° shown in Figure 1 in the horizontal plane (360° of coverage). Steps a) through i) shall be repeated for all angles.

k) Compare the average BRD response at each angle and source with that provided by the manufacturer. Perform the measurements and record the results regardless of the documentation provided by the manufacturer.

l) Repeat steps a) through k) for ^{137}Cs, and ^{60}Co.

To verify the neutron source requirement, place the moderated ^{252}Cf neutron source (see 4.10) with an emission rate of 20 000 s^{-1} at a distance of 1 m from the reference point of the BRD and repeat steps a) through c), e), and g) through k) described above.

6.7 Over range test

6.7.1 Requirements

If a BRD is exposed to a radiation field that is greater than the manufacturer-stated maximum ambient dose equivalent rate, an alarm indicating for example “over-range” or “high counts” shall be activated and shall remain activated until the radiation field is reduced or the alarm is reset/acknowledged by the user. If the alarm is reset/ acknowledged by the user without the radiation field being reduced, a visual indication shall be provided indicating that the radiation field is still present and that the BRD is not fully operational.

The time required to return to non-alarm condition after the ambient dose equivalent rate is returned to background levels shall not be greater than 1 min.

6.7.2 Method of test

a) Verify that the manufacturer states the maximum ambient dose equivalent rate. Record the result of the verification. The test is not performed if the maximum ambient dose equivalent rate is not provided by the manufacturer.

b) The BRD shall be set up as described in 4.8.

c) The reference point of the BRD does not need to be 1,5 m from the floor or ground surface, the height of the reference point of the BRD to the floor or ground surface used for the test shall be recorded.

d) The BRD shall be mounted on the phantom.

e) Initiate a monitoring cycle with the BRD operating in a stable background.

f) Using ^{137}Cs increase the radiation field to 50 % above the manufacturer-stated maximum as measured at the reference point and reference angle (0º) of the BRD (see Figure 1).

g) The BRD shall alarm and remain in alarm until the radiation field is reduced to the pre-test level. The BRD shall display an "over-range" or "high counts" indication.

h) Remove the radiation field and measure the time it takes the BRD to return to the pre-test count rate values, verify that this time is within 1 min.

i) Verify that the over-range display disappears when the radiation field is removed.

j) The BRD shall alarm and recover successfully in 3 successive trials.

If the alarm can be reset/ acknowledged by the user without the radiation field being reduced, verify that a visual indication is provided indicating that the radiation field is still present and that the BRD is not fully operational while the radiation field is present.

6.8 Neutron indication in the presence of photons

6.8.1 Requirements

Gamma radiation at ambient dose equivalent rates of up to 100 $\mu Sv \cdot h^{-1}$ with gamma-ray energies lower than 662 keV shall not trigger the neutron alarm. In addition, the BRD shall be able to detect an increase in neutron radiation while being exposed to the gamma radiation.

NOTE This requirement is not applicable to gamma-only BRDs.

6.8.2 Method of test

a) The BRD shall be set up as described in 4.8.

b) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).

c) The BRD shall be mounted on the phantom.

d) Using a ^{137}Cs source, increase the ambient gamma dose equivalent rate by 100 $\mu Sv \cdot h^{-1}$ (± 10 %, k = 1) as measured at the reference point and reference angle (0°) of the BRD (see Figure 1) for a minimum of 30 s.

e) Record all alarms displayed by the BRD.

f) Remove the radiation source and allow the BRD to return to normal operation and repeat the test for a total of 3 trials.

g) Immunity of neutron detectors to gamma radiation is confirmed if no neutron alarms are triggered during the exposure to the gamma radiation. Gamma alarms are allowed.

 NOTE The ambient dose equivalent rate increase is above the background level.

h) Repeat the gamma exposure from steps a) through d), but this time add the moderated ^{252}Cf neutron source while the ^{137}Cs source is present.

i) Expose the BRD to a moderate ^{252}Cf neutron source with an emission rate of 20 000 s^{-1} (± 20 %) (see 4.10) moving at a transient speed of 1,2 $m \cdot s^{-1}$ at a distance of closest approach of 1 m and reference angle (0°) and verify that the alarm activates no later than 3 s of exposure at the point of closest approach to the BRD. The response is acceptable if the neutron alarm is activated before the source passes through the distance of closest approach.

j) Record all alarms displayed by the BRD.

k) Remove the gamma and neutron radiation sources and allow the BRD to return to normal operation and repeat the test for a total of 3 trials.

l) The BRD shall provide a neutron alarm in less than or equal to 3 s and recover successfully in the 3 successive trials. Gamma alarms are allowed.

6.9 Detection of gradually increasing radiation levels

6.9.1 Requirements

The BRD's alarm threshold shall not be affected by slowly increasing radiation levels that may be caused when a wearer is slowly approaching or is being approached by a radiation source. The BRD shall alarm or alert the user that the radiation level has changed. The radiation level change alert shall be visual and/or audible and shall be different than monitoring alarms. The type of alarm shall be user selectable.

6.9.2 Method of test

a) The BRD shall be set up as described in 4.8.

b) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).

c) The BRD shall be mounted on the phantom.

d) Allow the BRD to obtain a background.

e) When the BRD is operational slowly approach a ^{137}Cs source at a speed of 0,12 m·s^{-1} at a distance closest approach of 1,5 m.

f) The ^{137}Cs source shall produce an ambient dose equivalent rate of 0,05 μSv·h^{-1} (± 20 %, k = 1) at the reference point and reference angle (0°) of the BRD at the point of closest approach.

g) The distance of closest approach of the source to the BRD reference point may vary between 1 m and 3 m at the reference angle (0°); the speed of 0,12 m·s^{-1} shall be adjusted as describe in 4.9 if the distance of closest approach used for the test is other than 1,5 m.

h) The source shall start from a position where the BRD is not able to detect its presence and then go past the BRD to a position where it is again not able to detect its presence.

i) There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background surrounding the BRD or shielded during the delay.

j) Return the source to the original position, allow the BRD to stabilize, and repeat the process nine additional times for a total of 10 trials.

k) The performance is acceptable if the appropriate gamma alarm is activated in less than or equal to 2 s after the source passed through the point of closest approach to the BRD or the user is alerted that the background radiation level has changed. The response is also acceptable if the gamma alarm is activated before the 0,05 μSv·h^{-1} field is reached. Performance is acceptable if the BRD alarms in 10 out of 10 total trials.

l) If the BRD has neutron capabilities, repeat steps a) through e), and h) through k) using the moderated ^{252}Cf neutron source with an emission rate of 20 000 s^{-1} (± 20 %) (see 4.10) at a distance of closest approach of 1 m from the reference point and reference angle (0°) of the BRD. For acceptance, the appropriate neutron alarm shall activate within 3 s after reaching the distance of closest approach between the BRD and the source, or the user is alerted that the background radiation level has changed. The response is acceptable if the neutron alarm is activated before the distance of closest approach is reached.

When applicable, repeat steps a) through l) for all possible BRD background modes of operation.

6.10 Networked area monitors

6.10.1 Requirements

The BRD may be designed to individually and collectively determine the location of a radioactive source and communicate this information to a central control station to permit large area monitoring. If this capability is provided, the manufacturer shall specify the maximum distance between each BRD and estimated radiation levels for alarm activation based on the maximum distance stated by the manufacturer (typically 6 m) based on a transient speed of 1,2 $m \cdot s^{-1}$ and a BRD layout as shown in Figure 3.

6.10.2 Method of test

a) The BRD shall be set up as described in 4.8.

b) The reference point of the BRDs shall be 1,5 m from the floor or ground surface (same as the source centre).

c) Arrange a series of BRDs (without the use of the phantom) using the manufacturer-provided instructions.

d) If manufacturer instructions are not provided, for evaluation purposes, an array of 3 BRDs should be set in a triangular form with a distance of 6 m between each BRD.

e) Divide the monitored area as shown in Figure 3.

f) Testing shall be performed using ^{241}Am, ^{137}Cs, and ^{60}Co each producing a photon fluence rate of 4 $photons \cdot s^{-1} \cdot cm^{-2}$ (± 5 %, k = 1) at the reference point of the BRDs when placed at the centre of the BRD array.

g) If the BRD is equipped with a neutron detector, testing shall be performed using the moderated ^{252}Cf source with an emission rate of 20 000 s^{-1} (± 20 %) as described in 4.10.

h) Pass each source through the transversal lines (Lines 1 through 8) as shown in Figure 3 at a transient speed of 1,2 $m \cdot s^{-1}$. There shall be 1 trial per source per line.

i) Verify that the system array indicates:

   1) the presence of the source as the source transits through the monitored area,

   2) the source's relative position as it passes through the array.

j) If the BRD has real time (i.e., dynamic) radionuclide identification capabilities, verify that the system array indicates the radionuclides identified as the source transits through the monitored area.

k) The source presence and location should be displayed at a control station. Record the alarms, source relative positions to the array and radionuclides identified for each source moving through each transversal line (Lines 1 through 8 in Figure 3).

6.11 Radionuclide identification, when provided

6.11.1 General requirements

6.11.1.1 Requirements

If the BRD is designed to identify radionuclides:

a) An indication shall be displayed or otherwise provided (e.g., "not identified", "unknown") if a radionuclide cannot be identified.

b) The BRD shall provide guidance to the user if its ability to identify radionuclides is compromised by high (e.g., "too high") or low (e.g., "too low") count rates.

c) The manufacturer shall state if the BRD can perform real time (i.e., dynamic) radionuclide identification while sources and/or the BRD are moving.

d) An indication should be displayed as to the confidence of the radionuclides identified.

e) If the confidence indicator is displayed, the manufacturer shall state the basis of the value to indicate radionuclide identification confidence.

6.11.1.2 Method of test

The test methods for each of the requirements lists above are as follows:

a) Indication that a radionuclide cannot be identified is verified through the performance of 6.11.6.

b) Indication that the ability to identify radionuclides is compromised by low count rates is verified through the performance of 6.11.7. Indication that the ability to identify radionuclides is compromised by high count rates is verified through the performance of 6.11.8.
c) Verify through review of the manual, and record the results.
d) Verify through review of the manual and/or BRD display, and record the results.
e) Verify through review of the manual, and record the results.

6.11.2 Radionuclide identification library

6.11.2.1 Requirements

The manufacturer shall state the radionuclides that the BRD can identify. As a minimum the BRD library shall contain HEU, DU, WGPu, ^{60}Co, ^{137}Cs, ^{57}Co, ^{133}Ba, ^{241}Am, ^{226}Ra (in equilibrium with progeny), ^{232}Th (in equilibrium with progeny), ^{40}K, ^{67}Ga, ^{99m}Tc, ^{131}I, and ^{201}Tl.

NOTE IAEA Safety Guide No. RS-G-1.9 contains a possible list of radionuclides and categories.

For this standard the isotopic composition for the HEU, WGPu, and DU sources shall meet the following conditions:

- HEU shall have at least 90 % ^{235}U,
- DU shall have no more than 0,4 % ^{235}U,
- WGPu shall have no more than 6,5 % ^{240}Pu and no less than 93 % ^{239}Pu.

6.11.2.2 Method of test

Verify that the requirement is met by review of manufacturer's provided information.

6.11.3 Single radionuclide identification

6.11.3.1 Requirements

The BRD shall correctly identify bare HEU, DU, WGPu, ^{60}Co, ^{137}Cs, ^{57}Co, ^{133}Ba, ^{241}Am, ^{226}Ra (in equilibrium with progeny) and ^{232}Th (in equilibrium with progeny) in 1 min or in the time as specified by the manufacturer, whichever is the shortest.

If the BRD can perform real time (i.e., dynamic) radionuclide identification while sources and/or the BRD are moving, it shall correctly identify bare HEU, DU, WGPu, ^{60}Co, ^{137}Cs, ^{57}Co, ^{133}Ba, ^{241}Am, ^{226}Ra (in equilibrium with progeny) and ^{232}Th (in equilibrium with progeny) while the sources are moving past the BRD at a speed of 1,2 $m \cdot s^{-1}$ at a distance of closest approach of 1,5 m.

6.11.3.2 Method of test – static mode

a) Record the static measurement time specified by the manufacturer.
b) The BRD shall be set up as described in 4.8.
c) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).
d) The BRD shall be mounted on the phantom.
e) The ambient dose equivalent rate produce by each source shall be calculated using Annex D.
f) Testing is performed with one source at a time.
g) Position the BRD and test phantom where the ambient dose equivalent rate produced by the source is 0,05 $\mu Sv \cdot h^{-1}$ (± 20 %, k = 1) at the reference point and reference angle (0°) of the BRD and initiate a radionuclide identification measurement. The integration time

required to perform the identification shall be as specified by the manufacturer or 1 min whichever is the shortest.

h) The source to detector distances to achieve the desired ambient dose equivalent rate shall be no less than 1 m and not greater than 3 m.

i) The test shall consist of 10 consecutive trials for each source listed in 6.11.3.1 (requirement clause). The source shall be removed and placed back in the same location between trials. There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background surrounding the BRD or shielded during the delay.

j) The performance is acceptable when the BRD correctly identifies the radionuclide in 10 out of 10 consecutive trials for each source, see Annex B. If naturally occurring radioactive materials (NORM) such as ^{40}K, ^{226}Ra and/or ^{232}Th are identified during a controlled test, actions should be taken to reduce or eliminate the source of radiation prior to continuing the test. If not possible, identification of NORM is acceptable.

NOTE 1 The ambient dose equivalent rate produced by the source is measured or calculated above the natural background and outside the source shielding container (e.g., steel, PMMA) or source encapsulation.

NOTE 2 Testing is performed with one source at a time.

6.11.3.3 Method of test – dynamic mode (if applicable)

a) The BRD shall be set up as described in 4.8.

b) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).

c) The BRD shall be mounted on the phantom.

d) The BRD is tested with each source moving past the BRD at 1,2 $m \cdot s^{-1}$ at a distance of closest approach of 1,5 m.

e) The distance of closest approach of the source to the BRD reference point may vary between 1 m and 3 m; the speed of 1,2 $m \cdot s^{-1}$ shall be adjusted as described in 4.9 if the distance of closest approach used for the test is other than 1,5 m.

f) The ambient dose equivalent rate produced by each source is 0,05 $\mu Sv \cdot h^{-1}$ ($\pm$ 20 %, k = 1) (independent of the background) at the reference point and reference angle (0°) at the point of closest approach to the BRD.

g) The ambient dose equivalent rate produced by each source shall be calculated as described in Annex D.

h) The source shall start its movement from a position where the BRD is not able to detect its presence and then go past the BRD to a position where it is again not able to detect its presence.

i) There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background surrounding the BRD or shielded during the delay.

j) The test shall consist of 10 consecutive trials for each source listed in 6.11.3.1 (requirement clause).

k) The performance is acceptable when the BRD correctly identifies the radionuclide in 10 out of 10 consecutive trials for each source, see Annex B. If NORM radionuclides such as ^{40}K, ^{226}Ra and/or ^{232}Th are identified during a controlled test, actions should be taken to reduce or eliminate the source of radiation prior to continuing the test. If not possible, identification of NORM is acceptable.

When applicable, repeat steps a) through k) for all possible BRD background modes of operation.

NOTE 1 The ambient dose equivalent rate produced by the source is measured or calculated above the natural background and outside the source shielding container (e.g., steel, PMMA) or source encapsulation.

NOTE 2 Testing is performed with one source at a time.

6.11.4 Identification of shielded radionuclides

6.11.4.1 Requirements based on shielding

The BRD shall correctly identify ^{60}Co and ^{137}Cs when the source is shielded by steel and PMMA to be configured to be equivalent to a steel box behind a brick wall in 1 min or in the time as specified by the manufacturer, whichever is the shortest. For testing purposes, the radionuclides shall be surrounded by 1 cm of steel and 10 cm of PMMA.

If the BRD can perform real time (i.e., dynamic) radionuclide identification while sources and/or the BRD are moving, it shall correctly identify these shielded sources while moving past the BRD at a speed of 1,2 $m \cdot s^{-1}$ at a distance of closest approach of 1,5 m.

The ambient dose equivalent rate produced by each source outside the shielding container is 0,05 $\mu Sv \cdot h^{-1}$ (± 20 %, k = 1) at the reference point and reference angle (0°) of the BRD.

6.11.4.2 Method of test – static mode

Repeat the test described in 6.11.3.2 for the shielded sources.

6.11.4.3 Method of test – dynamic mode

Repeat the test described in 6.11.3.3 for the shielded sources.

6.11.4.4 Requirements for medical radionuclides

The BRD shall correctly identify ^{67}Ga, ^{99m}Tc, ^{131}I, and ^{201}Tl when surrounded by 8 cm of PMMA or similar plastic to simulate in-vivo measurements in 1 min or in the time as specified by the manufacturer, whichever is the shortest.

If the BRD can perform real time radionuclide identification while sources and/or the BRD are moving, it shall correctly identify these medical sources while moving past the BRD at a speed of 1,2 $m \cdot s^{-1}$ at a distance of closest approach of 1,5 m.

The ambient dose equivalent rate produced by each source outside the PMMA container is 0,05 $\mu Sv \cdot h^{-1}$ (± 20 %, k = 1) at the reference point and reference angle (0°) of the BRD.

6.11.4.5 Method of test – static mode

Repeat the test described in 6.11.3.2 for the medical sources.

6.11.4.6 Method of test – dynamic mode

Repeat the test described in 6.11.3.3 for the medical sources.

6.11.5 Simultaneous and masked radionuclide identification

6.11.5.1 Requirements

The BRD shall have the ability to correctly identify more than one radionuclide simultaneously and a source of interest when combined ("masked") with other radionuclides in 1 min or in the time as specified by the manufacturer, whichever is the shortest. The target source shall produce an ambient dose equivalent rate of 0,05 $\mu Sv \cdot h^{-1}$ at the reference point and reference angle (0°) of the BRD while the masking sources shall produce an ambient dose equivalent of 0,2 $\mu Sv \cdot h^{-1}$ at the reference point of the BRD. The source combinations used for the test shall be the following:

(^{226}Ra + ^{232}Th) + HEU

(^{226}Ra + ^{232}Th) + WGPu

^{99m}Tc + HEU

^{131}I + WGPu

If the BRD can perform real time (i.e., dynamic) radionuclide identification while sources and/or the BRD are moving, it shall correctly identify these source combinations while moving past the BRD at a speed of 1,2 $m \cdot s^{-1}$ at a distance of closest approach of 1,5 m.

6.11.5.2 Method of test – static mode

To verify these requirements, expose the BRD to the following source combinations:

(^{226}Ra + ^{232}Th) + HEU

(^{226}Ra + ^{232}Th) + WGPu

^{99m}Tc + HEU

^{131}I + WGPu

For these combinations the target sources are HEU and WGPu.

The ambient dose equivalent rate from the masking sources shall be 0,2 $\mu Sv \cdot h^{-1}$ (± 20 %, k = 1). The ambient dose equivalent rate from the target source shall be 0,05 $\mu Sv \cdot h^{-1}$ (± 20 %, k = 1). Each ambient dose equivalent rate shall be measured at the reference point and reference angle (0°) of the BRD. The target source shall not be shielded by the masking material. The ambient dose equivalent rate shall be calculated as described in Annex D.

The ^{226}Ra and ^{232}Th (in equilibrium with their progeny) sources shall be surrounded by 9 cm of PMMA to simulate bulk material (each source producing a field of 0,1 $\mu Sv \cdot h^{-1}$ outside the PMMA container). The ^{99m}Tc and ^{131}I sources shall be surrounded by 8 cm of PMMA to simulate in-vivo measurements (producing a field of 0,2 $\mu Sv \cdot h^{-1}$ outside the PMMA container).

Repeat the test described in 6.11.3.2 for these source combinations.

Remove the target sources and repeat the tests for masking material only.

NOTE 1 ^{232}Th can be replaced by ^{232}U (older than 20 years).

NOTE 2 ^{226}Ra and ^{232}Th point sources are used for this test to ensure reproducibility in the test process.

6.11.5.3 Method of test – dynamic mode

Set up the source combinations as described in 6.11.5.2. Repeat the test described in 6.11.3.3 for these source combinations.

6.11.6 Radionuclide not in library

6.11.6.1 Requirements

The BRD shall indicate "not in library" or "unknown" when exposed to a radioactive source that does not produce photo-peaks and when exposed to a radionuclide that is not in the library.

6.11.6.2 Method of test

a) The BRD shall be set up as described in 4.8.
b) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).
c) The BRD shall be mounted on the phantom.

d) To verify the requirement for sources without photo-peaks, it is recommended that the test be performed using a ^{90}Sr/^{90}Y source in an assembly that produces Bremsstrahlung radiation.

e) The ambient dose equivalent rate at the reference point and reference angle (0°) of the BRD should be 0,1 μSv·h^{-1} (± 20 %, k = 1).

f) The integration time required to perform the identification shall be 1 min or as specified by the manufacturer.

g) The performance is acceptable when the BRD provides a message such as “not in library” or “unknown”, and alarms in 10 out of 10 consecutive trials. The identification of “Bremsstrahlung” is acceptable.

h) Repeat the steps a) through g) at the same ambient dose equivalent rate using a radionuclide that produces photo-peaks but that it is not in the library. Expose the BRD to a radionuclide that is not present in the library and verify that it provides an indication such as “not identified” or “unknown” (e.g., radionuclides that may be used for this test are ^{54}Mn or ^{166m}Ho). A radionuclide may be temporarily “removed” from the library to perform this test. The ambient dose equivalent rate shall be calculated as described in Annex D.

6.11.7 Low-exposure rate identification

6.11.7.1 Requirements

The BRD shall not identify a radionuclide that is not present when operated in a stable and low ambient radiation background (less or equal to 0,1 μSv·h^{-1} is preferred but not required). An indication shall also be provided stating if the BRD ability to identify radionuclides is compromised by low count rates (e.g., “count longer”, “get closer”, “field too low”, bar-graph), in this case the radiation filed may be “too low” to perform an identification.

6.11.7.2 Method of test

a) Acquire a background spectrum at the test location using a high energy resolution detector to verify that no radiation sources are present, measure and record the background ambient dose equivalent rate.

b) The BRD shall be set up as described in 4.8.

c) The reference point of the BRD shall be 1,5 m from the floor or ground surface (same as the source centre).

d) The BRD shall be mounted on the phantom.

e) Perform a static radionuclide identification with the BRD in a stable background with no radiation sources present as described in 4.9. The BRD integration time required to perform the identification shall be 1 min or as specified by the manufacturer.

f) The BRD shall not identify unexpected radionuclides. In addition, verify that the BRD indicates that the count rate is too low to perform an identification. The indication may consist of a statement such as “field too low”, “count longer” or “get closer.”

g) The test shall consist of 10 trials.

h) The performance is acceptable when the BRD does not identify a radionuclide in 10 out of 10 consecutive trials.

i) If NORM radionuclides such as ^{40}K, ^{226}Ra or ^{232}Th are identified, actions should be taken to reduce or eliminate the source prior to performing the test. If the radionuclide is expected and cannot be removed, the test result shall be acceptable when the expected naturally occurring radionuclide is identified.

6.11.8 Over range characteristics for identification

6.11.8.1 Requirements

The manufacturer shall state the maximum gamma-ray ambient dose equivalent rate (μSv·h^{-1}) relative to ^{137}Cs for which the BRD can perform a radionuclide identification. An indication shall also be provided stating if the BRD ability to identify radionuclides is compromised by high count rates (e.g., “move away”, “field too high”, bar-graph), in this case the radiation filed may be “too high” to perform an identification.

6.11.8.2 Method of test

a) The BRD shall be set up as described in 4.8.
b) The reference point of the BRD does not need to be 1,5 m from the floor or ground surface, the height of the reference point of the BRD to the floor or ground surface used for the test shall be recorded.
c) The BRD shall be mounted on the phantom.
d) Increase the ambient dose equivalent rate using ^{137}Cs to the maximum exposure rate for radionuclide identification as stated by the manufacturer at the reference point and reference angle (0°) of the BRD.
e) Position a ^{133}Ba source to produce an ambient dose equivalent rate of 0,05 μSv·h^{-1} (± 20 %, k = 1) at the reference point and reference angle (0°) of the BRD. The ambient dose equivalent rate shall be calculated as described in Annex D.
f) Perform a static radionuclide identification as described in 4.9. The BRD integration time required to perform the identification shall be 1 min or as specified by the manufacturer.
g) The test shall consist of 10 trials.
h) This test is acceptable if the BRD correctly identifies ^{133}Ba in 10 out of 10 consecutive trials; the identification of ^{137}Cs is allowed but not required as part of the correct identification.
i) In addition, verify that the BRD indicates that the count rate is too high to perform an identification. The indication may consist of a statement such as “field too high” or “move away.”
j) If NORM radionuclides such as ^{40}K, ^{226}Ra or ^{232}Th are identified, actions should be taken to reduce or eliminate the source prior to performing the test. If the radionuclide is expected and cannot be removed, the test result shall be acceptable when the expected naturally occurring radionuclide is identified.

6.11.9 Rejection of natural background variations

6.11.9.1 Requirements

The purpose of this function is to reduce alarms caused by sudden changes in the natural background level that may occur upon entering a building, walking on a granite pavement, or coming into close proximity of a ceramic tile wall.

This function shall not reduce the BRD detection capability. The user shall have the option to disable this function.

6.11.9.2 Method of test

a) Verify that the background rejection capability function can be disabled by the user. Record the result of the verification.
b) The BRD shall be set up as described in 4.8.
c) The reference point of the BRD shall be 1,5 m from the floor or ground surface.
d) The BRD shall be mounted on the phantom.
e) The ambient dose equivalent rate shall be measured at the reference point and reference angle (0°) of the BRD.
f) Expose the BRD to “low” background condition (background level at the test location, preferably less or equal to 0,1 μSv·h^{-1} ± 50 % (k = 1)) during the warm-up (and/or start-up) time stated by the manufacturer, no radioactive sources present.
g) Within 2 s, increase the ambient background to a “high” background condition (0,3 μSv·h^{-1} ± 30 % (k = 1)) at the reference point of the BRD).

h) No alarm shall occur and no radionuclides shall be identified, other than indications of NORM associated with background, in 10 out of 10 trials.

i) The "high" background condition shall be achieved by using a source combination composed of ^{226}Ra, and ^{232}Th (in equilibrium with their progeny) surrounded by 9 cm of PMMA or by using granite slabs or other similar bulk material.

j) While in the high background condition, verify that the BRD response capability remains unchanged by repeating 6.2 using ^{241}Am and ^{137}Cs (separately) at the reference angle (0°) in the vertical orientation (i.e., tested at only one angle).

When applicable, repeat steps b) through j) for all possible BRD background modes of operation.

7 Environmental requirements

The BRD shall comply with IEC 62706 requirements for the class "body-worn" or "portable" devices as applicable concerning the following:

- **Ambient temperature:** from –20 °C to 50 °C (portable).
- **Temperature shock:** from –20 °C to 50 °C (portable). The manufacturer shall provide the recovery time. During recovery time the instrument shall indicate that the instrument is not operational. If the manufacturer does not provide the recovery time the BRD shall be tested after 15 min.
- **Relative humidity:** up to 93 % RH at 40 °C.
- **Low/high temperature start-up:** –20 °C and 50 °C (portable).
- **Dust and moisture resistance:** IP54 (body worn) (IEC 60529).

Instrument functionality is verified as described in 4.11. The BRD is set up as described in 4.8. Testing needs to be carried out using the test methods described in IEC 62706 with the functionality tests performed as listed in Table 2.

The BRD shall not be mounted on a phantom.

8 Mechanical requirements

The BRD shall comply with IEC 62706 requirements for the class "body-worn" devices as applicable concerning the following:

- **Vibration:** random vibration at 0,01 $g^2.Hz^{-1}$ (acceleration spectral density) using 5 Hz and 500 Hz for the frequency endpoints for a period of 1 h in each of three orthogonal orientations (IEC 60068-2-64 Transportation Category 1b).
- **Microphonics/Impact:** low intensity sharp contacts at energies of 0,2 J (IEC 60068-2-75).
- **Mechanical shock:** 10 shock pulses of 50 g peak acceleration, each applied for a nominal 11 ms in each of three mutually orthogonal axes (IEC 60068-2-27).
- **Drop:** the BRD and the control device (if attached) shall continue to function correctly after being dropped from a height of 100 cm onto a concrete surface on each of their six sides. If the BRD control device is detached from the BRD, the control device shall also continue to function correctly after being dropped from a height of 100 cm onto a concrete surface on each of its six sides. The test method should be agreed upon by the manufacturer and testing laboratory.

Instrument functionality is verified as described in 4.11. The BRD is set up as described in 4.8. Testing needs to be carried out using the test methods described in IEC 62706 with the functionality tests performed as listed in Table 3.

When performing these tests, the BRD shall not be mounted on a phantom.

9 Electromagnetic requirements

The BRD shall comply with IEC 62706 requirements for the class "body-worn" devices as applicable concerning the following:

- **Electrostatic discharge:** Level 3 in IEC 61000-4-2.
- **Radio frequency:** Level X (with X = 50) from 80 MHz to 1 000 MHz and Level 3 from 1,4 to 6 GHz in IEC 61000-4-3.
- **Radiated emissions:** see Table 4.
- **Magnetic field:** Level 5 in IEC 61000-4-8.
- **Conducted immunity:** Level 3 in IEC 61000-4-6, only applicable if the BRD is equipped with cables longer than 1 m.

Instrument functionality is verified as described in 4.11. The BRD is set up as described in 4.8. Testing needs to be carried out using the test methods described in IEC 62706 with the functionality tests performed as listed in Table 5.

When performing these tests, the BRD shall not be mounted on a phantom.

10 Documentation

10.1 General

The requirements listed below are verified by revision of the manufacturer provided documentation.

10.2 Type test report

The manufacturer shall make available to the user (if requested), the report on the type tests performed to the requirements of this standard.

10.3 Certificate

The manufacturer shall provide a test report containing at least this information:

a) If the BRD displays ambient dose equivalent rate, provide the ambient dose equivalent rate calibration measurements for ^{241}Am, ^{137}Cs and ^{60}Co.

b) If the BRD has radionuclide identification capabilities, provide the energy resolution and energy calibration for ^{137}Cs.

c) Photon total efficiency (counts per second (cps) per μSv per hour) as a function of photon energies for at least ^{241}Am, ^{137}Cs and ^{60}Co.

d) If the instrument has neutron detection capabilities, neutron efficiency (cps per neutron per second per cm^2) for unmoderated ^{252}Cf and moderated ^{252}Cf (specify moderator).

The environmental test conditions for these parameters shall be indicated in the certificate.

10.4 Operation and maintenance manual

The manufacturer shall supply an operational and maintenance manual containing the following information to the user:

a) Contact information for the manufacturer including name, address, telephone number, fax number, email address

b) Type of instrument, detector and types of radiation the instrument is designed to measure

c) Power supply requirements

d) Battery life time
e) Recommended operational parameters shall include as a minimum:
   a) Background update modes
   b) If radionuclide identification capabilities, radionuclide library
   c) If radionuclide identification capabilities, integration time for radionuclide identification
   d) Alarm threshold default settings, for photon and neutrons as applicable
f) Detector energy response range
g) Photon ambient dose equivalent rate ranges for measurement and protection, and maximum over-range values
h) If the instrument has neutron detection capabilities, neutron count rate range
i) If radionuclide identification capabilities, photon ambient dose equivalent rate ranges and maximum over-range for identification values
j) If the BRD has real-time identification capabilities, integration time and mode (e.g., rolling integration time)
k) Time to alarm
l) Photon total efficiency (cps per μSv per hour) as a function of photon energies for at least ^{241}Am, ^{137}Cs and ^{60}Co
m) If the instrument has neutron detection capabilities, neutron efficiency (cps per neutron per second per cm^{2}) for unmoderated ^{252}Cf and moderated ^{252}Cf (specify moderator)
n) False alarm probability
o) Complete description of the BRD, to include dimensions, weight, detectors locations, reference points
p) If the instrument has radionuclide identification capabilities, the manufacturer shall describe the meaning of the confidence indication
q) If the instrument can transmit information to an external device, the manufacturer shall provide a description and protocol for communication methods of transmitting and receiving data
r) Energy calibration and stabilization requirements
s) Operational range for the environmental conditions listed in Clause 7.
t) Operational range for the electromagnetic tests listed in Clause 9.
u) Operational range for the mechanical tests listed in Clause 8.
v) Operating instructions and restrictions for operators and users
w) Maintenance instructions
x) Spare parts list
y) Troubleshooting guide

Table 1 – Standard test conditions

Influence quantity	Standard test conditions
Stabilization time	≤ 15 min
Ambient temperature	15 °C to 25 °C
Relative humidity	50 % to 75 %
Atmospheric pressure	86 kPa to 106,6 kPa (at 0 °C)
Gamma background	≤ 0,2 $\mu Sv \cdot h^{-1}$
Neutron background	≤ 300 neutrons per second per square meter
Electromagnetic field of external origin	Controlled, natural conditions
Magnetic induction of external origin	Controlled, natural conditions
Reference photon radiation*	^{241}Am, ^{137}Cs and ^{60}Co
Reference neutron radiation*	^{252}Cf unmoderated and moderated
* See 4.10 for details.	

Table 2 – Occurrence of functionality tests for environmental testing

Environmental tests	Functionality test execution
Ambient temperature	With sources: • before ambient temperature test • at the beginning of every step in temperature increments (during ramp up and down) • during the last 15 min of each step in temperature (during ramp up and down) • at the beginning, middle, and end of equilibrium (or soaking) time at minimum temperature • at the beginning, middle, and end of equilibrium (or soaking) time at maximum temperature Verify that the basic display indications listed in 5.14.2 are readable at the minimum and maximum temperatures. Without sources: • during test
Temperature shock	With sources: • before temperature shock test • after the manufacturer stated stabilization time if the manufacturer does not provide the stabilization time, perform the measurements 15 min after exposure to extreme temperature
Relative humidity	With sources: • before relative humidity test • 8 h after exposure to high humidity • 16 h after exposure Without sources: • during test
Low/high temperature start-up	With sources: • before low/high temperature start-up test • after warm-up time (low temperature) • after warm-up time (high temperature)

Environmental tests	Functionality test execution
Dust and moisture resistance – IP Classification	With sources: • before dust and moisture test • during exposure • after dust and moisture test Without sources: • during test

Table 3 – Occurrence of functionality tests for mechanical testing

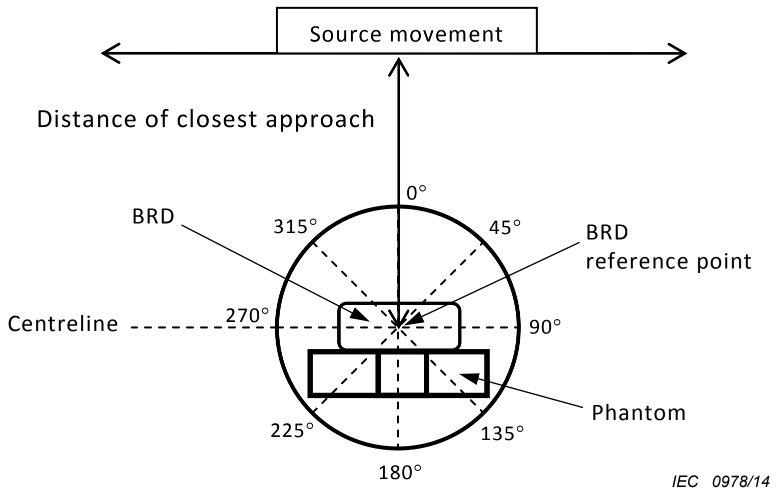
Mechanical tests	Functionality tests execution
Vibration test	With sources: • before vibration test • during exposure • after vibration test Without sources: • during test
Microphonics/Impact	With sources: • before microphonics/impact test • during exposure • after microphonics/impact test Without sources: • during test
Mechanical shock	With sources: • before shock I test • during exposure • after shock test Without sources: • during test
Drop	With sources: • before drop test • after drop test (after six drops)

Table 4 – Emission frequency range

Frequency of emission MHz	**Field strength** µV/m
30 to 88	100
88 to 216	150
216 to 960	200
>960	500

Table 5 – Occurrence of functionality tests for electromagnetic testing

Electromagnetic tests	Functionality tests execution
Electrostatic discharge	With sources: • before discharge test • during exposure • after discharge test Without sources: • during discharge
Radio frequency	With sources: • before radio frequency test • during exposure • after radio frequency test Without sources: • during sweep (continuously)
Radiated RF emissions	• Not applicable, record emission from instrument
Magnetic fields	With sources: • before magnetic field test • during exposure • after magnetic field test Without sources: • during exposure
Conducted immunity	With sources: • before conducted immunity test • during exposure • after conducted immunity test Without sources: • during sweep (continuously)



NOTE The displayed source movement represents the test configuration at an angle of 0°.

Figure 1 – Diagram of testing angles when source passes at an angle of 0° in the horizontal plane (top view)

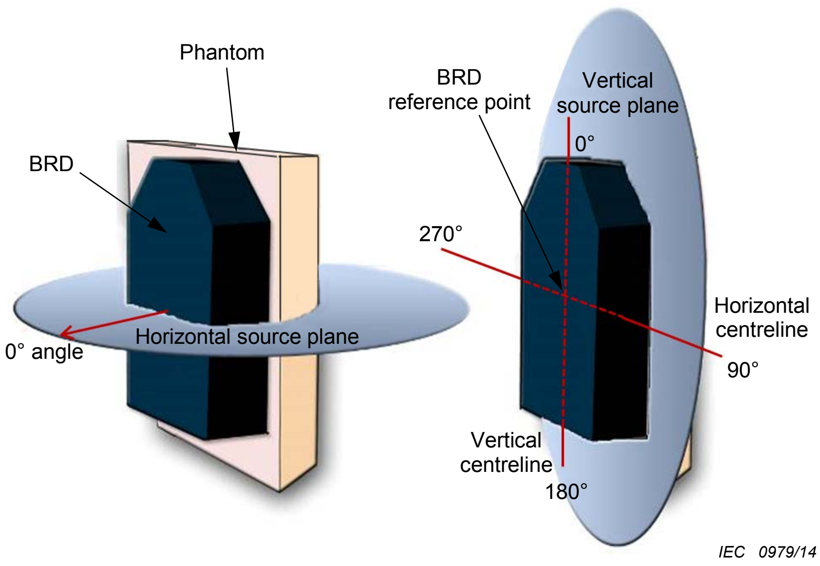


Figure 2 – Diagram of the two orthogonal planes (horizontal and vertical planes), the BRD reference point and testing angles

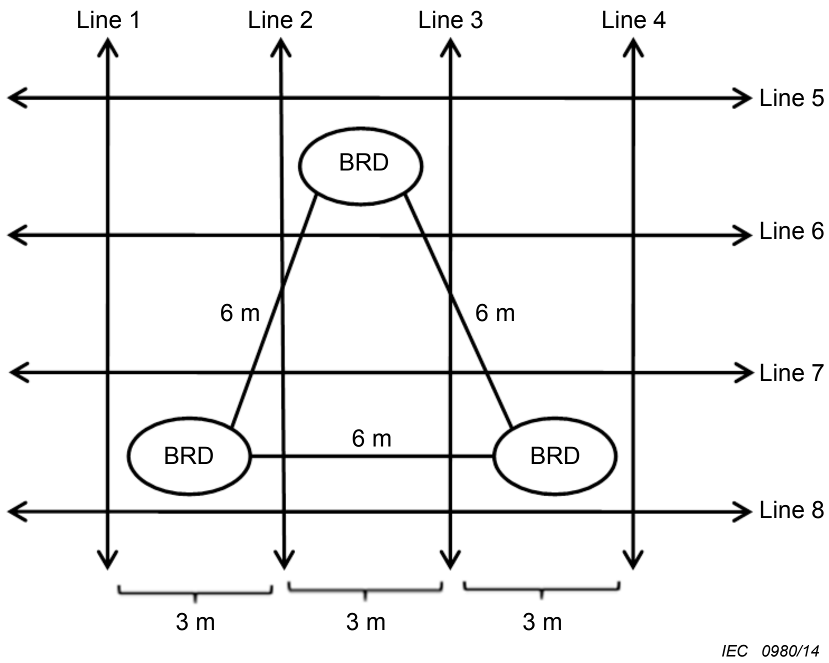


Figure 3 – BRD setup and testing source positions for network area monitoring

Annex A
(informative)

Statistical considerations

A.1 Poisson distribution

A random variable used to describe a number of occurrences of some phenomena over a fixed period of time or within a fixed region of space can often be modelled by the Poisson distribution. Examples include the number of radioactive particles that strike a certain target during a fixed period of time; and the number of bomb hits in a defined area.

The Poisson distribution is given as (Casella and Berger, 2002):

$$P(x \mid \lambda) = \frac{e^{-\lambda}\lambda^{x}}{x!} \qquad x = 0,1,2,\ldots\ ;\ 0 \le \lambda \tag{A.1}$$

The single positive parameter λ is the expected number of occurrences per unit time, sometimes referred to as the mean occurrence rate. In addition to being the expected value of the Poisson distribution, λ is also the variance of the distribution. The occurrence rate can be estimated by

$$\hat{\lambda} = \frac{x}{n} \tag{A.2}$$

Where x is the number of occurrences observed and n the number of units of time over which the observation was made.

A.2 Confidence intervals for Poisson distribution

A two-sided 100(1–α)% confidence interval for λ, given x occurrences in n units of time can be found by (Hahn and Meeker, 1991):

$$[\lambda, \tilde{\lambda}] = \left[\frac{0{,}5\ \chi^2(\frac{\alpha}{2};2x)}{n}, \frac{0{,}5\ \chi^2(1-\frac{\alpha}{2};2x+2)}{n}\right] \tag{A.3}$$

where $\chi^2_{(\gamma;r)}$ is the 100γ the percentile of a chi-square distribution with r degrees of freedom. One-sided lower and upper 100(1–α)% confidence bounds for λ are obtained by replacing $\alpha/2$ by α in the first and second parts of Formula (A.3), respectively. Thus, a 100(1–α)% one-sided upper confidence bound for λ is:

$$\tilde{\lambda} = \frac{0{,}5\ \chi^2(1-\alpha;2x+2)}{n} \tag{A.4}$$

A.3 False alarm testing

The number of false alarms produced by a radiation detection system over some fixed time period for which the false alarm rate is not expected to vary (e.g. stable background) can be reasonably modelled by a Poisson distribution. The false alarm occurrence rate can be estimated, as described by Formula (A.2) by the number of occurrences observed over a fixed period of time divided by the number of units of time this observation was made.

When reporting estimates that are a result of limited test observations, some measure of the sampling variability and hence the uncertainty of the estimate should be provided. One approach to including such information is in the form of a confidence interval or a confidence bound. As it is desired to maintain a false alarm rate as small as possible, a one-sided upper confidence bound is an appropriate measure to report as it provides information of how large the desirably small true false alarm rate may actually be. For example, if 0 false alarms were observed in a test period of 3 h, the false alarm rate would be estimated to be $\hat{\lambda} = 0$ per hour with a 95 % upper confidence bound of $\hat{\lambda} = 1$ per hour. Thus, one could state with 95 % confidence that the false alarm rate for the radiation detection system is no greater than 1 per hour.

When developing a false alarm test, the desired precision and strength in a false alarm statement as well as the estimate uncertainty shall be considered. In the noted example, stating that a false alarm rate does not exceed 1 per hour may be of limited use but given the limited test time, a stronger statement cannot be made. If one would like to state that the false alarm rate will not exceed 1 per 8 h work shift ($\hat{\lambda} = 0{,}125$), a false alarm test shall extend for 24 h with 0 occurrences observed. Table A.1 displays the 95 % one-sided upper confidence bounds for the hourly false alarm rate for test durations ranging from 1 h to 40 h and number of observed false alarm occurrences ranging from 0 to 10.

Table A.1 – One-sided 95 % upper confidence bounds for the false alarm rate for a given number of false alarms observed over a given time period

95 % One-sided upper confidence bound for false alarm rate (per hour)											
Test duration	Number of false alarms observed										
hours	0	1	2	3	4	5	6	7	8	9	10
1	3,00	4,74	6,30	7,75	9,15	10,51	11,84	13,15	14,43	15,71	16,96
2	1,50	2,37	3,15	3,88	4,58	5,26	5,92	6,57	7,22	7,85	8,48
3	1,00	1,58	2,10	2,58	3,05	3,50	3,95	4,38	4,81	5,24	5,65
4	0,75	1,19	1,57	1,94	2,29	2,63	2,96	3,29	3,61	3,93	4,24
5	0,60	0,95	1,26	1,55	1,83	2,10	2,37	2,63	2,89	3,14	3,39
6	0,50	0,79	1,05	1,29	1,53	1,75	1,97	2,19	2,41	2,62	2,83
7	0,43	0,68	0,90	1,11	1,31	1,50	1,69	1,88	2,06	2,24	2,42
8	0,37	0,59	0,79	0,97	1,14	1,31	1,48	1,64	1,80	1,96	2,12
9	0,33	0,53	0,70	0,86	1,02	1,17	1,32	1,46	1,60	1,75	1,88
10	0,30	0,47	0,63	0,78	0,92	1,05	1,18	1,31	1,44	1,57	1,70
11	0,27	0,43	0,57	0,70	0,83	0,96	1,08	1,20	1,31	1,43	1,54
12	0,25	0,40	0,52	0,65	0,76	0,88	0,99	1,10	1,20	1,31	1,41
13	0,23	0,36	0,48	0,60	0,70	0,81	0,91	1,01	1,11	1,21	1,30
14	0,21	0,34	0,45	0,55	0,65	0,75	0,85	0,94	1,03	1,12	1,21
15	0,20	0,32	0,42	0,52	0,61	0,70	0,79	0,88	0,96	1,05	1,13
16	0,19	0,30	0,39	0,48	0,57	0,66	0,74	0,82	0,90	0,98	1,06
17	0,18	0,28	0,37	0,46	0,54	0,62	0,70	0,77	0,85	0,92	1,00
18	0,17	0,26	0,35	0,43	0,51	0,58	0,66	0,73	0,80	0,87	0,94
19	0,16	0,25	0,33	0,41	0,48	0,55	0,62	0,69	0,76	0,83	0,89
20	0,15	0,24	0,31	0,39	0,46	0,53	0,59	0,66	0,72	0,79	0,85

A.4 Binomial distribution

When an observable is described by only two possible outcomes (e.g. alarm, no alarm) the number of occurrences is modelled by the Binomial distribution.

Let the observable X have $Bin(n,p)$ distribution. For a given $(1-\alpha)$% confidence level, the lower $(1-\alpha)$% confidence bound, $\underline{p}=\underline{p}(X,n,\alpha)$, for the binomial probability p is known (see Bickel and Doksum) to have the form

$$\underline{p}=\max\{p:\mathrm{binocdf}(X-1,n,p)\geq 1-\alpha\}.$$

where,

$$\mathrm{binocdf}(x,n,p)=\sum_{k=0}^{x}\binom{n}{k}p^{k}(1-p)^{n-k},$$

for the binomial cumulative distribution function is employed. Our goal is for given X to determine the range of n such that, say, for prescribed α, one has $\underline{p}\geq p_0$. This range is formed by all sufficiently large positive integers.

Notice that $\mathrm{binocdf}(n-1,n,p)=1-p^{n}$, so that when $X=n$ (i.e. there are no failures in n trials), the smallest sample size n can be found from the formula,

$$n=\frac{\log\alpha}{\log p_0}.$$

The following Table A.2 of more general n-values is constructed by using binocdf(x,n,p) function for several α and for different values of the $(1-\alpha)$% guaranteed probability of success p_0, i.e. the prescribed or guaranteed values of $\underline{p}$.

Table A.2 – Necessary sample sizes (n) for different levels (p_o) and number of failures (k)

k	α=0,05					α=0,1					α=0,15					α=0,2				α=0,3			
	p_o					p_o					p_o					p_o				p_o			
	0,99	0,98	0,95	0,90	0,80	0,99	0,98	0,95	0,90	0,80	0,99	0,98	0,95	0,90	0,80	0,99	0,95	0,90	0,80	0,99	0,95	0,90	0,80
0	298	148	58	28	13	229	113	44	22	10	189	94	37	18	9	160	31	15	7	119	23	11	5
1	473	235	58	44	22	388	193	76	37	18	336	167	66	29	10	299	59	29	14	243	48	24	11
2	627	313	93	61	29	531	265	105	52	25	471	235	93	33	16	427	84	42	20	361	71	35	17
3	773	385	124	75	36	666	332	132	65	32	600	299	119	46	22	550	109	54	26	475	94	47	23
4	913	465	153	89	43	797	398	158	78	38	725	362	144	59	29	671	133	66	32	588	117	58	28
5	1049	523	180	102	50	925	462	183	91	44	848	423	168	71	35	789	157	78	38	700	139	69	34
6	1180	594	207	115	56	1051	524	208	103	50	968	483	192	83	41	906	180	89	44	810	161	80	39
7	1319	658	234	128	63	1175	586	233	115	56	1088	543	216	95	47	1022	203	101	49	920	183	91	45
8	1440	720	260	141	69	1297	647	257	127	62	1206	602	239	107	52	1136	225	112	55	1028	205	102	50
9	1573	785	285	154	75	1418	708	281	140	68	1573	660	263	119	64	1250	249	123	61	1134	227	113	56

Annex B
(informative)

List of expected progeny and expected impurities

A BRD shall completely and correctly identify the radionuclides of interest. This classification follows the IAEA requirements and they can be summarized as follows:

a) Complete and Correct (C&C)

- Source "X" identified as "X"
- Sources "X+Y" identified as "X+Y"

For example:

- $^{235}U \rightarrow {}^{235}U$
- $^{235}U \rightarrow {}^{235}U + {}^{40}K$
- $^{235}U \rightarrow {}^{235}U + {}^{40}K + {}^{232}Th$
- $^{235}U \rightarrow {}^{235}U + {}^{40}K + {}^{232}Th + {}^{226}Ra$
- $^{235}U + {}^{67}Ga \rightarrow {}^{235}U + {}^{67}Ga + {}^{40}K + {}^{232}Th + {}^{226}Ra$

Complete and correct may also include progeny and impurities of the target radionuclide(s). NORM radionuclides can be displayed as they are part of the background even when they are not part of the source being tested. Table B.1 provides a list of progeny and expected impurities.

b) Incomplete

- Source "X+Y" identified as "X" or "Y"

For example:

- $^{235}U + {}^{226}Ra \rightarrow {}^{226}Ra$

c) Incorrect

- Source "X" identified as "X + Y".

For example:

- $^{235}U \rightarrow {}^{235}U + {}^{237}Np$
- $^{67}Ga \rightarrow {}^{235}U + {}^{67}Ga$

d) Incomplete & Incorrect (I&I)

- Source “A” being identified as “C”
- Source "A+B" identified as "C+D"

For example:

- $^{235}U \rightarrow {}^{67}Ga$
- $^{235}U + {}^{137}Cs \rightarrow {}^{99m}Tc + {}^{133}Ba$

The list of expected progeny and impurities is given below. If a radionuclide is not listed that means that there is no expected progeny for that particular radionuclide. Therefore, the required radionuclide is that one present.

NOTE Some systems do not distinguish the Plutonium and Uranium enrichment, in those cases these different sources are identified using the same radionuclide or source name.

Table B.1 – List of expected progeny and expected impurities

Source	Required radionuclide(s)	Expected progeny or impurities
^{201}Tl	^{201}Tl	^{202}Tl
DU	^{238}U	^{235}U, ^{226}Ra
RGPu	^{239}Pu	^{242}Pu, ^{241}Pu, ^{240}Pu, ^{238}Pu, ^{241}Am, ^{237}U, ^{242}Pa, ^{233}U, neutron, ^{252}Cf, ^{249}Cf, RGPu, Plutonium
WGPu	^{239}Pu	^{242}Pu, ^{241}Pu, ^{240}Pu, ^{238}Pu, ^{241}Am, ^{237}U, ^{242}Pa, ^{233}U, neutron, ^{252}Cf, ^{249}Cf, WGPu, Plutonium
HEU	^{235}U	^{238}U, ^{234m}Pa, HEU , Uranium
(^{226}Ra + ^{232}Th) + WGPu	^{239}Pu	^{242}Pu, ^{241}Pu, ^{240}Pu, ^{238}Pu, ^{241}Am, ^{237}U, ^{242}Pa, ^{233}U, neutron, ^{252}Cf, ^{249}Cf, ^{228}Th, ^{232}U, ^{214}Bi, ^{214}Pb, ^{232}Th, ^{226}Ra, WGPu, Plutonium
(^{226}Ra + ^{232}Th) + HEU	^{235}U	^{238}U, ^{234m}Pa, ^{228}Th, ^{232}U, ^{214}Bi, ^{214}Pb, ^{232}Th, ^{226}Ra, HEU, Uranium
^{131}I+ WGPu	^{239}Pu + ^{131}I	^{242}Pu, ^{241}Pu, ^{240}Pu, ^{238}Pu, ^{241}Am, ^{237}U, ^{242}Pa, ^{233}U, neutron, ^{252}Cf, ^{249}Cf, WGPu, Plutonium
^{99m}Tc+ HEU	^{235}U + ^{99m}Tc	^{238}U, ^{234m}Pa, ^{99}Mo, HEU, Uranium
^{99m}Tc	^{99m}Tc	^{99}Mo
^{232}Th	^{232}Th	^{228}Th, ^{232}U
^{226}Ra	^{226}Ra	^{214}Bi, ^{214}Pb

Annex C
(informative)

Summary of fluence rate calculations

Radiation from an x-ray generator or a radioactive source consists of a beam of photons, usually with a variety of energies. If we consider that the beam is monoenergetic, then one way to describe the beam would be to specify the number of photons, dN, that would cross an area, da, taken at right angles to the beam. The ratio of these would yield what the International Commission of Radiological Units and Measurements (ICRU) has called fluence or photon fluence represented by the capital Greek letter phi,Φ.

$$\Phi = \frac{dN}{da} \tag{C.1}$$

The fluence rate is the number of photons that pass through unit area per unit time and it is represented by the lower case Greek letter phi, ϕ, thus:

$$\phi = \frac{d\Phi}{dt} = \frac{dN}{da\,dt} \tag{C.2}$$

When the emission of the source is isotropic and we integrate Formula (C.2), we have that the fluence rate at a radius, r, from the source can be expressed as:

$$\phi = \frac{R}{4\pi r^2} \tag{C.3}$$

where *R* is the number of photons per second emitted from the source (i.e., emission rate).

R can be express as a function of the source activity, *A* (expressed in Becquerels), as:

$$R = A \times p(E) \tag{C.4}$$

where *p(E)* is the emission probability of a gamma ray at energy *E*. Then the fluence rate can be expressed as:

$$\phi = \frac{A \times p(E)}{4\pi r^2} \tag{C.5}$$

If the source emits gamma rays at different energies, then the fluence rate can be expressed as:

$$\phi = \frac{A}{4\pi r^2} \sum_i p(E_i) \tag{C.6}$$

Note that the fluence rate value obtained using Formula (C.6) will depend on the cut-off energy used in the calculation. Due to instruments’ response it is suggested to use a 40 keV cut-off energy for most calculations.

The emission probabilities listed in the LNE-LNHB, Le Laboratoire National Henri Becquerel, Table of Radionuclides (http://www.nucleide.org/DDEP_WG/DDEPdata.htm) shall be used for these calculations; if a given radionuclide is not listed in LNE-LNHB, Le Laboratoire National Henri Becquerel, Table of Radionuclides then use the data listed in the Evaluated Nuclear Structure Data File (ENSDF) National Nuclear Data Center, Chart of Nuclides (http://www.nndc.bnl.gov/).

If the required data are not available in the LNE-LNHB or ENSDF a list of the photo-peaks and emission probabilities used in the calculation shall be provided as part of the support documentation.

The fluence rate for a single gamma-ray line of energy, *E*, can be measured using a gamma-ray spectrometer equipped with a HPGe or NaI(Tl) detector. In this case the fluence rate can be expressed as:

$$\phi = \frac{Area_{net} \times \epsilon(E)}{T_{Live} \times 4\pi r^2} \qquad \text{(C.7)}$$

where $Area_{net}$ is the net photo-peak area of the gamma line of energy *E*, $\varepsilon(E)$ is the detector full-energy peak efficiency for the gamma-ray of energy *E*, and T_{Live} is the live time of the measurement (expressed in seconds) (see *Gamma- and X-ray Spectrometry with Semiconductor Detectors*. K. Debertin and R.G. Helmer. Editor North-Holland, 1998 Edition).

Examples of fluence rate calculations are shown in the Table C.1 below.

Table C.1 – Examples of fluence rate calculations

Fluence rate (photons/s/cm^2) (cut-off energy 40 keV)	0,642						3,4		4,01	
Distance (m)	0,75	1	1,5	2,5	5	6	1	2,5	1	2,5
Radionuclide	Activity (kBq)									
^{57}Co	47	84	188	523	2091	3011	443	2778	523	3267
^{133}Ba	33	59	133	370	1478	2129	313	1958	369	2308
^{137}Cs	53	95	213	592	2369	3412	502	3138	592	3703
^{60}Co	23	40	91	253	1012	1457	214	1337	252	1578
^{232}Th	13	23	53	147	586	844	124	775	146	914
^{241}Am	127	225	505	1404	5617	8088	1190	7433	1403	8766
^{226}Ra	22	38	87	241	963	1386	204	1275	241	1502

Annex D
(normative)

Calculation ambient dose equivalent rate

In order to have a consistent way to determine the ambient dose equivalent rate, $\dot{H}^*(10)$, among all users of this standard, the following method shall be used. There might be different and perhaps slightly better methods to perform these determinations, but the most critical issue to address in this standard is the reproducibility and consistency across all the testing laboratories in how the determination of the radiation fields are made. Due to the low ambient dose equivalent rates (*i.e.*, 0,05 μSv·h^{-1} above background) required to perform some of the tests, it would not be possible to make accurate measurements with the uncertainty required by the standard of ±20 % (k = 1).

The proposed method assumes a point source in air, and it does not account for build-up in air. The cut-off energy, δ, used for the calculations shall be 40 keV, and for practical purposes all photon emissions with a probability larger than 0,5 % shall be included in the calculation (The physics of radiology, 4th Edition, Publisher Charles C. Thomas, Authors: Harold Elford Johns and John Robert Cunningham (1983)).

For the point source in vacuum, the fluence rate $\dot{\Phi}_i$ of photons with energy E_i at a radial distance r is simply $\frac{AP_i}{4\pi r^2}$, where A is the source activity, and P_i is the probability per disintegration that a photon of energy E_i is emitted. Assuming charged-particle equilibrium, the air-kerma rate $\dot{K}_i$ from photons of energy E_i is then $\dot{K}_i = \dot{\Phi}_\mathrm{i} E_\mathrm{i} \frac{\mu_\mathrm{tr}(E_i)}{\rho_\mathrm{air}}$, where $\frac{\mu_{tr}(E_i)}{\rho_{air}}$ is the mass energy-transfer coefficient for air (Seltzer, 2004). In general, for a point source in vacuum, emitting more than one energy photon the air kerma rate is obtained by summing over all photon energies as follows:

$$\dot{K}_\delta = \sum_i \frac{A\, P_i\, E_i}{4\pi r^2} \frac{\mu_{tr}(E_i)}{\rho_{air}}, \tag{D.1}$$

where δ denotes the minimum photon energy included.

Now consider the point source surrounded by spherical shell(s) of encapsulating material in an infinite air medium. Each encapsulation material surrounding the source will have a thickness z_j and a density ρ_j. The attenuation of the photon beam from any material surrounding the source and the column of air between the source and the point of detection can be accounted for by using the following estimate of the air-kerma rate at a radial distance r:

$$\dot{K}_\delta = \frac{A}{4\pi r^2} \sum_i P_i\, E_i \frac{\mu_{tr}(E_i)}{\rho_{air}} \exp\left[-\sum_j \frac{\mu_j(E_i)}{\rho_j} \rho_j\, z_j \right] \exp\left[-\frac{\mu_{air}(E_i)}{\rho_{air}} \rho_{air}\, r \right], \tag{D.2}$$

where μ_j/ρ_j is the mass attenuation coefficient for the encapsulating-layer material of thickness z_j and a density ρ_j, and μ_{air}/ρ_{air} is that for air. Note that in Formula D.2 there are two exponentials. The first one accounts for the attenuation of all the materials surrounding the source while the second exponential accounts for the attenuation of the air column. From Formula D.2 an expression for the ambient dose equivalent rate, $\dot{H}^*(10)$, can be easily derived for the practical case of an encapsulated source in air as:

$$\dot{H}^*(10) = \frac{A}{4\pi r^2} \sum_i h_K^*(10)_i \; P_i \; E_i \frac{\mu_{tr}(E_i)}{\rho_{air}} \; \exp\left[-\sum_j \frac{\mu_j(E_i)}{\rho_j} z_j \; \rho_j\right] \exp\left[-\frac{\mu_{air}(E_i)}{\rho_{air}} r \; \rho_{air}\right], \text{(D.3)}$$

where $h_K^*(10)$ is the conversion coefficient from air kerma to ambient dose equivalent for mono-energetic and parallel photon radiation, and the use of the cut-off energy δ is assumed.

In order to ensure that all testing laboratories obtain a consistent calculated value of the ambient dose equivalent rate, the different coefficients and values for the different quantities used in the equations above shall only be taken from the following references:

- $h_K^*(10)$ values shall be taken from the ISO 4037-3:1999 standard. For convenience these values are also provided in Table D.1.
- μ_j/ρ_j and ρ_j shall be obtained from the *XCOM* database, see reference (National Institute of Standards and Technology (NIST), 2012, *XCOM: Photon Cross Sections Database*, available online at http://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html).
- P_i shall be obtained from reference [LNE-LNHB, Le Laboratoire National Henri Becquerel, Table of Radionuclides, http://www.nucleide.org/DDEP_WG/DDEPdata.htm]; if a given radionuclide is not listed in (LNE-LNHB, Le Laboratoire National Henri Becquerel, Table of Radionuclides, http://www.nucleide.org/DDEP_WG/DDEPdata.htm), then reference (ENSDF, Evaluated Nuclear Structure Data File, National Nuclear Data Center, Chart of Nuclides, http://www.nndc.bnl.gov/) shall be used. For convenience, due to the long decay chain, the values for the probabilities per disintegration (*P*) for ^{232}Th and ^{226}Ra (in equilibrium) are listed in Table D.2.
- The μ_{tr}/ρ_{air} and μ_{air}/ρ_{air} values are given in Table D.3.
- The density of air shall be ρ_{air} = 0,0012 g/cm^3.
- The cut-off energy, δ, used for the calculations shall be 40 keV.
- All photon emissions with a probability larger than 0,5 % shall be included in the calculation.

This method assumes that the sources used have small or negligible self-attenuation. This means that the dimensions and/or density of the source active material are such that the attenuation within the source is negligible. Appropriate corrections to Formula D.3 shall be applied to account for source self-attenuation for the case of large and/or dense sources.

Table D.1 – Conversion coefficient $h^*_K(10)$ from air kerma, K, to ambient dose equivalent, H*(10), for mono-energetic and parallel photon beams

Photon energy keV	$h^*_K(10)$ Sv/Gy
10	0,008
15	0,26
20	0,61
30	1,10
40	1,47
50	1,67
60	1,74
80	1,72
100	1,65
150	1,49
200	1,40
300	1,31

Photon energy keV	$h^*_K(10)$ Sv/Gy
400	1,26
500	1,23
600	1,21
800	1,19
1000	1,17
1500	1,15
2000	1,14
3000	1,13
4000	1,12
5000	1,11
6000	1,11
8000	1,11
10000	1,10

Table D.2 – Probabilities per disintegration for ^{232}Th and ^{226}Ra (in equilibrium) as a function of photon energy

^{232}Th (in equilibrium)		^{226}Ra (in equilibrium)	
Photon energy keV	***P***	**Photon energy** keV	***P***
72,805	7,51E-03	46,539	4,312E-02
74,815	1,04E-01	53,228	1,060E-02
74,969	1,26E-02	74,816	6,26E-02
77,107	1,75E-01	77,109	1,047E-01
84,373	1,22E-02	79,293	7,12E-03
86,83	2,09E-02	87,344	3,59E-02
87,349	4,01E-02	89,784	6,70E-03
89,784	1,46E-02	90,074	1,10E-02
89,957	1,96E-02	186,211	3,555E-02
93,35	3,19E-02	241,997	7,268E-02
99,509	1,26E-02	258,87	5,24E-03
105,604	7,40E-03	295,224	1,8414E-01
115,183	5,92E-03	351,932	3,56E-01
129,065	2,42E-02	609,312	4,549E-01
153,977	7,22E-03	665,453	1,53E-02
209,253	3,89E-02	768,356	4,892E-02
238,632	4,33E-01	785,96	1,064E-02
240,986	4,10E-02	806,174	1,262E-02
270,245	3,46E-02	839,04	5,87E-03
277,351	2,27E-02	934,061	3,10E-02
300,087	3,28E-02	1120,287	1,491E-01
328	2,95E-02	1155,19	1,635E-02
338,32	1,13E-01	1238,111	5,831E-02
409,462	1,92E-02	1280,96	1,435E-02

^{232}Th (in equilibrium)		^{226}Ra (in equilibrium)	
Photon energy keV	***P***	**Photon energy** keV	***P***
463,004	4,40E-02	1377,669	3,968E-02
510,77	8,12E-02	1385,31	7,95E-03
562,5	8,70E-03	1401,5	1,33E-02
583,191	3,04E-01	1407,98	2,389E-02
726,863	6,20E-03	1509,228	2,128E-02
727,33	6,58E-02	1583,22	7,07E-03
755,315	1,00E-02	1661,28	1,048E-02
763,13	6,52E-03	1729,595	2,844E-02
772,291	1,49E-02	1764,494	1,531E-01
794,947	4,25E-02	1847,42	2,025E-02
830,486	5,40E-03	2118,55	1,158E-02
835,71	1,61E-02	2204,21	4,913E-02
840,377	9,10E-03	2447,86	1,548E-02
860,564	4,46E-02		
904,19	7,70E-03		
911,204	2,58E-01		
964,766	4,99E-02		
968,971	1,58E-01		
1078,62	5,64E-03		
1247,08	5,00E-03		
1459,138	8,30E-03		
1495,93	8,60E-03		
1580,53	6,00E-03		
1588,19	3,22E-02		
1620,5	1,49E-02		
1630,627	1,51E-02		
2614,453	3,56E-01		

Table D.3 – Values of the mass energy-transfer, mass energy-absorption, and mass attenuation coefficients for air

Photon energy MeV	μ_{tr}/ρ cm^2/g	μ/ρ cm^2/g
1,000E-03	3,599E+03	3,606E+03
1,500E-03	1,188E+03	1,191E+03
2,000E-03	5,263E+02	5,279E+02
3,000E-03	1,615E+02	1,625E+02
3,203E-03	1,330E+02	1,340E+02
3,203E-03	1,460E+02	1,485E+02
4,000E-03	7,637E+01	7,788E+01
5,000E-03	3,932E+01	4,027E+01
6,000E-03	2,271E+01	2,341E+01
8,000E-03	9,448E+00	9,921E+00
1,000E-02	4,743E+00	5,120E+00
1,500E-02	1,334E+00	1,614E+00
2,000E-02	5,391E-01	7,779E-01
3,000E-02	1,538E-01	3,538E-01
4,000E-02	6,836E-02	2,485E-01
5,000E-02	4,100E-02	2,080E-01
6,000E-02	3,042E-02	1,875E-01
8,000E-02	2,408E-02	1,662E-01
1,000E-01	2,326E-02	1,541E-01
1,500E-01	2,497E-02	1,356E-01
2,000E-01	2,674E-02	1,233E-01
3,000E-01	2,875E-02	1,067E-01
4,000E-01	2,953E-02	9,549E-02
5,000E-01	2,971E-02	8,712E-02
6,000E-01	2,958E-02	8,055E-02
8,000E-01	2,889E-02	7,074E-02
1,000E+00	2,797E-02	6,358E-02
1,250E+00	2,675E-02	5,687E-02
1,500E+00	2,557E-02	5,175E-02
2,000E+00	2,359E-02	4,447E-02
3,000E+00	2,076E-02	3,581E-02
4,000E+00	1,894E-02	3,079E-02
5,000E+00	1,770E-02	2,751E-02
6,000E+00	1,683E-02	2,522E-02
8,000E+00	1,571E-02	2,225E-02
1,000E+01	1,506E-02	2,045E-02
1,500E+01	1,434E-02	1,810E-02
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